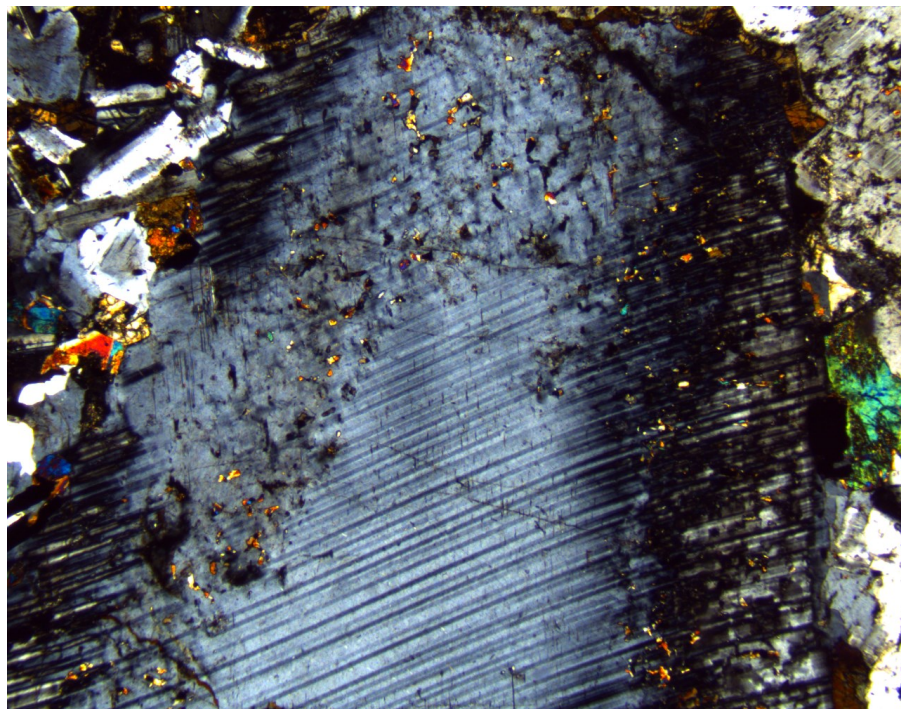


Major and trace element geochemical analysis of norites in the Hakefjorden Complex to constrain magma source and magma plumbing systems

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Department of Geology
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Cover Picture: Plagioclase megacryst in norite matrix. Photo: Aodhan Barrett

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AODHAN BARRETT

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Abstract: Major and trace element data taken from plagioclase crystals from anorthosites and related rock units in the Hakefjorden Complex located off the west coast of Sweden were investigated for the purposes of constraining magma chamber processes and the source of the magma. Although the anorthosite units were completely homogenous in regards to its chemistry, the plagioclase in the associated norite and ilmenite-leuconorite units showed substantial variation. The zoning profiles of the aforementioned plagioclase units showed sudden increases in Sr in the rims of the plagioclase. These patterns are likely to be caused by replenishment of the magma via recharge events. Peaks in An content coincide with patchy disequilibrium textures at the rims of the crystals - these are linked to either decompression via polybaric evolution of the magma chamber, magma recharge events or a combination of both. The peaks in trace element concentrations also coincide with the disequilibrium textures, which provide evidence that the recharge events are linked to the ascent of the magma chamber. The evidence of recharge events and the homogenous nature of the $^{87}\text{Sr}/^{86}\text{Sr}$ zoning profiles as indicated by Glommé (2015) suggest that a mantle derived source with crustal contamination is unlikely, and instead favours a lower crustal magma source.

Keywords: Anorthosite-norite, Plagioclase, Hakefjorden Complex, Sweden, Trace Elements, Geochemistry, Magma Origin

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Subject: Bedrock Geology

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Huvud- och spårelementsanalyser av norit i Hakefjorden för att påvisa ursprung och utveckling av mafisk magma

AODHAN BARRETT

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Sammanfattning: Jag har analyserat huvud- och spårelementkoncentrationer i plagioklas från en norit-anortositintrusion, Älgön, Hakefjorden vid Sveriges västkust med syfte att fastställa intrusionens magmatiska ursprung, magmans utveckling och dess transport upp genom jordskorpan. Megakrister av plagioklas i anortositen har en homogen fördelning med avseende på huvud- och spårelement medan plagioklas-megakrister i norit och ilmenit-leukonorit uppvisar betydande variation. Koncentrationsprofiler av Sr genom plagioklasmegakrister från norit och ilmenit-leukonorit visar på en ökning i Sr från kärna till kant. Dessa variationer är troligtvis orsakade av påfyllning av magma. Fläckvis varierande Ca-halt i plagioklas sammanfaller med inklusionsrika partier i ytterkanterna av plagioklasmegakrister. Texturen länkas till tryckminskning under kristallisation av magman. Topparna i spårelements-koncentrationer sammanfaller också med de inklusionsrika och varierande Ca-halterna, vilket ger belägg för att magman mobiliserats av magmapåfyllningshändelser. Trots att de varierande spårelements-koncentrationerna kan kopplas till påfyllning av ny magma har plagioklas en homogen och relativt radiogen $^{87}\text{Sr}/^{86}\text{Sr}$ isotopsammansättning (Glommé 2015), såväl i megakrister som i plagioklaskrystaller i matrix. Sammantaget talar det för ett magmaursprung från den djupare delen jordskorpan snarare än ett mantelursprung, där de radiogena Sr-isotopkvoterna skulle förklaras av kontaminering av äldre kisel-rik berggrund.

Nyckelord: Anortosit-norit, Plagioklas, Hakefjorden, Sverige, Spårelement, Geokemi, Magma ursprung.

Handledare: Anders Scherstén

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1 Introduction

Anorthosites, specifically Proterozoic massif-type anorthosites, have been the subject of a lot of debate with respect to their magma source, tectonic setting and emplacement mechanisms (Bowen 1917, Duchesne et al. 1999; Ashwal 2013). These rocks are composed almost entirely of just plagioclase, can cover large areas (up to 18,000 km²) and are temporally restricted to ~2.6 – 0.5 Ga, which makes the processes that generated these rocks somewhat enigmatic (Ashwal 2013; Ashwal & Bybee 2017). Typically, accompanying large masses of ultramafic rocks in the same geological suite of anorthosites are lacking. This makes it very difficult to model a magma source that could generate such a specific composition at such high quantities. If such large quantities of plagioclase are being produced from a primitive magma, there should be associated ultramafic rocks forming as a byproduct as the plagioclase component is extracted from the magma. This is known as the “anorthosite problem” (Bowen 1917; Ashwal 2013). Ashwal & Bybee (2017) reviewed petrogenetic models of anorthosite magmatism and argued that the collective evidence supports subduction zone regime and mantle derived magmas, this study will investigate a specific anorthosite suite to see if this is the case.

Located just off of the west coast of southern Sweden, Älgön along with Brattön, are the only islands that host outcropping rocks that belong to the Hakefjorden Complex (HFC), which consists mainly of norite, anorthosite and subordinate ilmenite rich cumulates (Årebäck 1995). The rock units found on Älgön belongs either to the HFC or to the surrounding country rock, the Stora Le-Marstrand Formation

(SLM) (Årebäck 1995). Studies of the HFC to further understand Proterozoic massif type anorthosites have been ongoing since Årebäck (1995) and still continues to this day with recent studies done by Glommé (2015) and Kullberg (2015).

In this study I will attempt to expand further on the findings of Glommé (2015) and Kullberg (2015), and try to constrain and understand the petrogenesis of Proterozoic massif-type anorthosites in more detail; specifically addressing the magma source of the HFC which may provide insight to the tectonic setting. The aforementioned studies have specifically looked at major element geochemistry, trace element ratios, and isotopic ratios within the plagioclase and oxide minerals. In this study I will focus on the Sr-Ba trace element concentration zoning in plagioclase in the anorthosite and surrounding norite units. Certain trends in the zonation could suggest magma replenishment events that could provide useful information regarding the source of the magma which then has further implications for a magma source.

2 Background

2.1 Geological setting

The HFC is an undeformed norite-anorthosite intrusion complex within the Sveconorwegian orogen that was emplaced into the SLM, a pre-sveconorwegian metamorphosed volcano-sedimentary supracrustal package (Årebäck 1995; Åhäll & Connelly 2008). The intrusion is dated to 916 ± 11 Ma (Scherstén et al. 2000), a period with voluminous magmatism that coincides with the late to post-orogenic collapse of the Sveconorwegian orogeny

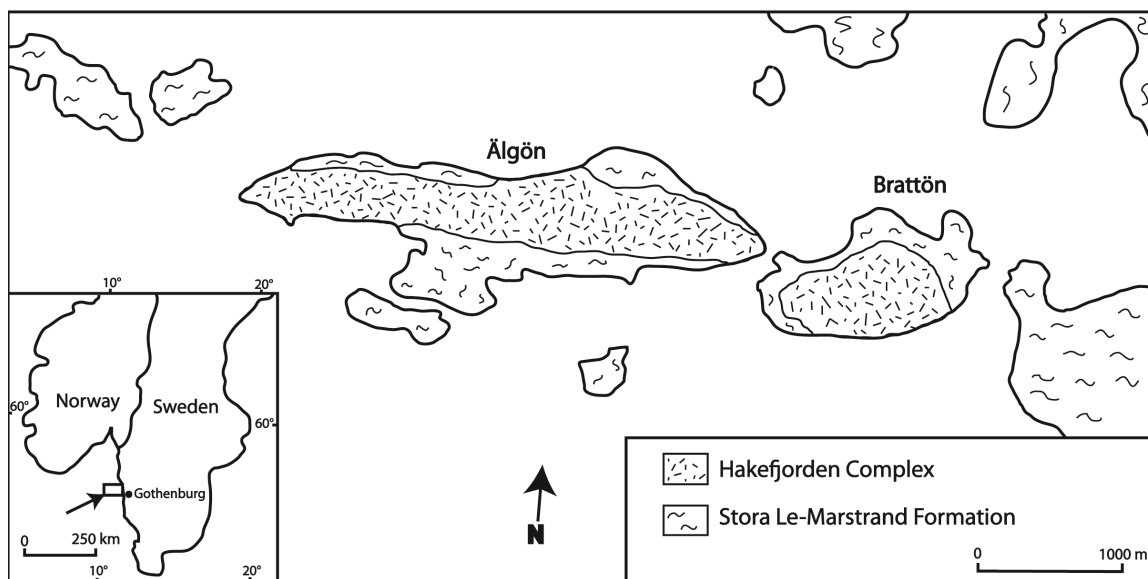


Fig. 1. A simplified geological map of Älgön and Brattön. The Hakefjorden complex is a norite-anorthosite intrusion only seen to outcrop on these two islands. The surrounding country rock is the Stora Le-Marstrand Formation, a metamorphosed volcano-sedimentary package. The location of these islands is depicted in the bottom left, they are found just off the west coast of Sweden, perpendicular to Gothenburg. Modified after Årebäck & Stigh (2000)

(1.1-0.9 Ga) (Årebäck 2001; Bingen et al. 2008; Ashwal & Bybee 2017). The intrusion crops out on the two islands of Älgön and Brattön just off the west coast of Sweden (Fig. 1).

The rocks of the HFC are dominated by medium grained norite and coarse grained anorthosite; other units include a monzonorite along the intrusion margin, ilmenite-rich leuconorites (IRL), mafic enclaves, granitic and dolerite dykes. Contact metamorphism surrounding the HFC lead to granulite facies recrystallisation at 0.6 GPa and 890-1015°C which establishes the intrusion emplacement depth to mid-crustal levels at approximately ~15-20 km (Årebäck & Andersson 2002). The granulite conditions along the intrusion contact led to partial melting and the formation of granite melt. The zircons from these granite melts yielded a 916 ± 10 Ma date, which is interpreted to being coeval with the HFC (Scherstén et al. 2000). The upcoming section is a general description of the most commonly found rock units on Älgön, for more a more detailed description of the samples in this study see the petrography section 4.1.

2.1.1 Anorthosite

This rock is an almost monomineralic adcumulate of plagioclase crystals with other accessory minerals in much smaller abundances and grain size. The anorthosite units occur as blocks, suspended within the norite, ranging in sizes anywhere between 2 cm to 50 metres and are mostly found on the western side of Älgön where they occur as dominating clusters and the norite is in small quantities (Årebäck 1995; Årebäck 2001).

2.1.2 Norite

A medium grained, mafic igneous rock which is compositionally and texturally similar to a gabbro but orthopyroxene is more prominent relative to clinopyroxene. The norites in the HFC often show a porphyritic texture with plagioclase megacrysts. The norite is the most common rock in the HFC on Älgön (Årebäck 1995).

2.1.3 Monzonorite

A medium grained, mafic igneous rock similar in composition to the norite, however plagioclase is less abundant, and k-feldspar is more common. The monzonorite occurs in the norite along the outer section of the norite in contact with the country rock. There is a gradational change between the monzonorite and the norite - it is believed that the monzonorite formed as a result of assimilation of the country rock by the norite (Årebäck 1995).

2.1.4 Ilmenite-Rich Leuconorite (IRL)

This rock is medium grained and dominated by ilmenite and magnetite with a noritic matrix. It often shows strong flow structures. The contacts between the norite and IRL are gradational, slowly increasing in the amount of oxides (Årebäck 1995).

2.1.5 Mafic Enclave

An aphanitic to fine grained mafic igneous rock which also includes plagioclase megacrysts similar to those seen in the norite units. Årebäck (1995) theorises that this unit is formed from the anatexis of the country rock (SLM) during the emplacement of the initial intrusion. The mafic enclave units are much less abundant than the aforementioned units and occur as small (1-30 cm) units around the contact of the country rock (Årebäck 1995).

2.1.6 Granitic and Doleritic Dykes

A number of both felsic and basic, younger intrusions can be seen in the HFC. Granitic dikes are observed on the west coast of Älgön, reaching around 0.5m in width, while doleritic dikes are only present on Brattön, ranging from 0.5-2m in width (Årebäck 1995).

2.1.7 Stora Le-Marstrand Formation (SLM)

The country rock formation which the HFC intruded into. On Älgön two different rock types are dominating: fine grained, peraluminous paragneisses (migmatized metagreywacke) and deformed pegmatites. Amphibolites also exist in the SLM formation, but are subordinate on Älgön (Åhäll et al. 1998, Årebäck 2001).

2.2 Summary of petrogenic and emplacement models of massif type anorthosites

The petrogenesis and emplacement mechanism of massif type anorthosites has been controversial and is still not widely agreed upon (Bowen 1917; Årebäck 1995; Arndt 2013; Ashwal & Bybee 2017). Given the main mineralogical components of anorthosites and trace element data it is widely accepted that the parental magma must have a mafic, high Al composition akin to basalt (Ashwal & Bybee 2017).

There are two main schools of thought regarding the source for the magma and tectonic setting: either a lower mafic crust source created by a post orogenic decompression derived melt (Duchesne et al. 1999; Duchesne 2001), or a mantle derived source in a subduction zone continental arc setting (Ashwal & Bybee 2017). Experimental data suggest that parental melts for anorthosite and associated rocks must be generated at crustal pressures that do not

indicate a mantle source (Duchesne et al. 1999; Duchesne 2001). These studies have been revisited and criticized by Ashwal & Bybee (2017), who state the unlikelihood of a lower crustal source for a number of reasons. There is an assumption in this theory that lower crust is inherently mafic, but experimental data provided by Hacker et al. (2011, 2015) shows that the composition of lower crusts could be relatively felsic. In addition to this, the extent of partial melting of the lower crust with the composition suggested by Duchesne (2001) would need to range from 80 to 100%. Such large degree of melting is complicated due to the lack of energy that is required and would significantly impact the stability of the crust due to the large amounts of volume and duration of magmatism (Ashwal & Bybee 2017).

A Recent study by Glommé (2015) utilises laser ablation spot techniques that provide substantially improved resolution of geochemical data in comparison with whole grain and whole rock analyses. Sr isotope data in minerals and across growth zones help in further understanding the magma source and evolution of massif type anorthosites in the HFC. Glommé (2015) obtained $^{87}\text{Sr}/^{86}\text{Sr}$ data from anorthosite and anorthosite associated units from the HFC with values of $^{87}\text{Sr}/^{86}\text{Sr} = 0.7046 - 0.7053$. These values were interpreted as a crustal isotope signal since it is more radiogenic than the mantle and it overlaps with regional mafic-ultramafic cumulates, which could provide a potential source rock.

In a subduction setting a mantle derived magma would assimilate some of the crustal host rock during emplacement. The recorded $^{87}\text{Sr}/^{86}\text{Sr}$ data is reasonably homogenous favouring a crustal magma source; a mantle derived source with crustal assimilation should show more variation as assimilation is unlikely to occur at a constant rate during emplacement. If large amounts of assimilation would be required to reach the observed isotope values then there should be some variation between late and early forming minerals as assimilation progresses.

The homogenous nature might be explained if all of the assimilation occurred before any crystallisation, but this is unlikely since the latent heat from crystallisation of the magma is a driving force in country rock assimilation (Winter 2009). Available Sr isotope data seems to require a homogenous source and the current interpretation is that the rocks are from a lower crustal source (Glommé 2015). In addition to the Sr isotope data, Kullberg (2015) investigated the trace element concentrations of whole rock analysis taken from different units in the HFC, and finds the rocks to come from an enriched source indicated by richness in incompatible trace elements when normalised to a primitive mantle source.

There are few models for formation and

emplacement of massif type anorthosites. A generally accepted model (Ashwal & Bybee 2017) proposes that a mafic magma/melt is emplaced into mid continental crust creating a magma chamber. Plagioclase begins to crystallise and floats to the top of the chamber forming a mush separated from the rest of the melt. Similarly, mafic silicates also fractionate from the melt and sink to the bottom of the chamber. The plagioclase mush is then said to ascend through the crust due to its strong buoyancy before crystallising entirely. This last stage of plagioclase rise through the crust is however said to be more controversial than the initial stages of separation in the magma chamber (Ashwal & Bybee 2017).

In contrast, Arndt (2013) proposes that after the fractionation of the plagioclase components, the residual, denser mafic magma migrates downwards through the crust due to its high density. This model is somewhat controversial as generally fractionating liquids rise as a more buoyant component, not sinking as a denser component. This model also fails to account for the presence of high aluminium orthopyroxene megacrysts, which requires crystallisation at greater depths.

It should be noted that the HFC anorthosite is not a typical massif type anorthosite, in that the anorthosite units occur in a noritic matrix, rather than as massive units. However, It is still considered a Proterozoic massif type anorthosite due to its age, texture and associated rock units (Årebäck 1995). The formation and emplacement model is quite similar to the aforementioned typical models; it is described by Årebäck (1995) and revised by Glommé (2015) and Kullberg (2015) as illustrated in figure 2. After the magma is emplaced into the crust, the IRL forms an early cumulate and sinks to the bottom of the magma chamber, the plagioclase begins to crystallise and rises to separate from the IRL as partially crystallised anorthosite blocks and the remaining siliceous magma. The magma then mobilizes and migrates upwards, bringing the plagioclase mush, parts of the crystallised IRL and crystallised anorthosites. The rest of the magma then cools forming the noritic matrix encompassing the anorthosites and IRL.

2.3 Plagioclase zoning

Plagioclase forms a complete solid solution series from albite ($\text{NaAlSi}_3\text{O}_8$) to anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$). The composition of plagioclase is dependent on the composition of the magma, temperature, pressure and water content (Ginibre 2007; Shcherbakov et al. 2011; Ustunisik 2014). Changes in these factors will then result in zonation of plagioclase.

A plagioclase that crystallises in a dry magmatic system will have a lower Ca/Na in comparison to a wet magma system. A decreasing pressure will result in an increasing Ca/Na in the

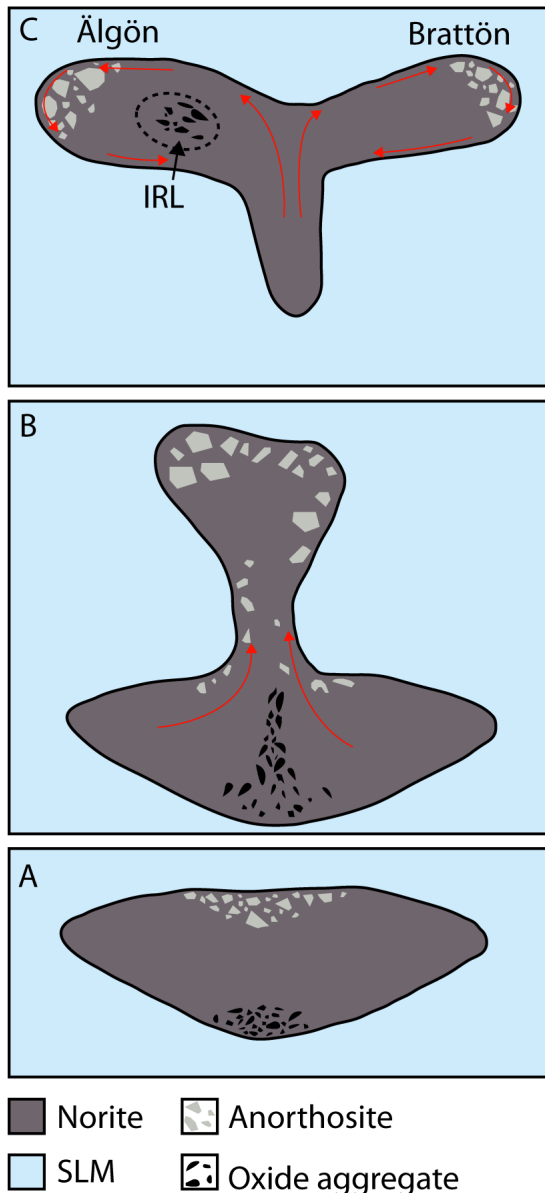


Fig. 2. A simplified model of the emplacement of the HFC. Stage A depicts a magma chamber and the initial formation of the anorthosite blocks that rise to the top as a semi crystallised cumulate. Oxide aggregates also begin to form at this stage which sink to the bottom of the chamber. stage B depicts the initial rise of the magma chamber along with the semi crystallised anorthosite cumulates and oxide aggregates, with the oxides being pulled into the centre of the chamber. Stage C depicts the final stages before complete crystallisation. The magma chamber now forms two lobes which are now recognised as the islands Älgön and Brattön. The anorthosite blocks are encompassed in a noritic matrix and are concentrated on the west side of Älgön and the east side of Brattön. The oxide aggregates are concentrated in the centre of älgön and are also encompassed in a noritic matrix, this formation is now recognised as the ilmenite rich leuconorite. Modified after Kullberg (2015)

crystallising plagioclase. A decreasing temperature results in a decreasing Ca/Na in the crystal phase (Ginibre 2007; Shcherbakov et al. 2011; Ustunisik 2014). Because of this, generally the earlier forming plagioclase is more Ca rich compared to the later forming, more Na rich plagioclase. Knowing the composition of plagioclase crystals can then provide information about the nature of the magma chamber and magma source. Furthermore, zonation within plagioclase can provide a timeline of evolution of aforementioned features (Ginibre 2007; Winter 2009).

It's worth noting that coupled substitution of plagioclase (between $\text{Na}^+ + \text{Si}^{4+}$ and $\text{Ca}^{2+} + \text{Al}^{3+}$) will occur to some extent to re-equilibrate and homogenise zonation profiles. Zonation in plagioclase, however, is often seen to be preserved due to the slow diffusion rates and faster temperature cooling rates (Morse 1984). This prevents intracrystalline diffusion, however, diffusion at the solid and liquid interface might be substantial enough to create homogenous profiles in plagioclase provided that growth rates of the plagioclase are slow enough and there is a constant influx of fresh magma (Morse 1984).

A short summary on commonly seen zonation patterns in plagioclase phenocrysts is given below and figure 3 displays a representation of the most common zoning trends.

2.3.1 Normal zoning

Normal zoning occurs when the magma chamber is isolated and the temperature is gradually cooling. As the temperature drops the plagioclase must re-equilibrate to a more Na rich composition, resulting in a more Ca rich core and a more Na rich rim (Winter 2009; Shcherbakov et al. 2011).

2.3.2 Reverse zoning

Reverse zoning shows the opposite trend of normal zonation, starting with a more Na rich core leading into a more Ca rich rim and is generally less common than normal zonation. Reverse zoning is said to occur most commonly due to rising changes of temperature and is commonly seen in metamorphic rocks (Ginibre et al. 2007; Winter 2009; Shcherbakov et al. 2011). A decrease in pressure could also, in theory, cause reverse zonation, but the pressure effect on An-content of plagioclase is seemingly negligible unless if there is a great deal of decompression (Shcherbakov et al. 2011). It should be noted, however, that plagioclase megacrysts from the Hakefjorden Complex have rims that are more Ca rich than the cores, which has been interpreted to reflect pressure decrease (Årebäck 2001).

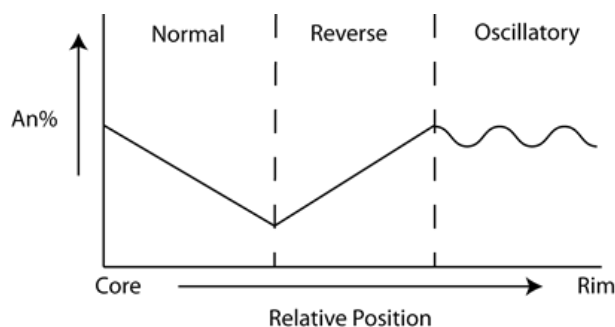


Fig. 3. A simplified representation of the most common anorthite zoning patterns in plagioclase. The y axis displays An% which is the relative proportion of anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) and albite ($\text{NaAlSi}_3\text{O}_8$) in plagioclase. The x axis depicts relative distance from the core to the rim, the An% will change over these distances creating a zoning profile. A normal zoning profile displays a plagioclase crystal that has high An% in the core and a low An% in the rim. A reverse zoning profile shows the opposite trend of a normal zoning profile. An oscillatory zoning profile displays small variations of An% from the core to rim.

2.3.3 Oscillatory zoning

Oscillatory zoning shows a repeating trend of An decreasing and increasing over much smaller intervals than both normal and reverse zoning. This is the most common form of zoning and is believed to be caused by small movements around a magma chamber, where the plagioclase crystallizes at different temperatures (Ginibre et al. 2007; Winter 2009; Shcherbakov et al. 2011). Ginibre et al. (2002a) also states that over smaller amplitudes and wavelengths, oscillatory zoning is more likely to represent finely spaced zones of resorption, caused not only by kinetics but also potentially changes to the magma in the form of magma recharge events.

2.3.4 Patchy zoning

Patchy zoning displays varying changes in An content with no clear pattern based on textural context, caused by different processes on a case by case scenario but generally reflects the kinetics of a magma chamber and/or dissolution processes (Ginibre et al. 2007).

2.4 Trace element compatibility

In order to properly interpret the trace element data the fundamentals behind trace element compatibility and distribution must be understood. In a crystal lattice of a mineral major elements will make up the bulk of the chemistry. However, certain trace elements that occur in much lower concentrations (less than 0.1% wt%) might substitute for a major element in the crystal lattice (Winter 2009, Rollinson 2014).

There are specific aspects that govern the compatibility of substitution between any given trace and major element. Firstly, ions with a similar ionic

radius and charge are more likely to substitute for each other. In the case of two ions having the same radius but different charge, the higher charged ion is substituted more preferentially. In the case of two ions having the same charge but different ionic radii, the ion with the smaller radius is substituted more readily (Winter 2009; Rollinson 2014).

Elements that are taken more preferentially into any given phase are referred to as being more compatible, the more compatible an element, the more concentrated in will be in the solid phase over the melt. This can be quantified by a distribution constant expressed as:

$$K_D = C_S / C_L$$

Where K_D is the distribution constant (also known as the partition coefficient), C_S is the concentration of the element in the solid and C_L is the concentration of the element in the liquid (Winter 2009). An element with $K_D > 1$ is compatible into the solid phase, while it is incompatible for $K_D < 1$. Different minerals incorporate trace elements at different coefficients, as seen in Table 1. The preferential intake of a certain trace element into the solid phase will also affect the concentrations of the surrounding residual liquid and as consequence crystals that grow later in the sequence will be affected. In large crystals it is common to see higher concentrations of a more compatible element in the core of the mineral in comparison to the rims of the mineral. This is caused by the liquid phase becoming progressively more depleted in the compatible elements as crystallisation occurs as it is incorporated into the solid phase. This is another process in which crystal growth profiles similar to that of major elements; however, concentration of trace elements is controlled primarily by the composition of the magma and the partition coefficient (Winter 2009).

The presence of large (>1cm) plagioclase crystals in the norite and anorthosite units makes plagioclase suitable for tracking different stages of magma evolution. Sr ($K_D > 1$, Table 1) is compatible in plagioclase while Ba is relatively incompatible ($K_D < 1$; Table 1). Assuming a simplistic, closed magmatic system that is solely controlled by fractional plagioclase crystallisation, Sr concentrations will drop in both the remaining liquid and in the plagioclase with successive crystallisation. Conversely, the Ba concentrations will relatively increase in both the liquid and the fractionating plagioclase. To summarise: fractionation without re-equilibration within the plagioclase will lead to decreasing Sr/Ba from the core to the rim. Plagioclase is assumed to faithfully record the magmatic evolution, but disruption from the predicted patterns might be caused by other crystallising minerals, liquid recharge into the

	Olivine	Opx	Cpx	Garnet	Plag	Amph	Magnetite
Rb	0.01	0.022	0.031	0.042	0.071	0.29	
Sr	0.014	0.04	0.06	0.012	1.83	0.46	
Ba	0.01	0.013	0.026	0.023	0.23	0.42	
Ni	14	5	7	0.955	0.01	6.8	29
Cr	0.7	10	34	1.345	0.01	2	7.4
La	0.007	0.03	0.056	0.001	0.148	0.544	2
Ce	0.006	0.02	0.092	0.007	0.082	0.843	2
Nd	0.006	0.03	0.23	0.026	0.055	1.34	2
Sm	0.007	0.05	0.445	0.102	0.039	1.804	1
Eu	0.007	0.05	0.474	0.243	0.1/1.5	4.557	1
Dy	0.013	0.15	0.582	3.17	0.023	2.024	1
Er	0.026	0.23	0.583	6.56	0.02	1.74	1.5
Yb	0.049	0.34	0.542	11.5	0.023	1.642	1.4
Lu	0.045	0.42	0.506	11.9	0.019	1.563	

Table 1. Partition coefficients of trace elements in commonly seen igneous minerals from a basaltic magma. Note that these values are taken from one source, different publications might show different partition coefficient values, and that partition coefficients will vary substantially based on the composition of the magma. Europium is seen to have two values for plagioclase because it will be less compatible as Eu^{3+} compared to Eu^{2+} as it is substituting for Ca^{2+} (Winter 2009). Values taken from Winter (2009).

evolving magma, contamination or diffusive re-equilibration within the plagioclase. In the HFC, the effect of other crystallising minerals is likely small or negligible, apatite being the only known competing phase for Sr and Ba (Winter 2009).

The effect of magma recharge is likely to increase Sr-concentration in the liquid as the residual fractionated liquid will be relatively depleted in Sr in comparison to the newer, more primitive magma. Because of this, trace element data could provide potential insights that major chemistry analysis (Ca and Na in this case) wouldn't, because the An content may be controlled by factors such as T, P and water content. The trace element data should be less dependant of the aforementioned factors, and represent the availability of the trace elements in the system i.e the composition of the magma (Ginibre et al. 2007; Winter 2009).

Although trace element concentrations might not be as affected by temperature and pressure in comparison to major elements, these factors may still have an effect on the partition coefficients of trace elements. Sun et al. (2017) investigated the effects of temperature and pressure on partition coefficients of trace elements in plagioclase by experimental modelling. They concluded that temperature has a minor or negligible effect on the partition coefficient on divalent trace elements (Sr and Ba) while pressure has a minor effect. In contrast, Nielsen et al. (2017) provides a compilation of measured partition coefficients of multiple trace elements, including Sr and Ba in plagioclase and compares them to the anorthite content. They observed a clear trend of a decreasing partition coefficient of Sr and Ba with increasing plagioclase anorthite content. Partition

coefficients range between 1 and 4 for plagioclase that range in An-content from 0 to 100 ($\text{An}_0 \text{D}_{\text{Sr}} = 4$, $\text{An}_{100} \text{D}_{\text{Sr}} = 1$).

Although this is just a compilation study that shows a correlation, Blundy and Wood (1991) also state there is a relationship between rising An content and lowering K_D of Sr and Ba in plagioclase by observing data from hydrothermal experiments on plagioclase. While temperature and pressure do not have a direct effect on the partition coefficient of Sr and Ba in plagioclase, it is possible they do have an indirect effect in that temperature and pressure are some of the factors that determine the plagioclase An-content, which could proceed to affect the K_D of the trace elements.

Diffusion in the crystallising plagioclase may also have an effect on the trace element concentrations, as trace elements diffuse faster than major elements (Ginibre et al. 2002b). It is possible for the rate of diffusion of a trace element in a mineral to be on the same magnitude of the growth rate of a plagioclase crystal (Ginibre et al. 2002b). This could partially or completely homogenize any variations in the concentrations. However, this depends heavily on the growth rates of a given mineral in a magmatic system and other factors that will change the composition of the magma, and therefore needs to be considered on a case by case scenario.

3 Methods

All the samples in this project are the same as those investigated by Glommé (2015) and Kullberg (2015). The sample set consists of a number of thin sections and epoxy mounts containing samples mainly from the

HFC and also from the SLM. More information about the sampling can be found in the aforementioned theses.

3.1 Petrography

24 thin sections were prepared at the Geological Institute at Slovak Academy of Sciences for the purpose of prior theses and have been repurposed for this study. The petrographic analyses were completed at Lund University using transmitted light microscopy, and photos were taken with a digital camera attached to the microscope. Only transmitted light microscopy was done, therefore opaque minerals were neglected from further analyses as these are not the focus of this study. For a more comprehensive discussion of the opaque mineral phases see Kullberg (2015).

3.2 Scanning electron microscopy (SEM)

Nine samples were cast into epoxy at Lund University and were analysed in a SEM instrument. Quantitative element analysis by energy dispersive x-ray analysis (EDS) was performed at Lund University to retrieve major element data, the main focus being the plagioclase crystals to determine An content by observing the Na, Ca and K concentrations. The spot analysis locations were also done from the centre to rim in the plagioclase megacrysts in order to observe any potential zonation in the plagioclase. Some larger element maps and transects were also taken for the purpose of making the visualisation of zonation easier. Before analysis, the epoxy mounts were carbon coated using a Cressington Carbon Coater, coating each sample with a 30 µm carbon layer. A Tescan Mira3 SEM with Oxford EDS and EBSD instruments was used to conduct the analysis. For the element analyses a beam intensity of 15 nA, 15 mm working distance and 18 kV acceleration voltage was used.

SEM works as follows: a concentrated beam of electrons is focused at the sample, which then produces two electron products from the sample. Backscattered electrons (BSEs) are reflected electrons from the initially fired beam from the electron source with a lower, but still high fraction of their initial energy. Secondary electrons (SEs) are electrons that escape from the atoms in the sample after being charged with the electron beam (Goldstein et al. 2017).

BSE can provide an image of the specimen by displaying a contrast in atomic weight: denser material produces lighter image shades. SE can provide an image of the specimen by providing a topographic image of the sample by detecting changes in surface inclination and depth. X-ray photo emissions are also produced; these have specific energy signals that work as fingerprints for different elements and are used for the EDS analysis (Goldstein et al. 2017).

3.3 Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICP-MS)

9 epoxy mounts were also analysed for trace element concentrations using a LA-ICP-MS at Lund University. Using in situ laser ablation, the plagioclase megacrysts were the main focus and spots were taken for the purpose of observing any zonation within the megacrysts. For this work, the following elements were analysed: Na, and Si for internal standardisation and Rb, Sr, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Er and Yb for their abundances.

A Teledyne Photon Machines G2 laser coupled to a Bruker Aurora Elite quadrupole ICP-MS was used for the analyses. The La-ICP-MS works by a laser ablating single spots on the samples, the ablated particles are then transported by a carrier gas to the plasma torch. The particles are then ionized before entering a mass spectrometer, where the atomic weight of the particles can be determined to provide element analyses (Sylvester 2001). The settings used for these instruments are as follows: laser wavelength – 193 nm, pulse width <4 ns, fluence – 3.5 J/cm², repetition rate – 8 Hz, spot size – 95x95 µm, background collection – 30 seconds, ablation duration – 30 seconds, gas flow – 0.8L/min, carrier gas – He. A certified SRM NIST612 reference glass was used as a standard and a SRM NIST614 glass was used as secondary standard for quality control. Ca values taken from the SEM analysis were used for an internal standardisation. Wavemetrics IgorPro was used for the data reduction.

3.4 Data quality

A note on quality for the SEM data: there were some issues which concern the accuracy of the results due to some low wt% values. This does not necessarily compromise results, but implies that wt% effects must be constrained. Observing the wt% values plotted against each of the components making up plagioclase (CaO, Al₂O₃, Na₂O, SiO₂) trends can be seen in both Na₂O values and SiO₂ values versus wt%. These trends however are absent when the oxide values are normalised; the An values shown in this study are calculated by calculating the percentage of the Ca ion in the sum of the Ca, Na and K ions (effectively normalising the data). Figure 4 shows that the majority of the samples lie closely to a perfect plagioclase trend with the exception of some offsets from samples AGSE03 and AGSKSE21; this implies caution should be taken when evaluating the major chemical data (anorthite content) from these samples.

Regarding the data quality for the LA-ICP-MS, the presence of an external standard (NIST614) meant that both the accuracy and precision could be tested. The accuracy was tested by normalising all of the

values gathered from this projects lab work to the available standard laboratory measurements of NIST614, and none of the normalised values exceeded the range of 0.95-1.05 (appendix II). The precision was tested by recording the reproducibility of the recorded values of NIST614 by measuring the coefficient variation (standard deviation/mean*100) which never exceeded 1.5% (appendix II).

4 Results

4.1 Petrography

Of the available 24 thin sections, 9 were examined to cover 7 rock types from both the HFC (6) and SLM (1). Figure 5 displays various snapshots of the thin sections using a digital camera attached to the microscope.

4.1.1 Norite (AGSE03, AGSE04, AGSE05 and AGSKSE10)

The norite units consist of plagioclase, orthopyroxene, clinopyroxene, oxides, biotite, quartz, and apatite. Overall the rock is fine to medium grained but contains phenocrystic plagioclase. The plagioclase sometimes occurs as megacrysts, reaching sizes of >1 cm. In general, plagioclase in the norite matrix is around 0.5 mm forming subhedral and elongate grains. Occasionally, the matrix plagioclase is slightly altered

and patchy (e.g. in AGSE04 and AGSE10) and the samples can be overall altered showing disequilibrium textures (AGSE10). The megacrysts often display a band of patchy inclusions just inside the rims of the crystals. These patchy areas are characterised by varying An-content and small inclusions of clinopyroxene, K-feldspar and Fe-Ti-oxides (Fig. 5B). The inclusions often form small composite clusters where all the aforementioned phases are present in an inclusion, rather than as separate minerals.

Orthopyroxene occurs as ~0.4 mm, anhedral grains, and coloured beige in PPL with a very slight pleochroism. Clinopyroxene is often associated with the orthopyroxenes, however less abundant and smaller (~0.2 mm), they vary from colourless to weak green pleochroism. Biotite occurs as ~0.1 mm, anhedral and sometimes elongate grains, showing a characteristic deep brown, almost red colour in PPL which is also strongly pleochroic. The oxides appear almost exclusively in association with the biotite, as ~0.4 mm grains. The apatite is by far the least abundant mineral in the samples, occurring as very fine (0.05 mm) crystals found exclusively as inclusions in the plagioclase rims (Fig. 5B).

4.1.2 Anorthosite (AGSE07)

The rock is near monomineralic, in that it almost entirely consists of plagioclase, with some accessory orthopyroxene, clinopyroxene, and oxides. The

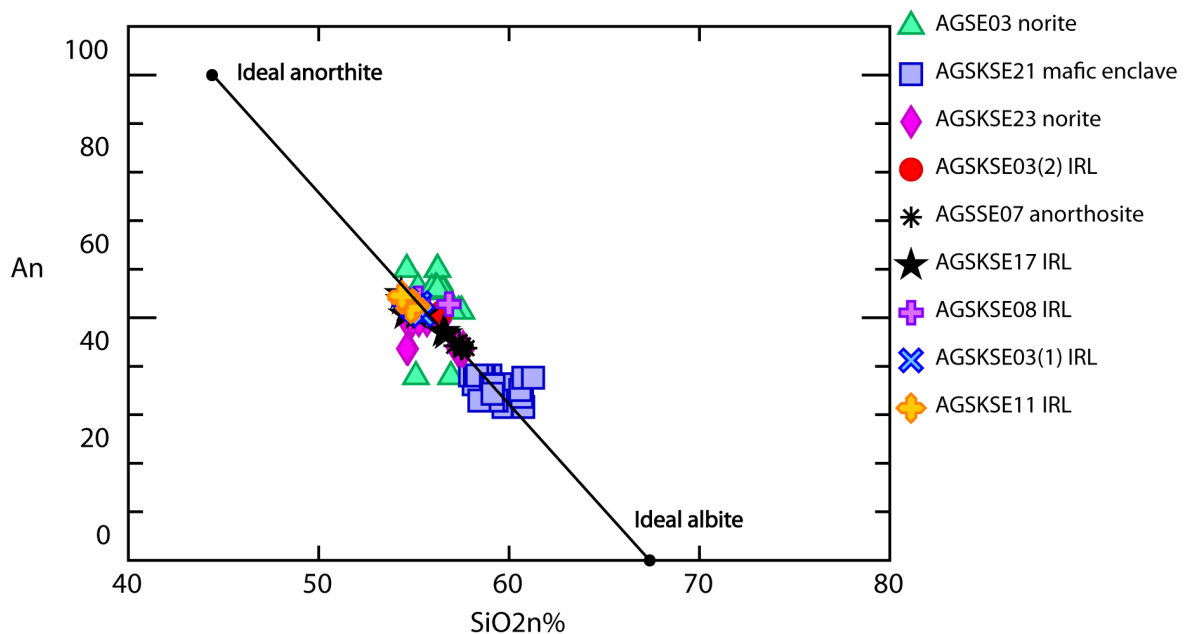


Fig. 4. Anorthite content plotted against normalised SiO₂%. The purpose of this figure is to visualise how accurate some of the major chemistry data might be. The black line represents the potential compositions of plagioclase with changing An-content and SiO₂ concentrations. How far any given sample lies from the plagioclase composition line provides an indication of how accurate the stoichiometry is and how reliable the major chemistry analyses are.

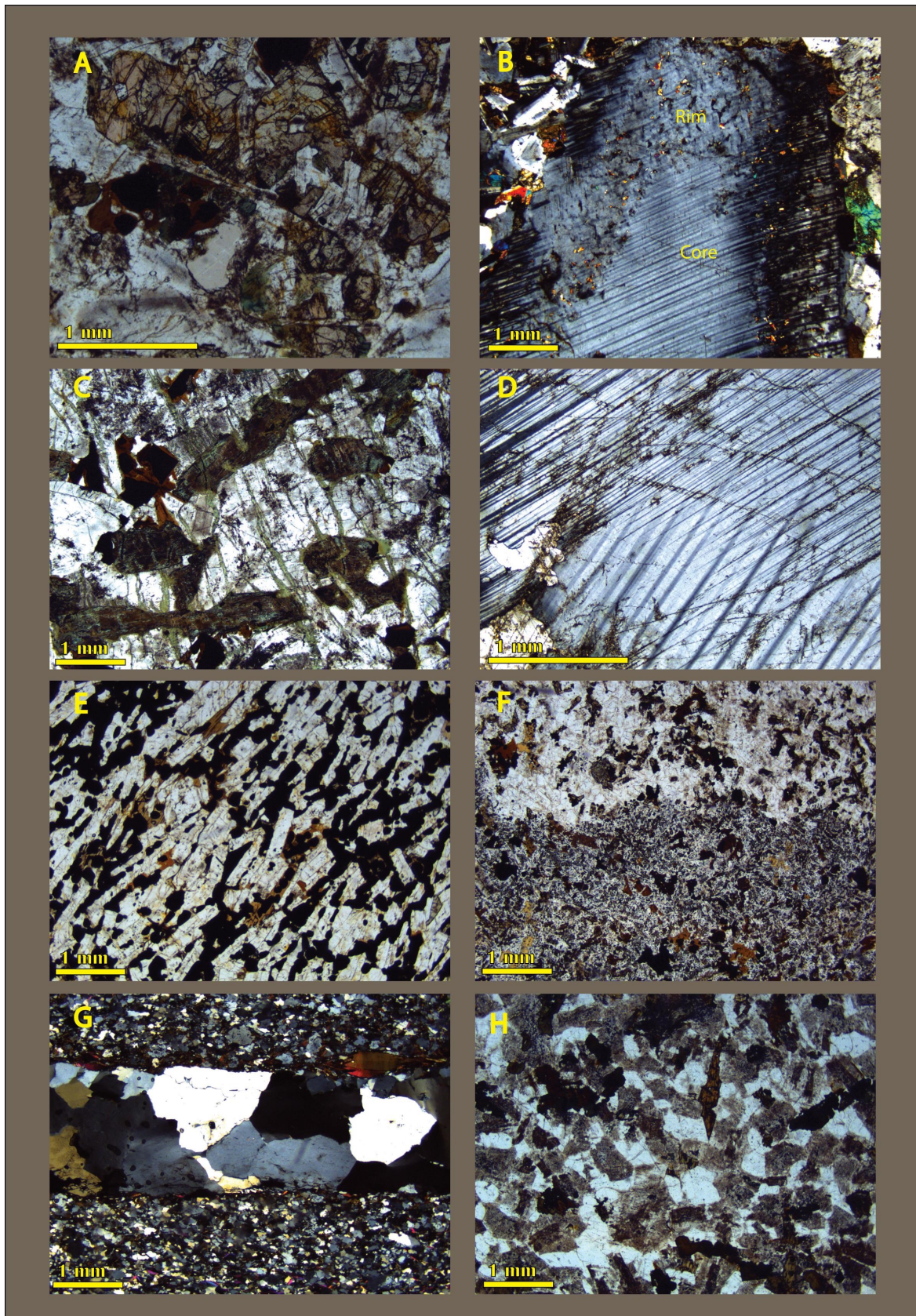


Fig. 5. Various snapshots of the thin sections. A: sample AGSE03 norite matrix in (PPL). B: sample AGSE03 norite with plagioclase megacryst displaying inclusion trails in the rim (XPL). C: sample AGSKSE10 altered norite matrix (PPL). D: sample AGSE07 anorthosite (XPL). E: sample AGSKSE03 IRL displaying flow structure (PPL). F: sample AGSKSE21(1) mafic enclave displaying the contact between fine and medium matrix (PPL). G: sample AGSKSE24 gneiss from the SLM displaying a quartz vein (XPL). H: sample AGSKSE25 monzonorite matrix (PPL).

plagioclase occurs as very coarse grains around 1 cm in size. Albite twinning is present throughout and patchy inclusion trails (similar to those seen in the norite plagioclase) are also present. However, unlike the norite plagioclase the trails do not follow the rims, instead presenting randomised directions following no textural pattern. The orthopyroxene, clinopyroxene, and oxides all occur as much smaller (0.2-1 mm) anhedral crystals (Fig. 5D).

4.1.3 Ilmenite Rich Leuconorite (AGSKSE03)

The ilmenite rich leuconorite (IRL) consists of oxides, plagioclase, orthopyroxene, and biotite. Since the rocks were only examined using transmitted light microscopy, the opaque minerals are just referred to as oxides. However, previous petrographic work indicate that the vast majority of these opaques are ilmenite (Årebäck 1995; Kullberg 2015). These oxides dominate the bulk of the rock as 0.6 mm subrounded, elliptical grains. The second most abundant mineral is plagioclase, occurring both as ~2 mm elongate grains and ~0.2 mm equigranular grains. Both orthopyroxene and biotite occur as less abundant ~0.5 mm grains. The rock displays a flow structure throughout that causes both mineralogical layering and also orientation of the elongate minerals (Fig. 5E).

4.1.4 Mafic enclave (AGSKSE 21(1))

The mafic enclave consists of quartz, plagioclase, biotite, orthopyroxene, and oxides. The sample is bimodal in grain size distributions having both fine (~0.2 mm) and medium to coarse (0.5-1 cm) sections separate from each other. The only other notable difference in the sections besides grain size was that quartz seemed to be more dominant in the coarser sections comparatively. Plagioclase megacrysts, similar to those seen in the norite are also present. However, these megacrysts have far more inclusions than those seen in the norite.

4.1.5 Stora Le-Marstrand Formation (AGKSE24)

This sample from the SLM is a gneiss primarily consisting of quartz, muscovite, and biotite. The rock is generally quite fine (~0.2 mm) and equigranular, with the exception of some quartz veins that are present where grain size is around 1.5 mm. A strong foliation is present causing mineralogical layering and orientation of the elongate grains; the quartz veins are also concordant with the foliations (Fig. 5F).

4.1.6 Monzonorite (AGKSE 25)

The monzonorite consists of quartz, plagioclase, orthopyroxene, clinopyroxene, biotite, and oxides. Mineralogically, the monzonorite is very similar to the

norite samples with the main difference being a higher abundance of quartz. The grain size is mostly medium to coarse (0.5-0.8 mm) with the exception of the less abundant clinopyroxene and oxides which are around 0.2 mm. The grains are all anhedral to subhedral and sometimes display a 'dusty' or altered appearance (Fig. 5H).

4.2 SEM and LA-ICP-MS

Figures 6, 7 and 8 show a display of all of the epoxy mounts and the points where analysis was taken, referring to appendix I. The SEM, LA-ICP-MS and, where applicable, the isotope data taken from Glommé (2015) are attempted to be presented all in the same context; however, at times the exact position at which one specific measurement is taken may be different to another (for example, the SEM spectra spots are taken in different locations to the LA-ICP-MS spots) so occasionally the spots are correlated together based on averages taken from textural similarities. Figures 9, 10, 11 and 12 show specific transects recorded in plagioclase megacrysts. Note that the lowest position value correlates to the most inner point of each transect. Relative anorthite percentages are reported as An_{xx} and trace element concentrations are reported in parts per million (ppm).

4.2.1 AGSE03 norite with megacryst

There are two transects taken in the megacryst in this sample. The first transect (points 1-7) shows a very slight general increase in the trace elements, showing a slight increase in Sr values up until point 6, point 7 then shows a slight decrease in Sr. Ba behaves in a similar way showing a slight increasing trend from points 1 to 7 (Fig. 9B-D). The second transect shows little to no systemic variation in both Sr and Ba, however, the last point at the end of the transect shows a slight decrease in Sr and increase in Ba resulting in a more significant change in the Sr/Ba ratio (Fig. 9F-H).

The An-content in the first transect shows no variation until the outermost point in the rim which shows a sudden increase (Fig. 9A) and the second transect shows a very slight reverse zonation throughout and a slightly steeper increase at the outermost point (Fig. 9E). A common trend in these transects is the more pronounced changes occur at the end of the rim which also somewhat coincides with a disequilibrium texture in the rim. Figure 13 displays an example of this showing the second transect in AGSE03; the exact transition in to this texture is somewhat arbitrary but occurs from around point 12 or 13, and the spikes in the second transect are seen in point 14. This texture was also observed in the first transect, occurring around point 7 where the trace element values also see an abrupt change. The matrix plagioclase shows variable readings, with the An-

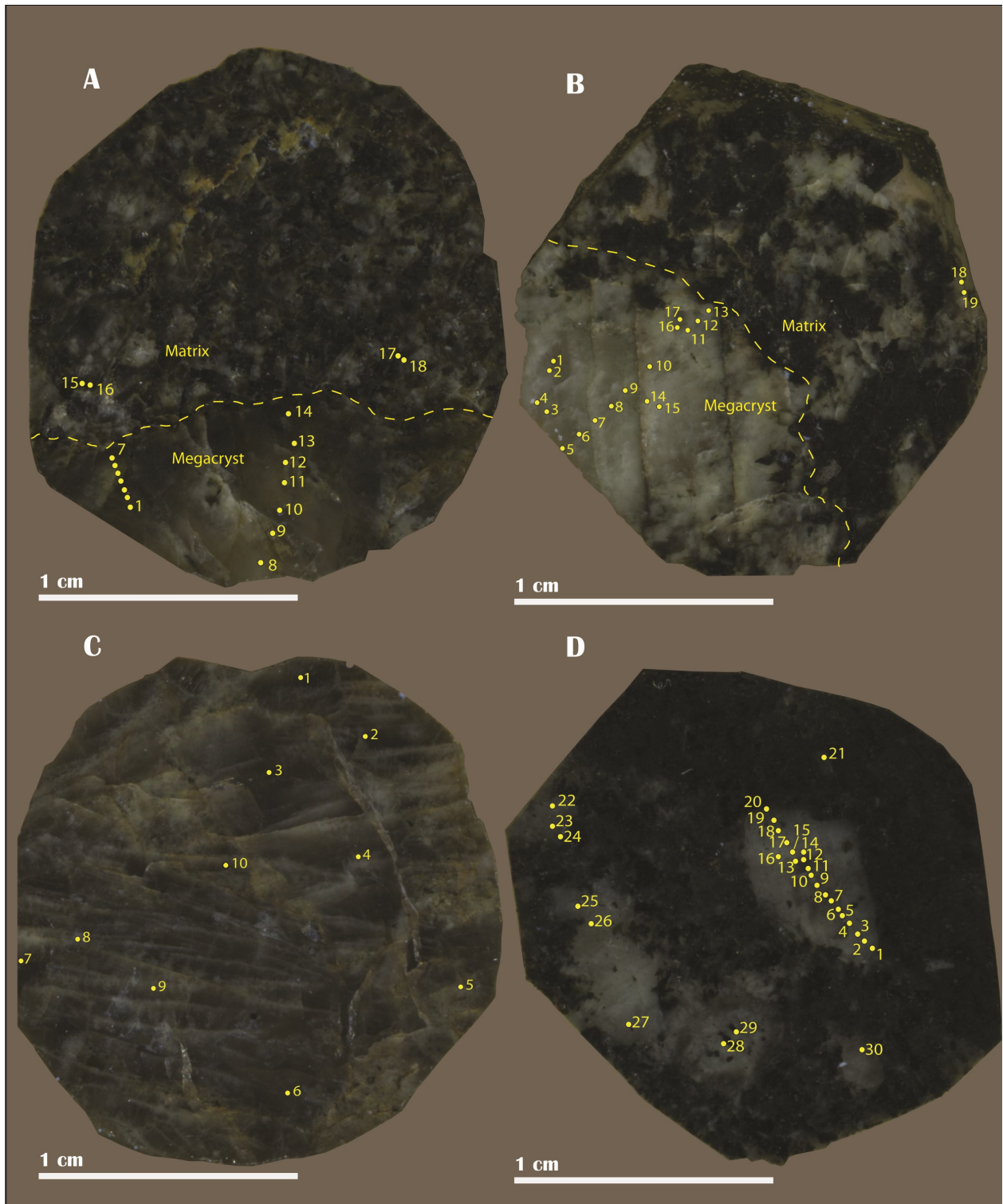


Fig. 6. Displays of the samples used for SEM and LA-ICP-MS analyses and the corresponding analysis points. Data for these analyses can be found in appendix I. A yellow dashed line are present in samples AGSE03 and AGSKSE23 to indicate the boundary of the plagioclase megacryst and surrounding matrix. A: sample AGSE03 a norite with a plagioclase megacryst. B: sample AGSKSE23 norite with a plagioclase megacryst. C: sample AGSE07 anorthosite. D: sample AGSKSE21 mafic enclave.

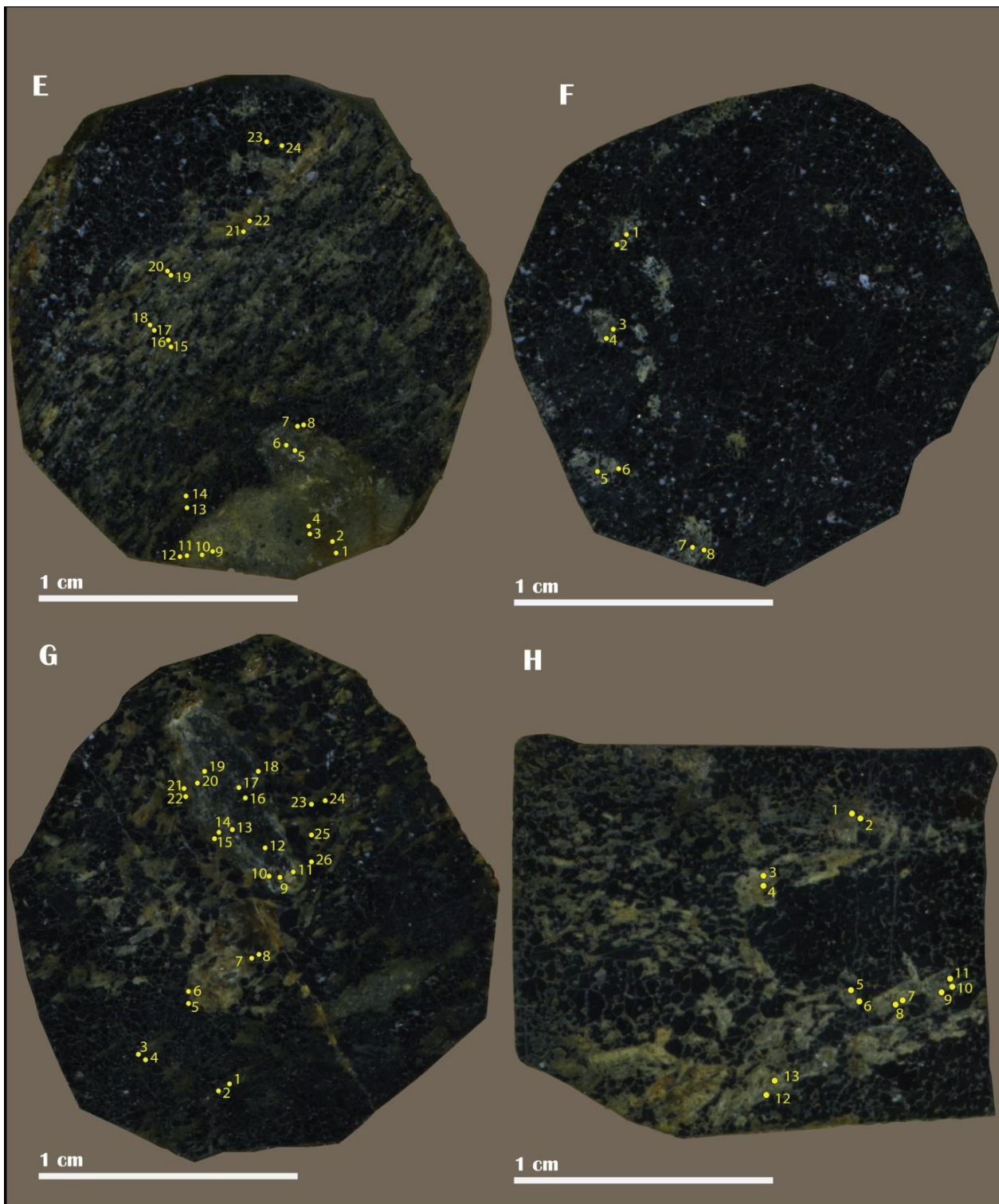


Fig. 7. A continuation on from figure 6. Displays of the samples used for SEM and LA-ICP-MS analyses and the corresponding analysis points. Data for these analyses can be found in appendix I. E: sample AGSKSE03(1) IRL with plagioclase phenocryst. F: sample AGSKSE03(2) IRL matrix. G: sample AGSKSE08 IRL with inclusion. H: AGSKSE11 IRL matrix.

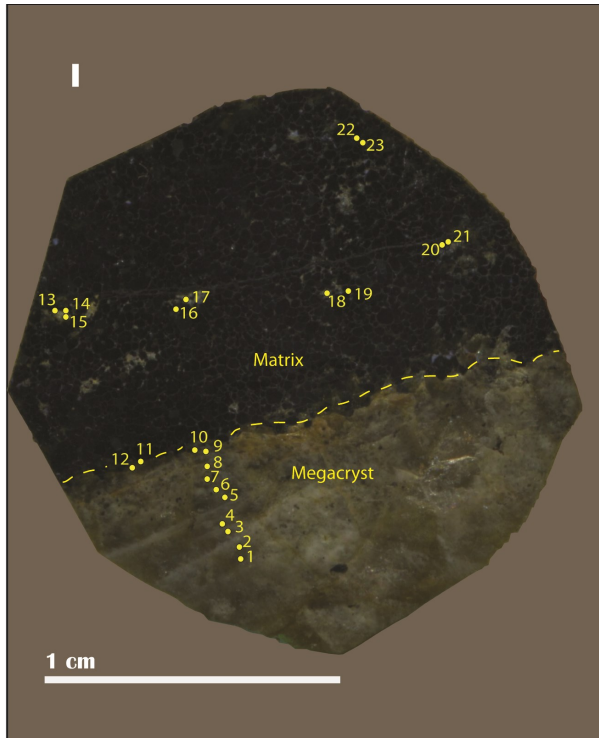


Fig. 8. A continuation on from figures 6 and 7. A display of sample AGSKSE17, an IRL with a plagioclase megacryst. The numbered points represent analysis points for the SEM and the LA-ICP-MS analyses. The corresponding data can be found in appendix I. The dashed yellow line depicts the boundary between the plagioclase megacryst and the surrounding matrix

content ranging from An_{38} to An_{56} and Sr ranging from 481 to 631 ppm (appendix I).

4.2.2 AGSKSE23 norite with megacryst

The plagioclase megacryst in this sample has two distinct zones as indicated by both An, Sr and Ba concentrations which also coincides with the patchy outer rim texture (Fig. 10 and 13). The core is homogenous in both An and Sr content (An_{43-45} and 865-885 ppm Sr). The rim is distinguished by a steep increase in An-content to An_{55} , (Fig. 10A) which is followed by normal zoning towards the edge. The Sr-concentration shows a sudden drop followed by an increase from 771 to 1084 ppm (Fig. 10B). The matrix plagioclase shows similar readings to that of the outer megacryst (An_{53-55} and 809-978 ppm Sr). Ba shows a similar trend to Sr in the megacryst, showing an initial homogenous trend in the core followed by a steep increase starting at the rim (Fig. 10C). The matrix readings of the Ba showed variable but relatively higher readings in comparison to the core (230-408 ppm Ba).

4.2.3 AGSKSE17 IRL with plagioclase megacryst

The An-content of the plagioclase megacryst initially shows no variation in the core, until an increase in the rim from points seven to nine (Fig. 11A) which also coincides with a patchy texture similar to that seen in other samples. The matrix plagioclase has similar An-content values to that of the megacryst plagioclase with a range from An_{51} to An_{54} (appendix I). The trace elements also show a similar trend in the megacryst - both Sr and Ba concentrations are homogenous in the core of the megacryst and the rim shows elevated values at points 7, 8 and 9 (Fig. 11B and 11C). The matrix Sr concentrations have similar readings to the megacryst values averaging 1035 ppm and the megacryst averaging 1034 ppm; however, they have a more uniform distribution compared to the bimodal distribution found in the megacryst. In contrast to this Ba values in the matrix show considerably more variation and are also show higher values than those seen in the megacryst (average of 289 and 535 ppm Ba in the megacryst and matrix respectively) (appendix I).

4.2.4 AGSKSE21 mafic enclave with phenocryst

A phenocryst in this sample has a core and a rim that can be identified texturally and also shows different geochemistry. There is some scatter in the An-content but a general decrease in the An-content towards the rim, ranging from An_{31} near the rim and to An_{40} near the centre (Fig. 12A). Sr-contents across this grain show stark contrasts between the core (381 ppm Sr average) and rim (715 ppm Sr average) which also coincides with a patchy texture (Fig. 12B). Ba showed very variable results that do not show any systematic variation (Fig. 12C). Sr in the plagioclase from the rest of the sample shows similar readings to that of the outer phenocryst (720 ppm Sr average), and An-content shows a similar trend (average of An_{34} in both the outer phenocryst and non phenocryst plagioclase).

It is also worth noting that this was the only sample that showed any significant variation in $^{87}\text{Sr}/^{86}\text{Sr}$, with values ranging from 0.7065-0.7078, with the highest readings being in the core of the phenocryst (Glommé 2015).

4.2.5 AGSKSE03(1) IRL with phenocryst

The sample is comparatively homogenous with small variations, An-contents range from An_{51-54} and Sr concentrations range from 939-1153 ppm. There are no systematic changes with textural setting and in contrast to AGSKSE17 the matrix and the inner and outer megacryst are indistinguishable from each other in regards to An-content and Sr. However, Ba shows

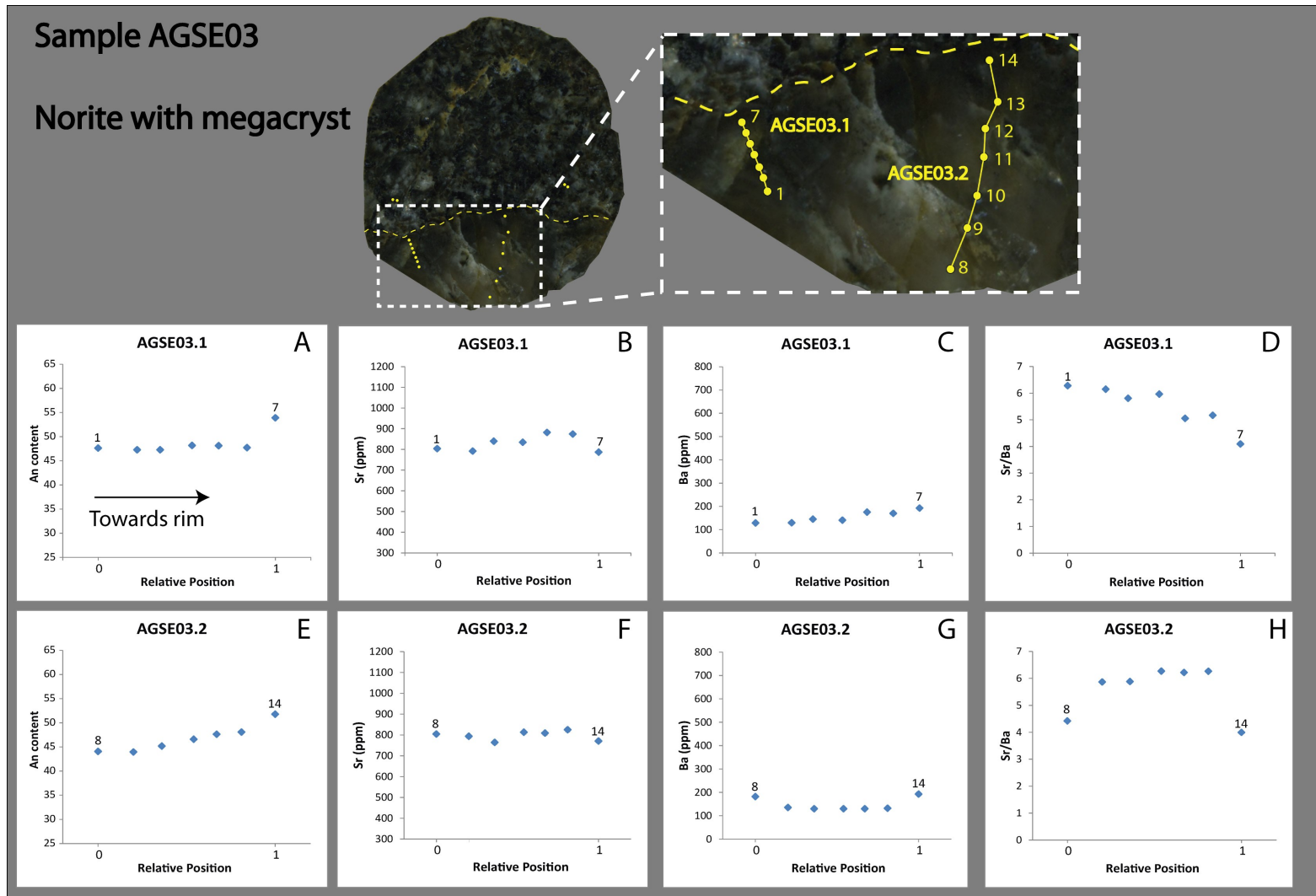


Fig. 9. A highlighted view of two analysed transects in a plagioclase megacryst taken from sample AGSE03. The first row of graphs depict the transect on the left side of the megacryst (points 1 to 7) and the second row depict the transect on the right side of the megacryst (points 8 to 14). The graphs show the An, Sr, Ba and Sr/Ba plotted against the relative position in transects. The graphs depict the progression of the transects going from core to rim as left to right on the graphs. Numbers found on the points in the middle of the graphs relate to the points found in the transects. The dashed yellow line on the image of the sample depicts the boundary of the plagioclase megacryst and the surrounding matrix. Error bars for trace element data are not included as they are smaller than the symbol size (never exceeding more than 2%, appendix I). For errors for major element data (wt % for An-content) the reader is referred to appendix I. The transects do not show much variation in the core of the megacryst, with the exception of An-content in the AGSE03.2 transect which shows a slight reverse zonation. The outermost point in both transects show a slight spike in An-content and slight dip in Sr concentrations.

Sample AGSKSE23

Norite with megacryst

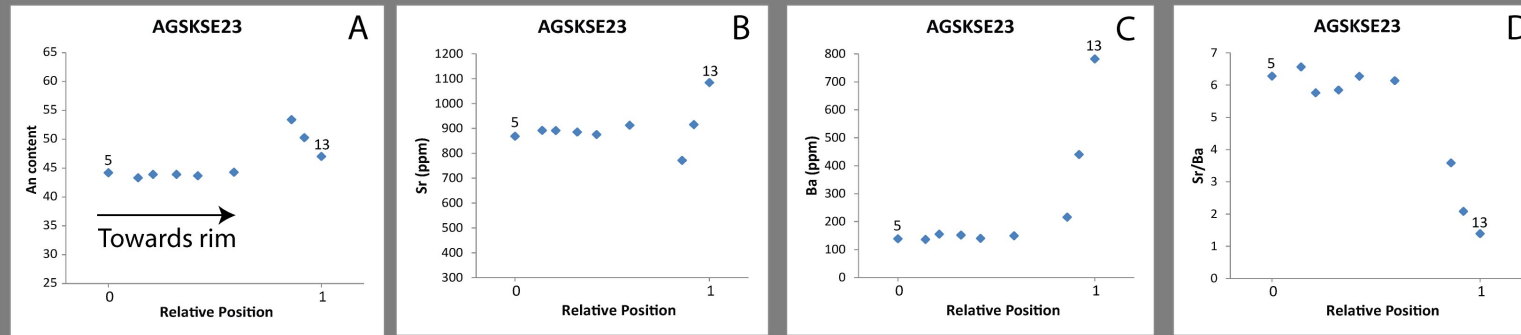
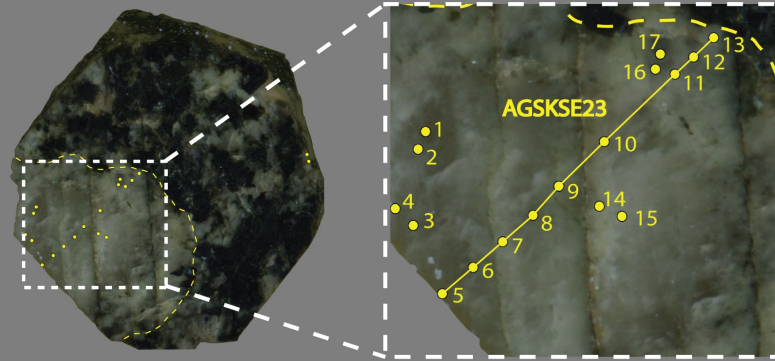


Fig. 10. A transect in a plagioclase megacryst taken from sample AGSKSE23. The core of this megacryst showed little to no variation in An, Sr and Ba. Points 11-13 however show substantial variation. An-content spikes in point 11 and then gradually decreases to point 13, typical of a normal zonation trend. Sr concentrations show an initial dip at point 11 and then two subsequent spikes in points 12 and 13. Ba shows a slight spike in point 11 followed by two more significant spikes in points 12 and 13. Increase in An-content has been interpreted as a pressure decrease in the system caused by an ascent of the magma chamber. Increases in Sr in the rim of the plagioclase have been interpreted as being caused by magma recharge.

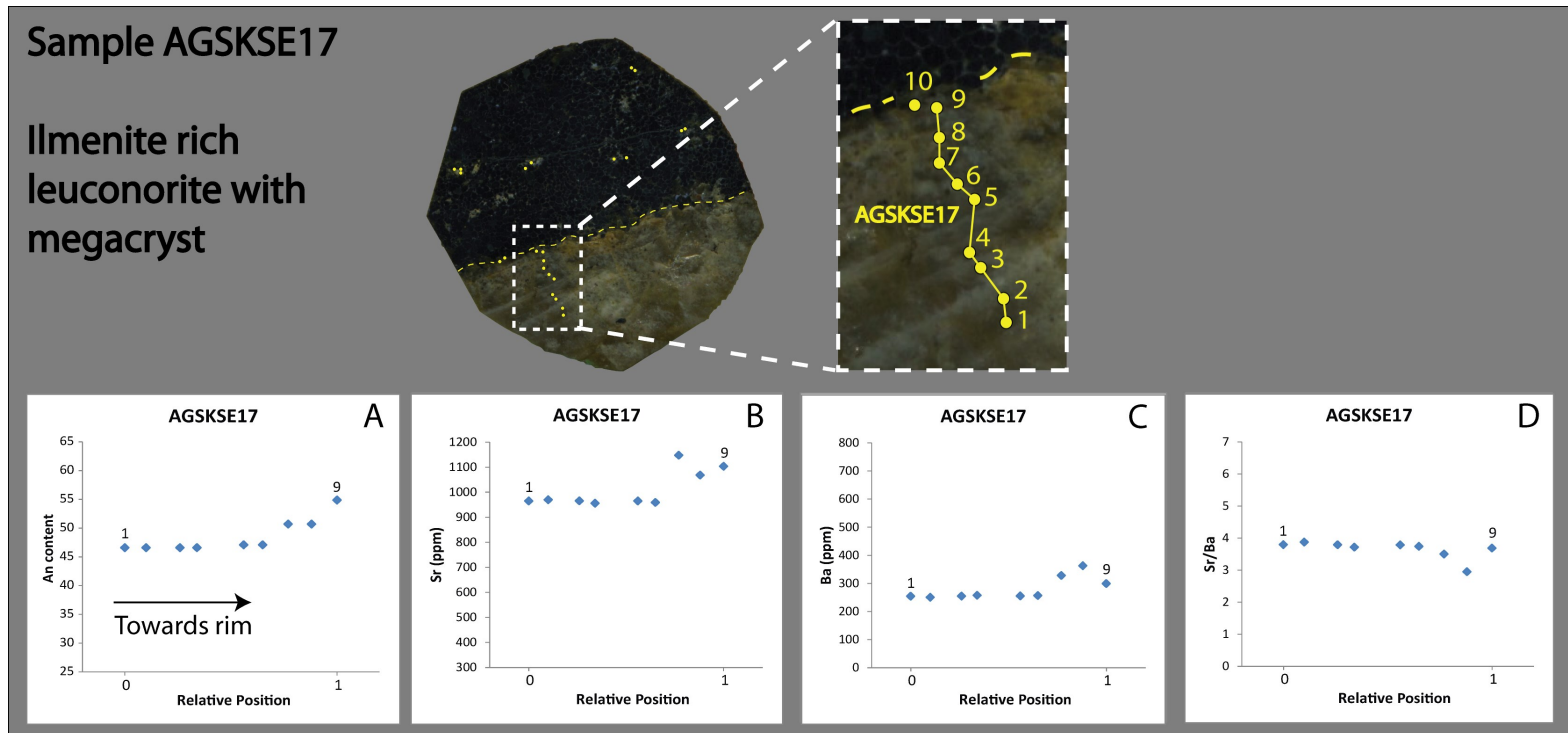


Fig. 11. A transect in a plagioclase megacryst taken from sample AGSKSE17. Similarly to sample AGSKSE23 the core of this megacryst appear to be homogenous in An-content, Sr and Ba concentrations. Some variations can be seen in points 7-9, An-content spikes at point 7 and then again at point 9. Sr concentrations spike at point 7; points 8 and 9 show similar values. Ba concentrations show a slight increase at point 7; points 8 and 9 also show similar values. Similarly to sample AGSKSE23, the rises in An-content and Sr concentrations have been interpreted to be caused by a magma chamber ascent and magma recharge respectively.

Sample AGSKSE21

Mafic enclave with phenocryst

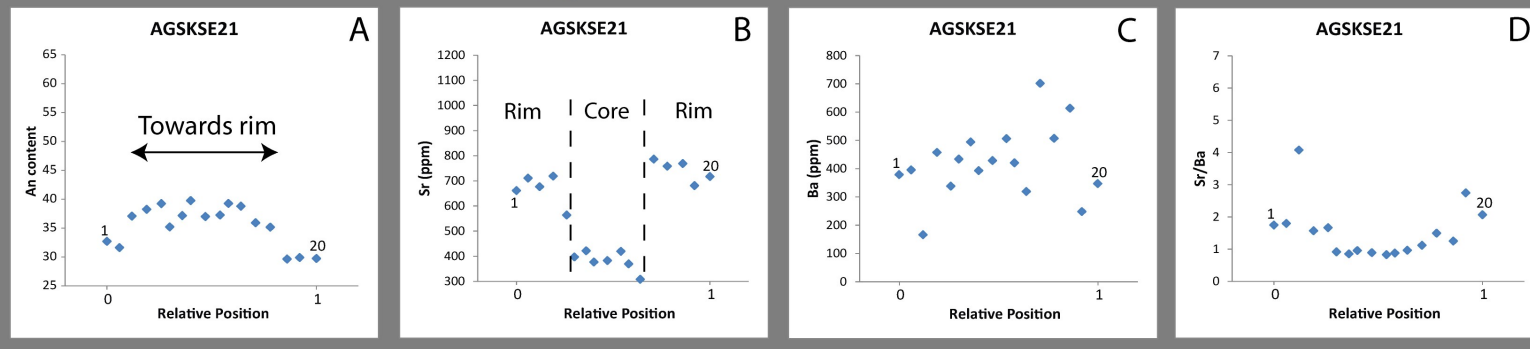
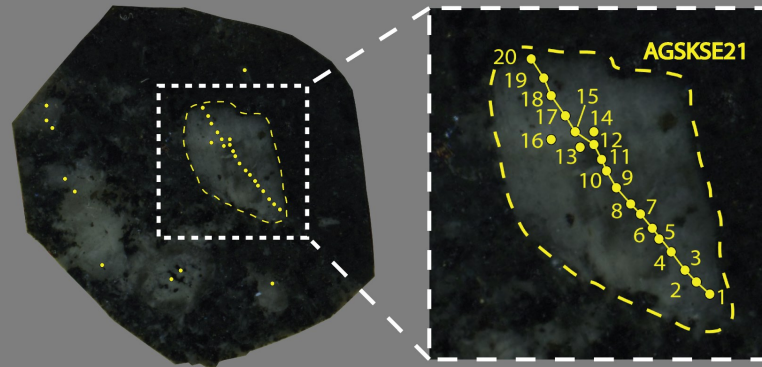


Fig. 12. A transect in a plagioclase phenocryst taken from sample AGSKSE21. An important note in for this sample is that unlike the previous samples, this transect spanned from one rim in the plagioclase to the other. This means that the centre of the graphs will represent the core of the plagioclase. The An-content depicts a normal zonation profile as the core of the sample is higher in An-content in comparison to the rims. The Sr concentrations, however, show a strong contrast between the core and the rims, with the core being relatively depleted in Sr concentrations compared to the rims. Ba concentrations show no systematic variations. The contrast of Sr concentrations in the core compared to the rim are likely to reflect the core of the plagioclase being a xenolith.

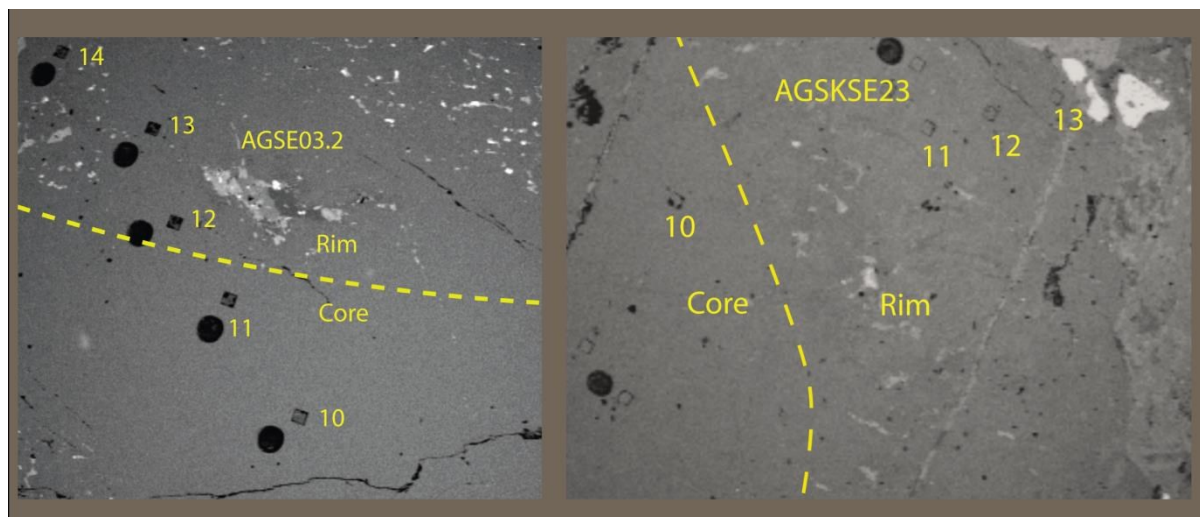


Fig. 13. Samples AGSE03 and AGSKSE23 highlighting the textural difference seen in between the core and the rim of plagioclase megacrysts. The numbers refer to data points found in figures 9, 10 and appendix I. The change from the core to the rim are also generally reflected by a change in the major and trace elements. The exact boundary of the rim in sample AGSE03 was not well defined as the onset of the texture was gradual. Although the dashed line depicts the boundary between point 11 and 12 it could also be between points 12 and 13. There was also a discrepancy in the changes in chemistry and texture in transect AGSE03.2 as the changes in chemistry were seen in point 14 (a slight increase in An-content and a slight decrease in Sr concentration).

variation throughout the sample ranging from 331-1015ppm Ba (appendix I) but does not show any trend with textural context.

4.2.6 AGSKSE03(2) IRL

This sample is indistinguishable from AGSKSE03(1) except for showing less spread in the Ba values. An-contents range between An_{51-53} , Sr ranges from 921-989 ppm and Ba ranges from 305-449 ppm (appendix I).

4.2.7 AGSKSE08 IRL with inclusion

This sample is homogenous in An throughout, in both the matrix and the inclusion (An_{53-56}) with no textural patterns and Sr and Ba show similar results, however, the centre of the inclusion shows lower Sr concentrations. Some of the points show elevation in Ba, La, and Ce (appendix I). These points were located on the edge of the inclusion where it was difficult to find a location that was just plagioclase – therefore, this might be the effect of contamination by ablating other minerals.

4.2.8 AGSKSE11 IRL

This unit is similar to the other IRL samples without megacrysts, the An and Sr concentrations are homogenous. There is spread in the Ba values and there are no systematic variations within the geochemical data and textural setting (An_{52-55} , 904-1077 ppm Sr, 270-607 ppm Ba) (appendix I).

4.2.9 AGSE07 anorthosite

The sample is homogenous throughout in regards to An, Sr and Ba. It has a range of An_{43-45} , 842-942 ppm Sr (average of 873 ppm and a standard deviation of 28) and 158-199 ppm Ba (average of 171 ppm and a standard deviation of 11) (appendix I).

5 Discussion

Firstly, it is necessary to highlight a few of the shortcomings of the data in this project that will have implications on the validity of the discussion. Most of the discussion points are related to the observed zonation in plagioclase megacrysts, in this study there are only 3 samples that contain a plagioclase megacryst which is a low sample size. Furthermore, some of the observations of data points are extrapolated to represent the entire textural section of a mineral. For example, single line transects of data points are used to represent an entire megacryst. While this does give a partial representation, more data points that span the entire megacryst, rather than just a single line transect, would be a better representation of the samples. Section 3.4 also highlights that there are additional uncertainties in the accuracy of the major element compositions due to the wt % from the SEM data not being ideal.

5.1 Trends in anorthite content

All 3 of the observed samples that included megacrysts (AGSE03, AGSKSE23 and AGSKSE17) show a similar trend in An-content, in that a spike in An-content is seen at the rims of the megacryst that also coincides with a patchy texture (Fig. 9, 10, 11

and 13). Furthermore, samples AGSKSE23 and AGSKSE17 show homogenous An-content readings in the core of the megacrysts and sample AGSE03 showed a slight reverse zonation trend in the core of the megacryst. Sample AGSKSE21 included a plagioclase phenocryst which showed a general normal zonation trend.

Reverse zonation (either gradual or in sudden spikes) in plagioclase crystals is linked to either rising temperature or decreasing pressure conditions during crystallisation (Winter 2009; Ustunisik et al. 2014). Årebäck and Stigh (1997) explained the observed trends through polybaric crystallisation and emplacement of the HFC, where they attributed the patchy texture in the megacryst rims to disequilibrium conditions due to pressure decrease during emplacement into shallower crustal levels. While the trends in An content found in this study are consistent with what Årebäck & Stigh (1997) found, it is possible that newly introduced magmas may also be causing the reverse zonation trend in An content, more on this further in the discussion (section 5.3).

The anorthosite unit (AGSE07) shows homogenous readings of An-content throughout the crystal (section 4.1.2), similarly to the cores of the IRL units AGSKSE23 and AGSKSE17 (Fig. 10 and 11). The homogenous nature of the anorthosite and megacryst cores are not easily explained. However, a potential scenario could be that the magma chamber system is being buffered by injections of new magma, effectively negating any crystal fractionation by keeping the magma at a constant composition and temperature. If the magma is being kept at a consistent composition and temperature the crystallising plagioclase would also reflect this by showing no zonation. This could also potentially explain the slight reverse zonation seen in sample AGSE03 (Fig. 9E), with the difference being that the injections of magma are gradually increasing in temperature and/or becoming more calcic in composition.

The mafic enclave (AGSKSE21) is the only sample that displays normal zoning in plagioclase (Fig. 12A), which would represent a near isobaric scenario with a cooling temperature and evolving liquid in the magma chamber. Trends in this sample's trace element profile indicate this sample has a xenolithic core (section 5.2). However, it is still possible for each component (xenolithic core and rim) to experience normal zoning from a reducing temperature.

The matrix plagioclase shows somewhat variable results in any given sample, but generally has higher An-content than the cores of the megacrystic plagioclase as seen in figures 14 and 15. The variability could be linked to magma chamber kinetics, as Kullberg (2015) describes there being substantial kinetic activity in the magma chamber in the final

stages of cooling (when the matrix plagioclase is forming), which will change pressure conditions and also move the crystallising materials to compositionally differing areas in the magma chamber due to convective currents (Upton 1996). The polybaric evolution of the magma chamber could also explain the generally higher An content of the matrix plagioclase. This is because as the magma chamber rises upwards through the crust the system will experience less pressure at shallower depths.

5.2 Trends in trace element concentrations

Firstly, it is necessary to assess all of the relative effects of the factors that can contribute to the concentrations of trace element concentrations in plagioclase which are the melt composition, changing partition coefficients and diffusion.

Figures 16 and 17 display the relationship of Sr concentrations with An-content, and Ba concentrations with An-content respectively. What is observed is a slight positive correlation in Sr and An-content and no correlation in Ba concentrations and An-content. This is in contrast with predicted effects of crystal chemistry on K_D for Sr and Ba in plagioclase (as highlighted in section 2.4), which states that there should be a correlation between increasing An content in plagioclase and a decrease in K_D for Sr and Ba (Blundy and Wood 1991; Nielsen et al. 2017). While the K_D data is not determined in this study, there should be a noticeable effect on the concentrations if the K_D is changing - the results here imply an increasing K_D for Sr with increasing An-content and no effect Ba.

There is a chance that there is some effect of crystal chemistry on the K_D of Sr and Ba, but its effects are overprinted by the other governing factors of Sr and Ba concentrations (magma composition and also potentially diffusion). Considering that the observed effects are opposite to what is expected, the effects of a changing K_D in Sr and Ba with An content are likely to be negligible. T and P have also been recognised to have potential minor effects on the K_D of trace elements (Vander Auwera et al. 2000; Sun et al. 2017); however, no geothermometry or geobarometry data were collected for this project. Considering that the aforementioned studies (Vander Auwera et al. 2000; Sun et al. 2017) suggest there is only potentially a minor effect of both T and P on K_D of trace elements, and that these factors should be reflected in the crystal chemistry which showed the opposite trend of what is expected, these factors can be considered insignificant.

Diffusion must also be considered which presents considerable difficulty – knowing the net effects of diffusion necessitates knowledge of exact diffusion rates of trace elements in both the magma

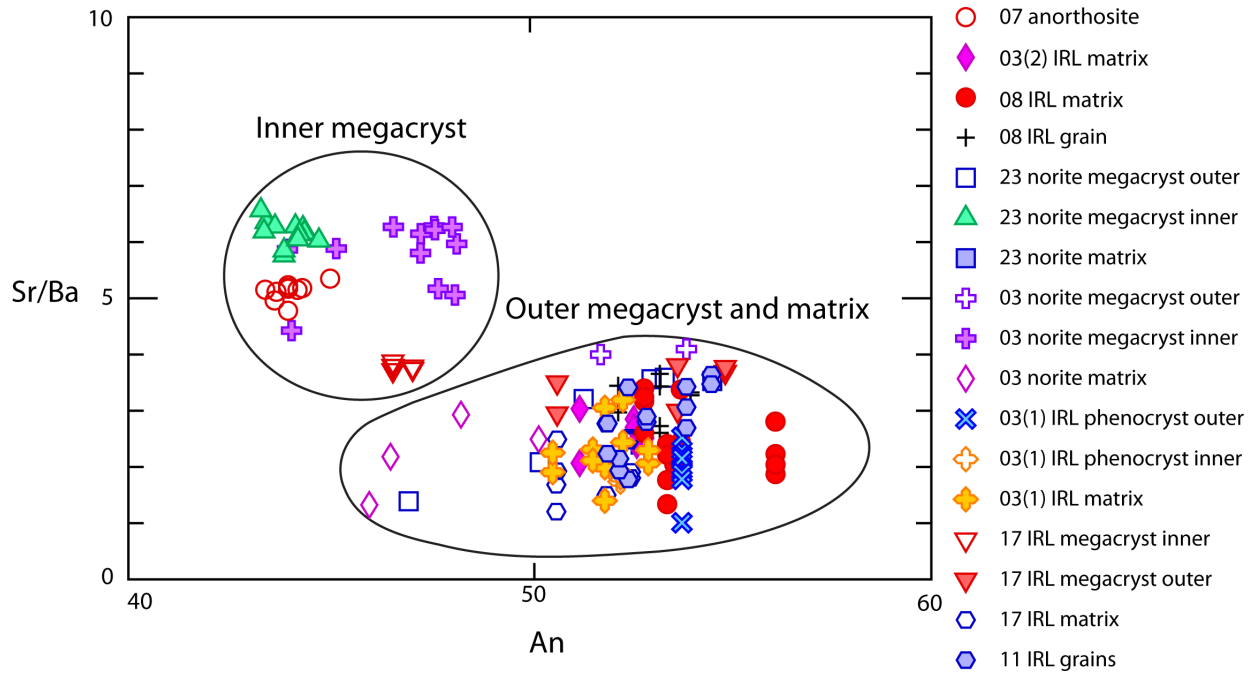


Fig. 14. Sr/Ba plotted against An content for each data point excluding the mafic enclave. Error bars are not included as they are smaller than the symbol size. A clear distinction can be seen between the samples from an inner megacryst and the samples from either an outer megacryst or matrix. A lower Sr/Ba in the later forming plagioclase minerals (the rims of a plagioclase megacryst and matrix plagioclase) is likely to be caused by crystal fractionation. A higher An-content in the later forming plagioclase minerals is likely due to the polybaric evolution of the magma chamber. The mafic enclave sample was excluded because the readings of the xenolithic component of the sample would not represent any process caused by the magma chamber system.

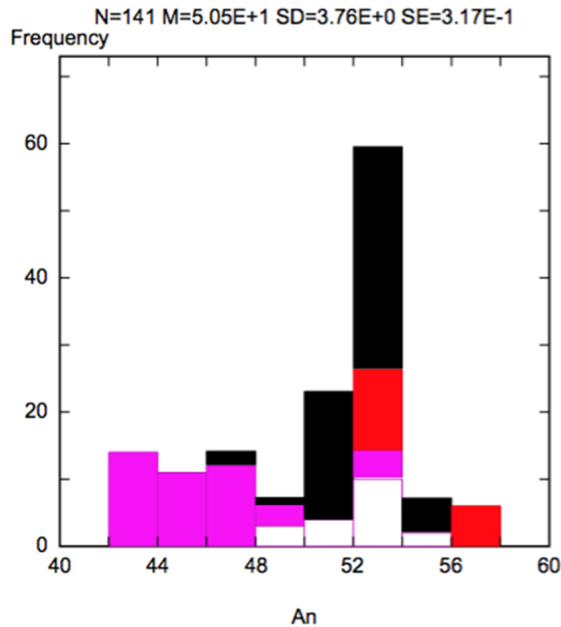


Fig. 15. Histogram of An content for each data reading. Legend: Purple: megacryst plagioclase cores, white: megacryst plagioclase rims, black: matrix plagioclase and red: other plagioclase (not megacrystic or matrix). The lower values of the earlier forming megacryst core plagioclase and higher values of the later forming megacryst rim and matrix plagioclase is most likely caused by the polybaric evolution of the magma chamber

and the crystal. Furthermore, the exact growth rate of the crystal is required. The present study is constrained by the lack of these measurements, but we shall nonetheless reason on the effects of diffusion and its implications for this work.

High rates of diffusion should work to make the samples homogenous. Homogenous trace element profiles are observed in the cores of the megacrysts of samples AGSKSE23 (Fig. 10), AGSKSE17 (Fig. 11) and AGSE03 (Fig. 9). The anorthosite unit (AGSE07) also showed homogenous trace element concentrations (section 4.2.9). Similarly to the process that caused the homogeneity in the major element profiles, the magma composition could be buffered by magma injections causing the homogenous trace element profiles. Variations of trace element concentrations in the rims of the megacrysts however, have been preserved (Fig. 9, 10 and 11), so intracrystalline diffusion is likely to not be a significant factor.

The remaining contributing factor to trace element concentrations is the melt composition. Considering that if the effects of crystal chemistry, temperature and pressure on the K_D of Sr in plagioclase can be considered insignificant, the only way to increase the concentration of a compatible element (Sr in this case) is by an enrichment of the magma. This can be caused either by a magma

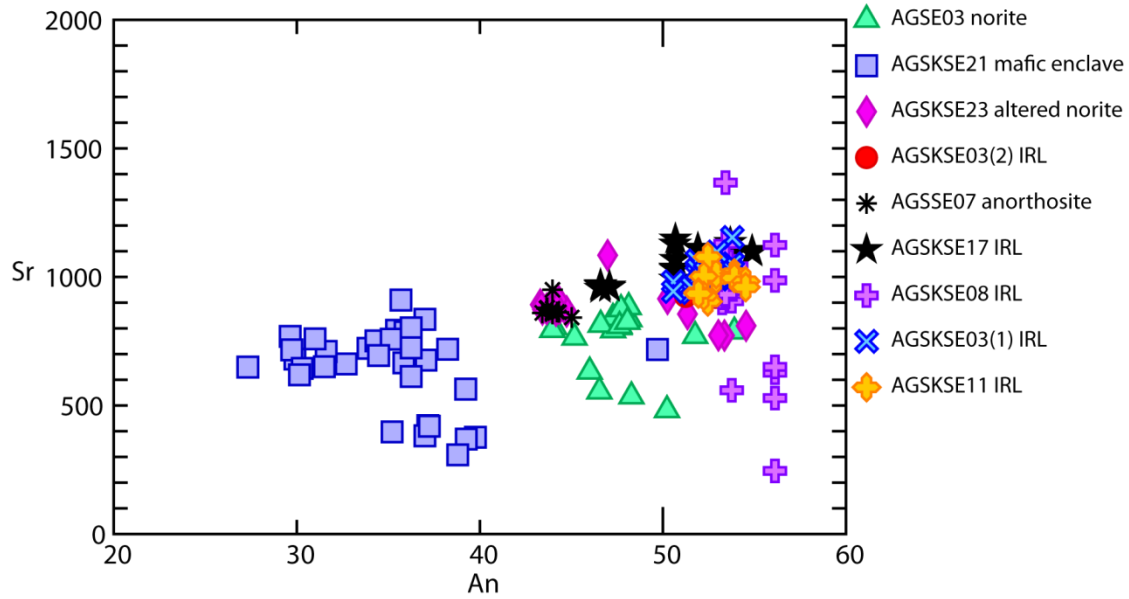


Fig. 16. Sr vs An content for every sample. Error bars are not included as they are smaller than the symbol size. A slight positive trend can be seen between Sr and An-content. This is in contrast to the Sr and An-content trends observed in Blundy & Wood (1991) and Nielsen et al. (2017) which state there should be a negative correlation between Sr and An. This suggests that the effects of crystal chemistry on the K_D of Sr in plagioclase are likely to be negligible for these samples. A possible explanation for the positive correlation seen here is the effect of magma recharge. This would both increase Sr concentrations by enriching the magma and increase the An-content by either increasing the temperature of the magma, triggering the polybaric evolution of the magma chamber and decreasing the pressure of the system, or both.

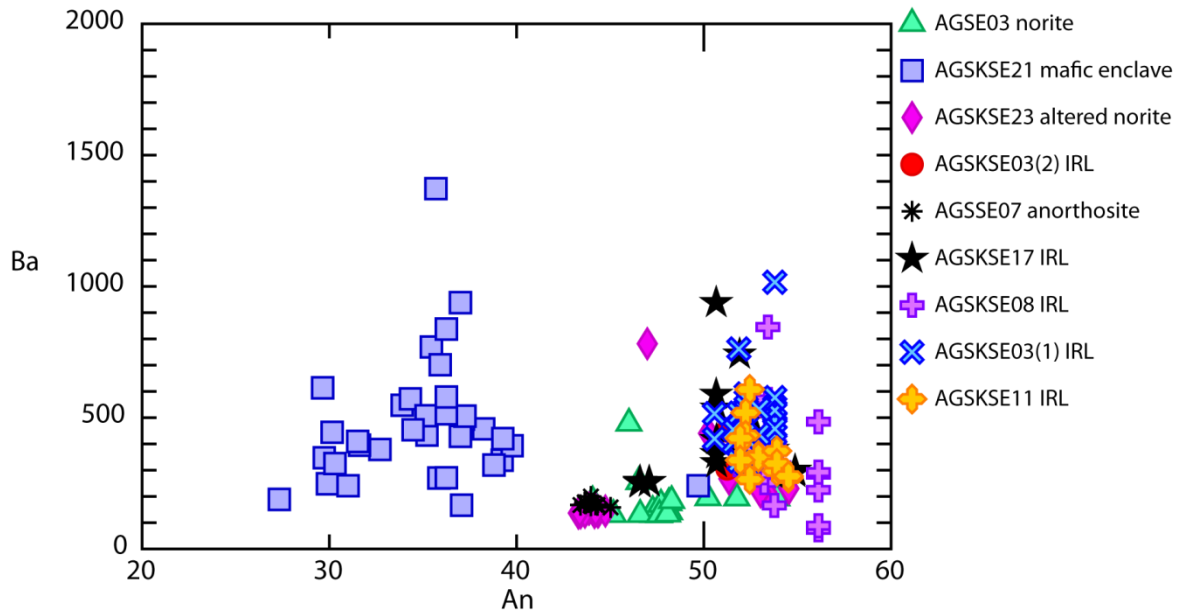


Fig. 17. Ba vs An content for every sample. Error bars are not included as they are smaller than the symbol size. No correlation can be seen for Ba vs. An-content, which is again contrasts the observations found in Blundy & Wood (1991) and Nielsen et al. (2017). This implies that the crystal chemistry also does not have an effect on the K_D of Ba in plagioclase in these samples

injection event or by assimilating enriched material, e.g. through crustal assimilation.

$^{87}\text{Sr}/^{86}\text{Sr}$ data taken from Glommé (2015) shows that with the exception of the mafic enclave unit, the units in the HFC have homogenous $^{87}\text{Sr}/^{86}\text{Sr}$ profiles (Fig. 18). Because of this, the elevated peaks in Sr seen in the megacrysts in samples AGSKSE23 and AGSKSE17 are more likely to be caused by magma injections. If the peaks were caused by crustal assimilation there would be variability in the $^{87}\text{Sr}/^{86}\text{Sr}$ which instead is homogenous throughout. The recharge events also increase the Sr concentrations to higher than the previous peaks, indicating that the newly introduced magma might have a different composition than the initial magma. The change in composition is likely to be caused by different degrees of melting of the magma source, resulting in different concentrations of trace elements such as Sr, but with constant $^{87}\text{Sr}/^{86}\text{Sr}$ (Winter 2009).

The mafic enclave also shows elevated Sr concentrations in the rims of a phenocryst (Fig. 12B), however past studies on this same sample have determined that the core of this phenocryst is likely to be a xenolith due to the contrasting $^{87}\text{Sr}/^{86}\text{Sr}$ values and textural contrasts (Glommé 2015). Because of this, the elevation in Sr is likely just a contrast between

the depleted xenolith and the more enriched local magma crystallising around it.

Sample AGSE03 was the only unit with a plagioclase megacryst that did not display elevated Sr concentrations in the rim of the megacryst, and instead showed a slight decrease (Fig. 9B and 9F). A potential explanation for this observation is simply that this unit was not affected by a magma injection. It is also possible that the injected magma was relatively depleted, however this explanation is less likely as fresher magmas should be more primitive.

The composition of the melt will also change from the initial composition through fractional crystallization. As the minerals begin to crystallize the composition of the residual liquid will change as certain elements are removed from the solution based on how compatible they are (Winter 2009). Increases in Sr are most readily explained by magma recharge events, however, Sr concentrations in the matrix plagioclase are either similar to or lower than the megacrysts. Even more telling is that the Ba concentrations are on average (per rock unit) higher in the matrix than the concentrations in the megacryst (Fig. 14). Both of these trends can be explained by fractional crystallisation, as Sr will become relatively depleted in the liquid as crystals form resulting in

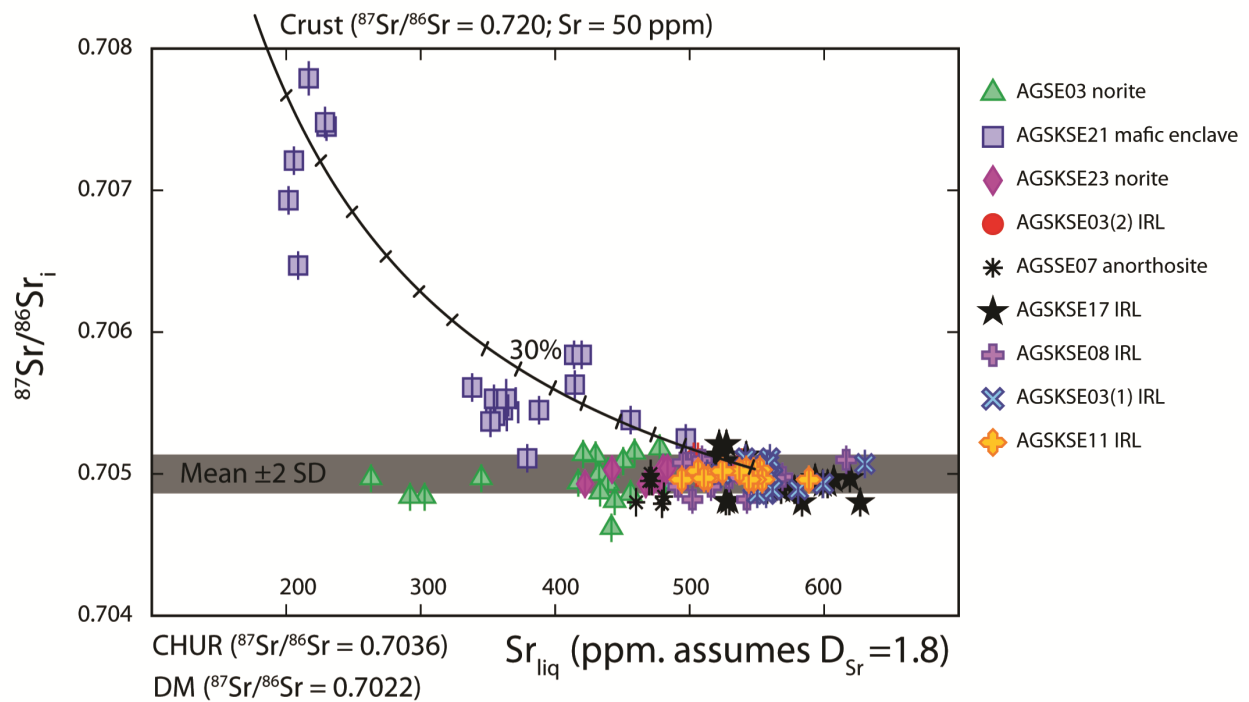


Fig. 18. $^{87}\text{Sr}/^{86}\text{Sr}$ plotted against Sr liquid concentrations. Displays the effects of crustal contamination in the AGSKSE21 mafic enclave sample, a clear mixing trend can be seen from the $^{87}\text{Sr}/^{86}\text{Sr}$ values of the other HFC units (0.705) to $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.720 which has been interpreted to be upper crust. Mantle values taken from Palme & O'Neill (2003). $^{87}\text{Sr}/^{86}\text{Sr}$ values taken from Glommé (2015). CHUR: chondritic uniform reservoir, these values represent an approximation of the bulk chemistry of the earth. DM: depleted mantle, these values represent a typical mantle that has been depleted by melting. The $^{87}\text{Sr}/^{86}\text{Sr}$ values of the HFC (0.705) lie between depleted mantle values and upper crust values, and are likely to represent a lower, mafic crust. Modified after Glommé (2015)

lower Sr values in later forming crystals and Ba will become relatively enriched in the liquid as crystals form resulting in higher Ba values in later forming crystals.

With all the potential factors being evaluated, the trends in trace element concentrations can be interpreted as follows: rising Sr concentrations indicate a changing magma composition from magma recharge. Stationary or decreasing Sr accompanied by a rise in Ba indicates the ongoing change of the magma composition through fractional crystallisation. Both samples AGSKSE23 and AGSKSE17 show signs of magma recharge from raising Sr levels. Most samples also show some form of fractionation through decreasing Sr/Ba from the megacrysts to the matrix plagioclase. Figure 19 displays the Sr and Ba values from sample AGSKSE17, which illustrates both the effects magma recharge and fractional crystallization between the different textural settings of the plagioclase.

Another observation in the trace elements is that similarly to the An-content, the peaks in trace elements coincide with a patchy texture in the rims of the plagioclase (Fig. 5B and 13). Årebäck & Stigh (1997) describes these as disequilibrium textures due to a decrease in pressure, but the sudden changes in trace element data also suggests that they also coincide with a magma injection event. The texture strongly resembles a sieve texture, a term used to describe disequilibrium in a profile of a plagioclase phenocryst in volcanic rocks, these are generally caused by either

an injection of magma of differing composition or a rapid decrease in pressure before an eruption (Nelson & Montana 1992).

5.3 Implications for trends of major and trace element chemistry

The presence of these recharge events has implications for the magma source. A recent study by Glommé (2015) investigated the Sr isotope ratios of the units in the HFC, and the data yielded a homogenous and high $^{87}\text{Sr}/^{86}\text{Sr} = 0.705$ that are consistent from core to rim.

The only exception is the mafic enclave, which shows a clear trend of contamination towards the an upper crustal isotopic signature ($^{87}\text{Sr}/^{86}\text{Sr} = 0.720$) (Fig. 18).

A possible explanation for the homogeneity of $^{87}\text{Sr}/^{86}\text{Sr}$ is that the magma source had been contaminated in a way that all of the crustal assimilation was completed before any crystallisation occurred. This scenario is already unlikely, as heat generated from crystallisation is a factor that contributes to assimilation. This was already highlighted by Glommé (2015) but now that recharge events have been identified this explanation for homogeneity is complicated even further.

In the case of multiple recharge events from a mantle source magma that obtained its radiogenic signature through contamination - each batch of new magma must have had the exact same amount of crustal assimilation to explain the homogeneity of the rocks. This account is unlikely because once a magma

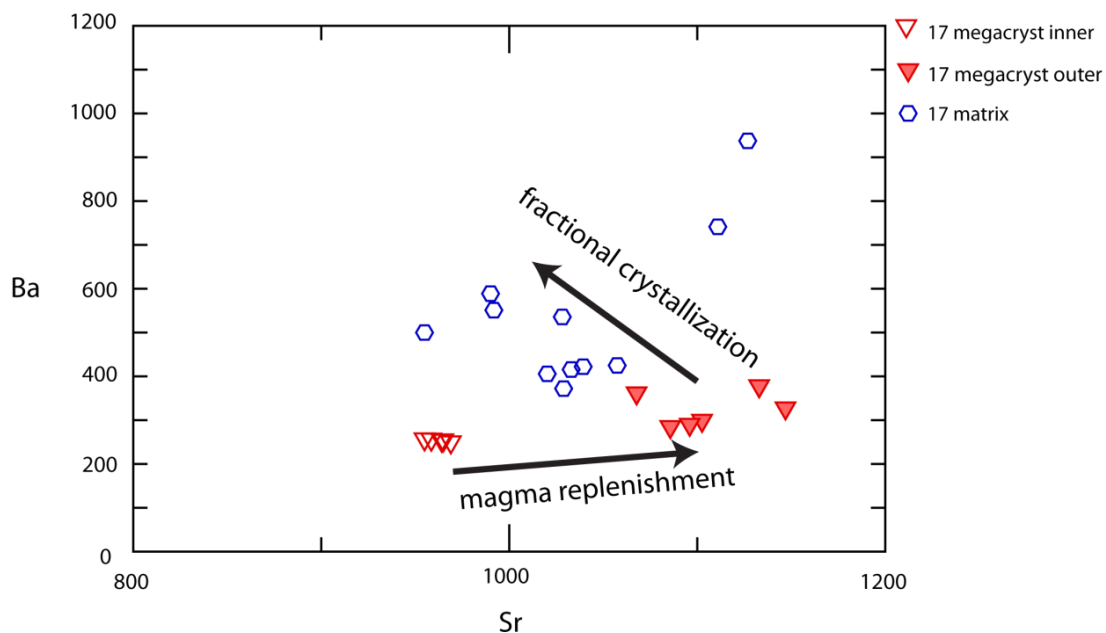


Fig. 19 Ba plotted against Sr for data points taken from sample AGSKSE17. The analyses from this sample illustrates both magma replenishment and fractional crystallization between the different textural settings. An increase in Sr between the inner megacryst and the outer megacryst, this has been interpreted as magma replenishment from a more primitive magma. The gradual decrease in Sr and increase in Ba from the outer megacryst to the matrix has been interpreted as crystal fractionation of the magma.

pathway has been established it should not produce the same level of crustal assimilation in recharge events in comparison to prior magmas. Furthermore it is likely that any partial crystallisation of the magma during transport would also shield the new batches of magma from contact and contamination with the host rock. A more likely scenario is simply that the recorded isotope values from the samples simply reflect the magma source (a lower crust source) without any significant crustal assimilation.

The magma source has further implications for the tectonic setting. Ashlway & Bybee (2017) suggest a subduction zone in a continental arc regime to explain a mantle derived magma with crustal contamination which is typical of a continental arc. Now with new evidence from this study that suggests a crust derived magma source is more likely, a continental arc setting is less plausible because of the lack of crustal contamination (excluding the mafic enclave). The tectonic setting of the melt is more likely a convergent margin with a post orogenic decompression melt, in line with the observations of Duchesne et al. (1999). This is also logical given the age of the rocks in the HFC (916 ± 11 Ma, Scherstén et al. 2000) coincide with the late stages and decompression of the Sveconowegian orogeny (Bingen et al. 2008).

The presence of recharge events as indicated by elevations in Sr also provide general evidence for open system processes in the magma chamber. This makes the explanation of the homogenous cores of the megacrysts and also the entirely homogenous anorthosite being buffered by magma injections more plausible.

As noted previously disequilibrium textures are observed to coincide with both increasing An-content and Sr concentrations. Previously, this was just linked to decompression from an adiabatic rise of the magma chamber (Årebäck & Stigh 1997). However, new trace element data from this study shows that a magma injection must also be occurring at the same time. There is a possibility that these two events are linked rather than coincidental, in that the magma injections could be a catalyst for the rise of the magma chamber. Alternatively, magma injections also could be an explanation for the increasing An, rather than an increase in pressure. Newly introduced magma will be hotter and more primitive than the existing magma, resulting in an overall more Ca rich composition and could also be the cause of the disequilibrium. It is also possible that rise in An content could be caused by both the composition and temperature change from the magma injection and also a polybaric evolution.

Magma injection events have often been linked to volcanic eruptions. Classically, a mafic magma will inject into a felsic magma chamber resulting in a release of volatiles which increase the internal pressure

of the chamber and that may lead to fracturing and eventually an eruption (Morgavi et al. 2017). There are a few key differences in this example and the HFC: the HFC rocks are not volcanic and that the initial magma was not felsic in composition. The significance of an initial felsic magma may be concerned with the levels of volatiles present in the magma, mafic magmas generally comprise of 1-2% volatiles and felsic magmas comprise of 4-7% volatiles (Earle 2018) and therefore release less gasses and have less of an effect on the buoyancy. Despite the potential lower amount of buoyancy produced this could still be a plausible explanation for the polybaric evolution.

6 Summary

Trends in trace element concentrations found in the megacrystic plagioclase of the norite and IRL units found in the Hakefjorden complex show rising levels of Sr - a compatible trace element in plagioclase. Due to the positive correlation between An content and Sr, the effects of crystal major chemistry on the partition coefficients of Sr are likely to be overprinted by other factors (magma composition) – and by extension effects of T and P are also overprinted as they should also be reflected in crystal chemistry. Therefore, a rise in a compatible element such as Sr can only be explained by introducing new magma or material via crustal contamination into the magma chamber. The possibility of crustal contamination can be ruled out because $^{87}\text{Sr}/^{86}\text{Sr}$ data taken from Glommé (2015) show that the isotope signals are homogenous throughout the plagioclase: an unlikely scenario for repeated assimilation of crust material. Instead, it is more likely that the $^{87}\text{Sr}/^{86}\text{Sr}$ data reflects the signal of its source which is a lower crust source.

The lack of crustal contamination also suggests that a continental arc tectonic setting is unlikely. Instead, a post orogenic decompression melt is a more likely scenario as there is a temporal association between the rocks in the HFC and the late stages of the Sveconowegian orogeny (Bingen et al. 2008).

An-content found in the megacrystic plagioclase of the norite and IRL units from this study are consistent with the findings of Årebäck & Stigh (1997) which states that the rise in An content towards the rims of the plagioclase is due to decompression during a rise of the magma chamber which also causes the disequilibrium texture found in the rims. The magma recharge events indicated by rising Sr also coincide with these events, potentially suggesting that the magma injections are a catalyst to the mobilisation of the magma chamber. The rise in An-content, and by extension disequilibrium textures could also be attributed to magma recharge events.

7 Recommendations

The sample size of this study was limited to only 3

samples that included plagioclase megacrysts, further investigation of more samples would help the increase the confidence that the observations being made are representative of the whole HFC. To further constrain the controls on trace element concentrations in the plagioclase, the partition coefficients need to be calculated. Being able to account for this factor and how it might change in this system based on other factors (crystal chemistry for example) would yield better predictions for the composition of the magma.

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Appendix I 1(13)

AGSE03

Analytical point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
context	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MO	MO	MA	MA	MA	MA
Wt %	97.27	94.97	97.16	93.60	96.98	97.40	96.98	97.66	97.18	97.81	97.45	97.32	96.90	97.32	94.33	94.69	96.26	96.82
An (mol %)	47.62	47.29	47.28	48.18	48.13	47.72	53.90	44.07	43.96	45.18	46.60	47.64	48.07	51.77	50.22	46.00	46.53	48.29
Rb (ppm)	1.507	1.447	2.878	3.81	4.6	3.827	3.397	5.81	1.365	1.172	1.737	2.527	2.21	0.611	0.896	1.426	0.6071	0.966
Rb error	0.033	0.014	0.056	0.11	0.31	0.065	0.056	0.089	0.019	0.017	0.046	0.045	0.096	0.01	0.03	0.031	0.009	0.047
Sr (ppm)	804	791.7	840	834.4	881.7	874.2	786.9	803.9	793.1	763.4	812.9	808.5	824.5	770	481.3	631.4	554.2	534.4
Sr error	5.6	5.7	5.9	6.1	6.5	6.7	5.9	5.3	5.1	5.8	5	5.9	6.1	6	3.6	4.6	3.8	3.7
Ba (ppm)	128.1	128.8	144.7	139.9	174.4	169.2	192.2	181.8	135.2	129.8	129.72	130	131.6	192.7	193.2	477.8	254.3	182.5
Ba error	1.1	1	1.2	1.2	2.4	1.6	1.4	1.7	1.1	1.2	0.9	1.2	1.1	1.5	1.6	3.9	2	1.4
La (ppm)	1.765	1.779	1.884	1.894	1.891	1.854	2.97	1.386	1.395	1.386	1.47	1.656	1.448	2.588	3.394	14.73	1.85	1.795
La error	0.019	0.018	0.019	0.022	0.021	0.023	0.059	0.014	0.014	0.018	0.014	0.016	0.016	0.028	0.039	0.19	0.019	0.016
Ce (ppm)	2.895	2.909	3.133	3.165	3.176	3.152	5.32	2.353	2.396	2.394	2.524	2.755	2.361	4.242	5.808	22.53	2.925	2.826
Ce error	0.033	0.027	0.031	0.032	0.036	0.039	0.13	0.024	0.024	0.032	0.023	0.027	0.026	0.041	0.067	0.4	0.027	0.025
Pr (ppm)	0.3254	0.3329	0.3556	0.3634	0.369	0.3595	0.598	0.2684	0.2747	0.2759	0.2941	0.3129	0.2648	0.4515	0.6251	2.262	0.313	0.298
Pr error	0.0054	0.0057	0.0054	0.0058	0.0062	0.0064	0.017	0.0041	0.0046	0.0048	0.0044	0.0051	0.0046	0.006	0.0089	0.06	0.0044	0.0041
Nd (ppm)	1.344	1.354	1.453	1.516	1.479	1.476	2.38	1.1	1.128	1.124	1.227	1.289	1.071	1.743	2.304	7.87	1.203	1.156
Nd error	0.025	0.025	0.025	0.027	0.027	0.028	0.08	0.021	0.02	0.022	0.022	0.024	0.021	0.026	0.029	0.28	0.019	0.018
Sm (ppm)	0.209	0.2155	0.2314	0.2303	0.238	0.229	0.386	0.1653	0.175	0.1718	0.1943	0.204	0.1653	0.2471	0.3329	0.992	0.1661	0.1599
Sm error	0.0084	0.0089	0.0098	0.0093	0.01	0.0094	0.021	0.0076	0.008	0.0079	0.0087	0.0086	0.0084	0.0093	0.0095	0.061	0.0067	0.0067
Eu (ppm)	0.5144	0.5129	0.549	0.5429	0.5608	0.762	0.911	0.4955	0.498	0.4929	0.5363	0.5225	0.5429	0.892	1.329	2.42	1.793	0.7901
Eu error	0.0092	0.0083	0.0082	0.0079	0.0089	0.013	0.011	0.0086	0.0076	0.0084	0.0076	0.0083	0.0091	0.012	0.016	0.028	0.018	0.0088
Gd (ppm)	0.1528	0.145	0.1713	0.1697	0.1668	0.1678	0.298	0.115	0.1234	0.1216	0.1482	0.1497	0.1224	0.1578	0.2191	0.604	0.1091	0.1007
Gd error	0.0073	0.0074	0.0082	0.0076	0.0074	0.0085	0.02	0.0056	0.0058	0.0065	0.0074	0.0077	0.0068	0.0074	0.0075	0.053	0.0054	0.0049
Dy (ppm)	0.0759	0.0776	0.087	0.0941	0.092	0.0882	0.219	0.0607	0.0615	0.064	0.0768	0.0725	0.0638	0.0789	0.1324	0.297	0.0498	0.0458
Dy error	0.0042	0.0041	0.0047	0.0047	0.0043	0.0044	0.017	0.0032	0.0038	0.0037	0.0042	0.0043	0.004	0.004	0.0052	0.031	0.0029	0.0027
Er (ppm)	0.0265	0.0263	0.0286	0.0339	0.0354	0.0309	0.106	0.0198	0.0187	0.0203	0.0286	0.0257	0.0227	0.026	0.0522	0.094	0.0139	0.015
Er error	0.0022	0.0022	0.0024	0.0026	0.0032	0.0022	0.009	0.0021	0.0018	0.0019	0.0023	0.0022	0.0021	0.0024	0.0031	0.011	0.0014	0.0014
Yb (ppm)	0.0144	0.015	0.0162	0.0187	0.0223	0.0169	0.0943	0.0096	0.01	0.0116	0.0191	0.0124	0.0114	0.0125	0.0398	0.046	0.0108	0.0073
Yb error	0.0021	0.002	0.0021	0.0019	0.0024	0.0022	0.0092	0.0018	0.0015	0.0018	0.0023	0.0019	0.002	0.0018	0.003	0.0058	0.0015	0.0012
87Sr/86Sr	0.70510	0.70513	0.70530	0.70498	0.70511	0.70538	0.70519	0.70503	0.70493	0.70500	0.70487	0.70472	0.70519	0.70519	0.70507	0.70507	0.70494	0.70494

AGSE03: norite with plagioclase megacryst. MI: megacryst inner MO: megacryst outer MA: matrix . ⁸⁷Sr/⁸⁶Sr data taken from Glommé (2015)

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AGSKSE21

Analytical point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
context	PO	PO	PO	PO	PO	PI	PI	PI	PI	PI	PI	PI	PO	PO	PO
Wt %	98.02	98.27	97.77	97.50	97.61	97.45	97.18	97.44	96.91	96.95	96.80	96.68	96.88	96.79	96.91
An (mol %)	32.71	31.62	37.06	38.24	39.24	35.21	37.16	39.77	37.00	37.25	39.26	38.79	35.45	33.89	35.92
Rb (ppm)	19.4	41.2	2.71	51.6	2.896	2.471	2.925	2.659	2.545	3.106	2.41	2.552	51.4	2.67	14.8
Rb error	0.42	1.1	0.31	1	0.041	0.023	0.028	0.035	0.023	0.027	0.023	0.053	1.2	0.11	1.2
Sr (ppm)	660.8	709.9	676	718.3	563.2	396.5	420.8	376.4	382.1	418.7	369	307.7	791.6	721.5	785.6
Sr error	5	6.4	5.6	5.2	5	3	3.5	3.2	3.3	3.5	3.2	3.1	8	6.6	8.2
Ba (ppm)	378.3	394.9	165.8	457.1	337.8	433.4	493.7	392.5	427.9	505.5	419.8	318.7	769	546.8	701
Ba error	5.9	5.3	2.2	6.8	3.4	3.2	4.4	3.5	3.7	4.3	3.9	3.4	13	5.6	16
La (ppm)	21.35	22.99	35	27.7	16.02	14.21	14.45	14.38	13.9	12.32	11.53	44.17	27.57	17.58	17.82
La error	0.49	0.45	1.2	1	0.16	0.12	0.14	0.15	0.14	0.12	0.13	0.78	0.54	0.2	0.25
Ce (ppm)	30.32	31.52	54	40.6	25.22	22.37	22.68	23.48	21.85	19.04	18.45	103.3	40.78	27.92	27.96
Ce error	0.79	0.52	2.7	1.7	0.24	0.23	0.25	0.26	0.25	0.19	0.21	1.9	0.93	0.4	0.48
Pr (ppm)	2.694	2.718	4.88	3.7	2.457	2.288	2.28	2.559	2.267	1.959	1.956	16.29	3.74	2.751	2.778
Pr error	0.07	0.043	0.26	0.16	0.028	0.024	0.028	0.033	0.03	0.022	0.026	0.34	0.098	0.04	0.053
Nd (ppm)	8.25	8.18	13.93	11.73	8.249	7.809	7.697	9.44	7.83	6.824	7.01	82.3	11.64	9.3	9.39
Nd error	0.2	0.14	0.64	0.51	0.091	0.088	0.099	0.15	0.11	0.084	0.11	1.8	0.33	0.16	0.22
Sm (ppm)	0.901	0.88	1.368	1.419	1.001	0.964	0.919	1.506	1.03	0.845	0.951	19.83	1.414	1.147	1.193
Sm error	0.028	0.029	0.058	0.073	0.019	0.021	0.021	0.052	0.026	0.02	0.025	0.48	0.057	0.032	0.041
Eu (ppm)	4.482	4.548	4.487	5.007	4.932	5.37	5.796	5.19	5.317	5.642	5.228	5.664	4.759	5.085	4.811
Eu error	0.051	0.054	0.057	0.07	0.054	0.055	0.068	0.064	0.072	0.061	0.064	0.067	0.066	0.064	0.059
Gd (ppm)	0.498	0.451	0.768	0.839	0.515	0.49	0.46	1.118	0.546	0.431	0.53	18.36	1.038	0.63	0.69
Gd error	0.019	0.018	0.034	0.047	0.014	0.013	0.013	0.074	0.018	0.012	0.016	0.44	0.047	0.026	0.03
Dy (ppm)	0.266	0.212	0.322	0.504	0.1979	0.1894	0.1589	0.94	0.24	0.1431	0.2151	13.09	1.275	0.292	0.343
Dy error	0.018	0.014	0.016	0.036	0.0065	0.0074	0.0059	0.13	0.015	0.005	0.009	0.33	0.097	0.017	0.02
Er (ppm)	0.117	0.0814	0.141	0.25	0.0573	0.0556	0.0392	0.504	0.0837	0.0359	0.063	5.44	0.822	0.0972	0.133
Er error	0.012	0.0084	0.01	0.022	0.0027	0.0036	0.0026	0.085	0.0097	0.0024	0.0041	0.14	0.063	0.0078	0.01
Yb (ppm)	0.101	0.072	0.16	0.271	0.0339	0.0307	0.0244	0.53	0.0642	0.0306	0.0522	3.455	0.67	0.0635	0.0895
Yb error	0.013	0.01	0.015	0.026	0.0028	0.0028	0.0019	0.1	0.0083	0.0023	0.0039	0.081	0.1	0.0071	0.0076
⁸⁷ Sr/ ⁸⁶ Sr	0.70607	0.70607				0.70804	0.70777	0.70754	0.70667	0.70797	0.70716				

AGSKSE21: mafic enclave with phenocryst. PO phenocryst outer PI: phenocryst inner. ⁸⁷Sr/⁸⁶Sr data taken from Glommé (2015)

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AGSKSE21

Analytical point	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
context	PO	PO	PO	PO	PO	MA	GR	GR	GR	GR	GR	GR	GR	GR	GR
Wt %	96.50	96.58	96.40	96.26	96.68	96.29	95.57	96.15	97.29	94.50	96.37	96.21	96.87	97.06	97.80
An (mol %)	34.33	35.17	29.65	29.90	29.73	49.70	34.47	35.69	37.00	31.51	30.30	30.16	31.00	27.33	35.86
Rb (ppm)	8.74	69.8	136.3	11.87	8.66	3.37	3.172	199	3.318	29.3	1.402	33.99	27.01	12.94	2.88
Rb error	0.67	2.4	5.7	0.3	0.28	0.12	0.074	5.4	0.068	1.2	0.033	0.56	0.71	0.47	0.14
Sr (ppm)	750.9	757.6	768	680.1	716.3	717.3	693.9	909.7	834.6	650.2	643.8	619	758.6	648.7	665.3
Sr error	6.6	7.1	7.7	5.6	5.8	5	5.7	9.5	6.7	5.2	4.8	6.1	8.4	6.3	8.7
Ba (ppm)	571	506.7	613	247.5	346.7	240.7	452.9	1372	937.6	408.8	324.3	443.8	240.6	188.1	270
Ba error	7.6	8.3	23	3.1	4.7	2.4	6.4	28	8	4.9	2.2	3.9	3.5	5.3	3.9
La (ppm)	16.87	26.67	161	29.06	28.28	3.219	17.49	20.09	9.964	34.1	24.05	21.52	23.79	21.13	19.06
La error	0.19	0.71	25	0.59	0.78	0.034	0.24	0.45	0.077	1.8	0.24	0.26	0.33	0.19	0.26
Ce (ppm)	25.38	41.4	247	41.9	39	4.969	23.94	23.92	14.23	52.6	31.42	31.7	30.03	26.09	26.39
Ce error	0.33	1.8	36	1.1	1.4	0.063	0.37	0.53	0.12	3.5	0.3	0.56	0.51	0.26	0.33
Pr (ppm)	2.485	4.02	29	4.07	3.59	0.5492	2.288	2.091	1.461	5.02	2.814	3.287	2.503	2.117	2.389
Pr error	0.036	0.24	4.5	0.14	0.13	0.0088	0.041	0.049	0.014	0.35	0.03	0.081	0.042	0.025	0.039
Nd (ppm)	8.26	12.9	87	13.08	11.07	2.127	7.32	6.49	5.17	16.5	8.94	12.14	7.76	6.359	7.63
Nd error	0.12	0.79	13	0.49	0.39	0.041	0.12	0.16	0.057	1.1	0.1	0.4	0.14	0.087	0.14
Sm (ppm)	0.947	1.529	9.6	1.707	1.202	0.349	0.856	0.702	0.723	2.11	0.975	2.34	0.727	0.6	0.823
Sm error	0.021	0.098	1.2	0.091	0.046	0.014	0.024	0.027	0.016	0.17	0.021	0.13	0.03	0.018	0.031
Eu (ppm)	4.513	5.066	5.69	4.732	4.968	1.603	4.619	5.25	5.919	4.929	4.803	4.499	4.046	3.574	4.312
Eu error	0.056	0.082	0.12	0.067	0.071	0.021	0.067	0.079	0.056	0.085	0.053	0.065	0.057	0.037	0.067
Gd (ppm)	0.5	1.005	5.9	1.083	0.673	0.262	0.473	0.389	0.426	1.31	0.508	2	0.372	0.313	0.429
Gd error	0.013	0.096	0.6	0.067	0.029	0.012	0.014	0.015	0.011	0.12	0.014	0.13	0.02	0.011	0.018
Dy (ppm)	0.244	0.681	3.07	0.695	0.297	0.217	0.2013	0.1913	0.2151	0.852	0.2102	1.77	0.143	0.1311	0.1702
Dy error	0.01	0.091	0.26	0.054	0.017	0.013	0.0071	0.0092	0.0064	0.096	0.0076	0.13	0.01	0.0057	0.0093
Er (ppm)	0.0923	0.364	1.36	0.319	0.1096	0.1153	0.0576	0.0712	0.0679	0.375	0.0588	0.965	0.0405	0.0458	0.0499
Er error	0.0048	0.057	0.11	0.028	0.0091	0.0059	0.0032	0.005	0.0032	0.051	0.0034	0.071	0.0049	0.0029	0.0054
Yb (ppm)	0.0863	0.394	1.52	0.304	0.08	0.1097	0.0258	0.0385	0.043	0.331	0.0243	0.9	0.0207	0.0278	0.023
Yb error	0.0063	0.068	0.18	0.031	0.011	0.0054	0.0022	0.0045	0.0027	0.053	0.0025	0.07	0.0039	0.0027	0.0037
⁸⁷ Sr/ ⁸⁶ Sr	0.70599	0.70599					0.70557	0.70558	0.70586	0.70602	0.70598	0.70569	0.70613	0.70600	

Continuation of AGSKSE21: mafic enclave with phenocryst. PO phenocryst MA: matrix GR: grain. ⁸⁷Sr/⁸⁶Sr data taken from Glommé (2015)

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AGSKSE23

Analytical point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
context	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MO	MO	MO	MI	MI	MO	MO	MA	MA
Wt %	99.85	100.04	98.88	98.78	99.28	99.89	99.57	100.23	100.43	100.28	100.48	99.70	100.09	99.88	100.14	100.50	100.45	101.50	101.93
An (mol %)	44.35	44.39	43.43	44.75	44.16	43.30	43.88	43.88	43.66	44.26	53.36	50.25	46.98	44.22	43.38	53.03	51.34	52.76	54.55
Rb (ppm)	2.294	1.15	0.94	1.226	1.372	1.099	2.23	1.704	1.821	4.87	9.02	34.23	43.05	1.386	1.284	1.426	4.1	29.54	1.08
Rb error	0.022	0.022	0.02	0.024	0.02	0.022	0.066	0.067	0.073	0.13	0.15	0.8	0.49	0.055	0.04	0.031	0.1	0.4	0.025
Sr (ppm)	876.5	880.2	873.5	865.1	868	891.6	891	885.1	875.6	912.6	771.5	915	1084	878.9	884.9	631.4	855.2	978.4	809.3
Sr error	6.3	6.5	7.5	6.4	6.5	7.1	6.7	7.1	6.6	8.8	6.1	11	11	6.6	6.1	4.6	6.1	8.8	6
Ba (ppm)	140.4	142.8	137.5	143.6	138.3	135.9	154.7	151.4	139.6	148.7	215.3	439.5	781	145.4	143.1	477.8	267	408.2	229.6
Ba error	1.1	1.1	1.2	1.1	1.1	1.3	2.2	1.5	1.2	1.4	1.9	9.3	11	1.2	1.2	3.9	2.1	3.7	1.9
La (ppm)	1.267	1.282	1.242	1.262	1.325	1.319	1.314	1.308	1.29	1.365	2.342	5.699	4.52	1.271	1.66	14.73	2.652	4.283	2.409
La error	0.012	0.015	0.015	0.014	0.018	0.017	0.018	0.015	0.017	0.016	0.023	0.07	0.084	0.017	0.02	0.19	0.027	0.053	0.022
Ce (ppm)	2.311	2.311	2.277	2.28	2.3	2.318	2.295	2.305	2.263	2.349	3.751	8.57	7.35	2.315	2.731	22.53	4.346	6.286	3.952
Ce error	0.024	0.023	0.03	0.021	0.024	0.028	0.027	0.027	0.024	0.025	0.038	0.12	0.13	0.03	0.035	0.4	0.045	0.073	0.037
Pr (ppm)	0.262	0.2693	0.2591	0.2632	0.2778	0.2705	0.2721	0.2699	0.2684	0.2835	0.4015	0.869	0.827	0.2691	0.336	2.262	0.4653	0.749	0.4283
Pr error	0.005	0.0048	0.0053	0.0043	0.0055	0.0048	0.0043	0.005	0.0049	0.0056	0.0062	0.013	0.016	0.0056	0.0063	0.06	0.0072	0.012	0.0066
Nd (ppm)	1.11	1.131	1.112	1.101	1.148	1.145	1.144	1.158	1.132	1.181	1.569	3.181	3.176	1.126	1.409	7.87	1.763	2.89	1.66
Nd error	0.022	0.022	0.024	0.021	0.024	0.023	0.024	0.025	0.024	0.023	0.027	0.052	0.066	0.023	0.028	0.28	0.029	0.048	0.029
Sm (ppm)	0.17	0.1762	0.182	0.188	0.1799	0.1781	0.1802	0.1814	0.183	0.1856	0.2153	0.396	0.473	0.1794	0.225	0.992	0.2415	0.415	0.238
Sm error	0.0088	0.008	0.0094	0.0085	0.0093	0.0086	0.0087	0.0088	0.0089	0.0093	0.0083	0.013	0.017	0.0087	0.01	0.061	0.0093	0.015	0.011
Eu (ppm)	0.5258	0.5389	0.535	0.5249	0.5426	0.562	0.5578	0.557	0.5452	0.616	0.877	1.425	2.91	0.5512	0.625	2.42	1.146	1.663	1.13
Eu error	0.0097	0.0091	0.011	0.0081	0.0093	0.01	0.0097	0.01	0.0094	0.01	0.011	0.026	0.04	0.0098	0.011	0.028	0.017	0.026	0.016
Gd (ppm)	0.1208	0.1258	0.117	0.1182	0.1255	0.1283	0.1291	0.1221	0.1265	0.1307	0.1456	0.234	0.286	0.1181	0.1547	0.604	0.1497	0.28	0.1467
Gd error	0.0066	0.007	0.0075	0.0062	0.0076	0.0072	0.0065	0.0073	0.0066	0.0067	0.0067	0.01	0.011	0.0075	0.0085	0.053	0.0069	0.011	0.0079
Dy (ppm)	0.0585	0.0542	0.056	0.0572	0.0641	0.0609	0.0579	0.061	0.056	0.0637	0.0637	0.1093	0.1408	0.0551	0.0754	0.297	0.0702	0.1545	0.0681
Dy error	0.0042	0.0032	0.004	0.004	0.0043	0.0042	0.0042	0.0043	0.0039	0.0045	0.0034	0.0047	0.0064	0.0039	0.0041	0.031	0.0041	0.0068	0.0044
Er (ppm)	0.0176	0.0181	0.0155	0.0161	0.0193	0.0173	0.0157	0.0171	0.0187	0.0205	0.0184	0.036	0.0495	0.0177	0.0211	0.094	0.0196	0.0627	0.0221
Er error	0.0023	0.002	0.0022	0.0019	0.0022	0.002	0.0019	0.0022	0.0022	0.0022	0.0019	0.0025	0.0032	0.0021	0.0021	0.011	0.0019	0.0038	0.0025
Yb (ppm)	0.0075	0.0066	0.0077	0.0072	0.0094	0.0071	0.0065	0.0067	0.0066	0.0093	0.0094	0.0268	0.0323	0.0078	0.0114	0.046	0.0105	0.042	0.0108
Yb error	0.0017	0.0014	0.0019	0.0014	0.0016	0.0017	0.0016	0.0017	0.0015	0.0018	0.0018	0.0027	0.0031	0.0016	0.002	0.0058	0.0017	0.0039	0.0021
87Sr/86Sr		0.70501	0.70501											0.70512	0.70512	0.70500	0.70500	0.70508	0.70508

AGSKSE23: norite with megacryst. MI: megacryst inner MO: megacryst outer MA: matrix ⁸⁶Sr data taken from Glommé (2015)

Appendix I 5(13)

AGSKSE03(2)

Analytical point	1	2	3	4	5	6	7	8
context	MA	MA	MA	MA	MA	MA	MA	MA
Wt %	96.91	96.91	96.62	96.62	96.15	96.15	95.61	95.61
An (mol %)	51.24	51.24	52.59	52.59	52.67	52.67	52.88	52.88
Rb (ppm)	2.133	2.881	2.514	3.142	3.111	2.51	2.068	2.003
Rb error	0.023	0.03	0.045	0.042	0.041	0.032	0.023	0.022
Sr (ppm)	924.1	926.3	934.6	930.4	985.8	929.8	926.3	920.5
Sr error	8.2	8	8.7	7	8.5	7.6	6.6	6.8
Ba (ppm)	304.9	448.8	328.2	344.3	413.1	377.4	369.1	318.1
Ba error	3.2	4.2	3.4	3.1	3.6	3.4	3.1	2.4
La (ppm)	3.799	4.117	3.88	3.781	4.174	3.816	4.91	3.782
La error	0.046	0.046	0.046	0.037	0.044	0.04	0.049	0.037
Ce (ppm)	5.989	6.895	6.214	5.869	6.501	5.972	8.131	5.972
Ce error	0.079	0.073	0.077	0.058	0.071	0.058	0.079	0.051
Pr (ppm)	0.638	0.7497	0.668	0.621	0.681	0.6166	0.869	0.6294
Pr error	0.011	0.0097	0.011	0.009	0.01	0.009	0.011	0.0086
Nd (ppm)	2.39	2.85	2.562	2.327	2.506	2.336	3.302	2.428
Nd error	0.041	0.041	0.046	0.037	0.037	0.036	0.043	0.039
Sm (ppm)	0.324	0.412	0.352	0.306	0.331	0.299	0.466	0.309
Sm error	0.012	0.014	0.013	0.012	0.011	0.012	0.014	0.01
Eu (ppm)	2.196	2.662	2.062	2.161	2.348	2.411	2.397	2.017
Eu error	0.033	0.031	0.03	0.025	0.026	0.028	0.026	0.02
Gd (ppm)	0.191	0.2438	0.2136	0.1874	0.2056	0.1752	0.29	0.1964
Gd error	0.0092	0.0095	0.0099	0.0085	0.0097	0.0086	0.01	0.0079
Dy (ppm)	0.0853	0.1181	0.0991	0.0801	0.0861	0.0828	0.1386	0.0882
Dy error	0.0045	0.0054	0.005	0.0045	0.0047	0.0047	0.0052	0.0051
Er (ppm)	0.0259	0.0413	0.0293	0.0218	0.0267	0.022	0.0402	0.0272
Er error	0.0023	0.0029	0.0025	0.0021	0.0025	0.0021	0.0028	0.0024
Yb (ppm)	0.0122	0.0329	0.0194	0.0104	0.0147	0.0122	0.0206	0.0109
Yb error	0.002	0.0029	0.0024	0.0018	0.0022	0.0022	0.0024	0.0019
⁸⁷ Sr/ ⁸⁶ Sr	0.70527	0.70527	0.70511	0.70511	0.70518	0.70518	0.70520	0.70520

AGSKSE03(2): IRL matrix. MA: matrix. ⁸⁶Sr data taken from Glommé (2015)

Appendix I 6(13)

AGSE07

Analytical point	1	2	3	4	5	6	7	8	9	10
context	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Wt %	98.60	98.20	96.87	97.27	97.16	96.44	97.42	97.42	97.42	97.42
An (mol %)	43.41	43.69	44.22	45.02	43.64	44.33	43.98	43.98	43.98	43.98
Rb (ppm)	1.998	2.095	2.118	3.139	2.554	2.215	1.852	1.801	3.399	5.608
Rb error	0.025	0.023	0.022	0.046	0.025	0.023	0.022	0.02	0.083	0.083
Sr (ppm)	859.7	879.9	863.4	842	877.3	861.8	855.5	861.7	875.8	949.4
Sr error	6.7	5.4	6.5	6.3	6	6.1	6	6	6.2	8.3
Ba (ppm)	166.9	172.1	167.7	157.5	176.9	166.4	163.6	166.1	169.5	198.8
Ba error	1.4	1.4	1.4	1.3	1.3	1.5	1.2	1.2	1.3	2
La (ppm)	1.368	1.437	1.471	1.536	1.415	1.376	1.369	1.35	1.226	1.456
La error	0.016	0.015	0.016	0.019	0.014	0.017	0.015	0.015	0.014	0.018
Ce (ppm)	2.342	2.472	2.556	2.698	2.476	2.366	2.398	2.331	2.128	2.544
Ce error	0.026	0.024	0.028	0.033	0.025	0.031	0.023	0.025	0.021	0.03
Pr (ppm)	0.2758	0.2943	0.3087	0.327	0.2953	0.2817	0.2833	0.2767	0.2529	0.3006
Pr error	0.0049	0.0049	0.0051	0.0058	0.0042	0.0047	0.0053	0.0047	0.0042	0.0055
Nd (ppm)	1.187	1.248	1.317	1.395	1.274	1.207	1.219	1.165	1.079	1.284
Nd error	0.023	0.021	0.023	0.024	0.024	0.025	0.022	0.022	0.02	0.027
Sm (ppm)	0.1847	0.2069	0.2238	0.2467	0.2307	0.1988	0.2042	0.208	0.1922	0.221
Sm error	0.0091	0.0089	0.009	0.0093	0.0097	0.0091	0.0088	0.009	0.0088	0.01
Eu (ppm)	0.585	0.6038	0.5904	0.5731	0.6196	0.5873	0.5806	0.6041	0.5935	0.647
Eu error	0.0085	0.0096	0.0089	0.0088	0.0081	0.0098	0.0082	0.0096	0.0085	0.011
Gd (ppm)	0.1537	0.168	0.1857	0.1989	0.1738	0.1724	0.166	0.1582	0.1474	0.1844
Gd error	0.0077	0.0079	0.0082	0.009	0.0073	0.0079	0.0072	0.0073	0.0071	0.0087
Dy (ppm)	0.0858	0.0993	0.1104	0.1144	0.1041	0.1031	0.0964	0.091	0.0963	0.1158
Dy error	0.0043	0.0045	0.005	0.0052	0.0049	0.0051	0.0046	0.0047	0.0045	0.0058
Er (ppm)	0.0293	0.0346	0.0407	0.0427	0.0348	0.0388	0.0365	0.0341	0.0322	0.0501
Er error	0.0023	0.0025	0.003	0.0028	0.0026	0.0024	0.003	0.0028	0.0022	0.0035
Yb (ppm)	0.0157	0.0172	0.0203	0.0202	0.0248	0.0181	0.0157	0.0161	0.0185	0.0353
Yb error	0.0023	0.002	0.0023	0.002	0.0024	0.0021	0.0022	0.0023	0.0023	0.0032
87Sr/86Sr	0.70503	0.70492	0.70503	0.70490	0.70491	0.70509				

AGSE07: anorthosite. MC: megacryst ⁸⁶Sr data taken from Glommé (2015)

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AGSKSE17

Analytical point	1	2	3	4	5	6	7	8	9	10
context	MI	MI	MI	MI	MO	MO	MO	MO	MO	MO
Wt %	103.00	103.00	103.00	103.00	103.25	103.25	104.44	104.44	103.20	103.20
An (mol %)	46.59	46.59	46.59	46.59	47.08	47.08	50.68	50.68	54.87	54.87
Rb (ppm)	3.532	4.02	3.044	2.832	4.418	2.251	1.871	5.09	1.046	3.56
Rb error	0.045	0.1	0.041	0.039	0.071	0.027	0.058	0.37	0.035	0.13
Sr (ppm)	964.2	969	965	955	964	958.6	1147	1067.8	1102.6	1096
Sr error	9.3	13	12	10	13	9.1	12	8.7	9.4	13
Ba (ppm)	254	250.2	254.5	256.9	254.7	256.3	327.7	362	299	290.2
Ba error	2.8	4.1	3.8	3.6	3.8	3.1	4.5	4	2.3	4.7
La (ppm)	1.704	2.001	1.541	1.444	1.368	1.274	1.74	5.854	4.597	4.206
La error	0.028	0.042	0.03	0.026	0.022	0.02	0.034	0.077	0.061	0.074
Ce (ppm)	3.237	3.916	2.996	2.741	2.667	2.355	3.325	9.51	7.473	6.78
Ce error	0.053	0.09	0.063	0.053	0.028	0.044	0.08	0.13	0.074	0.13
Pr (ppm)	0.3815	0.47	0.3645	0.3235	0.3297	0.2862	0.394	1.015	0.795	0.721
Pr error	0.0088	0.014	0.0099	0.0076	0.0075	0.0068	0.013	0.019	0.014	0.018
Nd (ppm)	1.61	2.01	1.568	1.407	1.38	1.201	1.655	3.787	2.946	2.711
Nd error	0.039	0.062	0.045	0.035	0.035	0.03	0.06	0.074	0.07	0.072
Sm (ppm)	0.252	0.35	0.258	0.229	0.239	0.21	0.274	0.504	0.422	0.366
Sm error	0.012	0.021	0.014	0.013	0.015	0.012	0.015	0.019	0.024	0.016
Eu (ppm)	1.275	1.317	1.311	1.315	1.325	1.334	1.375	1.661	1.385	1.259
Eu error	0.024	0.033	0.029	0.03	0.019	0.028	0.03	0.027	0.027	0.03
Gd (ppm)	0.189	0.259	0.181	0.1545	0.174	0.1329	0.18	0.339	0.227	0.216
Gd error	0.012	0.017	0.011	0.0094	0.014	0.0083	0.011	0.016	0.016	0.011
Dy (ppm)	0.1024	0.164	0.0896	0.0833	0.088	0.0768	0.0945	0.1687	0.1177	0.0923
Dy error	0.0064	0.011	0.0064	0.0051	0.0068	0.0054	0.0066	0.0084	0.0097	0.0064
Er (ppm)	0.0356	0.0612	0.0304	0.0244	0.036	0.0277	0.0294	0.0629	0.0369	0.027
Er error	0.0036	0.0063	0.003	0.0028	0.0044	0.0032	0.0036	0.0048	0.0055	0.0033
Yb (ppm)	0.0173	0.0385	0.0175	0.0218	0.0349	0.0243	0.0185	0.042	0.0139	0.0132
Yb error	0.0029	0.006	0.0031	0.0031	0.0045	0.0032	0.0032	0.0045	0.0043	0.0025
⁸⁷ Sr/ ⁸⁶ Sr	0.70493	0.70493	0.70531	0.70531	0.70518	0.70518	0.70491	0.70491	0.70505	0.70505

AGSKSE17: IRL with megacryst. MI: megacryst inner MO: megacryst outer ⁸⁶Sr data taken from Glommé (2015)

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AGSKSE17

Analytical point	11	12	13	14	15	16	17	18	19	20	21	22	23
context	MO	MO	MA	MA	MA	MA	MA	MA	MA	MA	MA	MA	MA
Wt %	103.71	103.71	103.77	103.77	103.77	104.36	104.36	104.44	104.44	101.56	101.56	104.62	104.62
An (mol %)	53.68	53.68	52.48	52.48	52.48	51.91	51.91	50.66	50.66	50.68	50.68	52.52	52.52
Rb (ppm)	4.353	2.721	1.568	1.584	2.207	3.196	2.033	1.957	3.99	2.449	1.595	2.657	1.871
Rb error	0.092	0.079	0.021	0.032	0.031	0.065	0.029	0.03	0.045	0.034	0.025	0.053	0.025
Sr (ppm)	1085.7	1133	1039.4	1057.5	1020.3	1111	1029	990.1	1126.9	1033	1028.3	955	991.9
Sr error	7	12	7.3	6.6	9.5	17	7	9	8.9	10	6.6	5.7	6.6
Ba (ppm)	285.2	378	421.9	424.5	405.5	741	372	588.5	937.2	415.4	535.5	499.8	550.7
Ba error	1.8	5	2.6	2.5	5	14	2.5	5.8	8.7	5.5	3.4	3.6	3.6
La (ppm)	4.888	6.064	4.734	7.71	5.042	11.82	4.462	8.92	16.94	4.246	4.751	6.69	4.669
La error	0.039	0.095	0.043	0.19	0.078	0.22	0.039	0.22	0.21	0.068	0.041	0.1	0.043
Ce (ppm)	7.981	9.65	7.725	12.83	9.48	19.19	7.216	15.79	24.8	6.87	7.57	10.16	7.431
Ce error	0.055	0.16	0.061	0.3	0.19	0.43	0.061	0.38	0.33	0.13	0.072	0.14	0.06
Pr (ppm)	0.835	1.01	0.828	1.382	1.137	1.964	0.768	1.678	2.412	0.739	0.789	1.049	0.783
Pr error	0.011	0.02	0.012	0.034	0.028	0.052	0.011	0.044	0.038	0.016	0.012	0.016	0.01
Nd (ppm)	3.159	3.807	3.221	5.12	4.64	7.06	2.909	6.13	8.48	2.81	3.068	3.874	2.989
Nd error	0.044	0.079	0.053	0.12	0.13	0.2	0.048	0.15	0.15	0.067	0.047	0.064	0.044
Sm (ppm)	0.43	0.499	0.461	0.755	0.816	0.977	0.387	0.902	1.026	0.386	0.417	0.563	0.406
Sm error	0.018	0.019	0.018	0.029	0.033	0.058	0.016	0.03	0.03	0.016	0.015	0.022	0.015
Eu (ppm)	1.313	1.551	2.631	2.857	2.39	3.646	2.507	3.01	3.816	2.46	2.516	3.105	2.714
Eu error	0.018	0.03	0.031	0.035	0.053	0.092	0.03	0.048	0.055	0.05	0.031	0.026	0.031
Gd (ppm)	0.264	0.319	0.297	0.442	0.531	0.541	0.242	0.491	0.551	0.234	0.245	0.325	0.253
Gd error	0.014	0.014	0.014	0.02	0.024	0.04	0.013	0.021	0.02	0.013	0.011	0.014	0.012
Dy (ppm)	0.1255	0.138	0.1446	0.25	0.366	0.241	0.1122	0.248	0.239	0.1181	0.1046	0.1543	0.1194
Dy error	0.0076	0.0076	0.0075	0.013	0.017	0.023	0.0072	0.011	0.011	0.007	0.0053	0.0078	0.0069
Er (ppm)	0.039	0.039	0.0497	0.0806	0.1447	0.065	0.0352	0.0651	0.0581	0.0325	0.0299	0.0469	0.0358
Er error	0.0039	0.0037	0.0043	0.0058	0.0093	0.012	0.0036	0.0047	0.0049	0.0032	0.0027	0.0038	0.0035
Yb (ppm)	0.0218	0.0158	0.0328	0.0574	0.1278	0.041	0.019	0.046	0.0257	0.0131	0.0175	0.029	0.0205
Yb error	0.0038	0.0031	0.0041	0.0059	0.0095	0.011	0.0033	0.0043	0.0039	0.0026	0.0027	0.0039	0.0032
87Sr/86Sr	0.70501	0.70501	0.70499	0.70499	0.70499	0.70504	0.70504			0.70498	0.70498	0.70524	0.70524

Continuation of AGSKSE17: IRL with megacryst. MO: megacryst outer MA: matrix. ⁸⁶Sr data taken from Glommé (2015)

Appendix I 9(13)

AGSKSE08

Analytical point	1	2	3	4	5	6	7	8	9	10	11	12	13
context	MA	MA	MA	MA	MA	MA	MA	MA	INC	INC	INC	INC	INC
Wt %	99.20	99.20	98.70	98.70	96.09	96.09	96.09	96.09	97.52	96.81	96.81	96.81	97.61
An (mol %)	54.01	54.01	52.20	52.20	53.24	53.24	53.24	53.24	56.12	56.12	53.60	56.12	53.76
Rb (ppm)	3.206	2.595	2.265	2.106	2.794	2.037	1.767	6.67	7.56	53.1	3.057	17.01	2.845
Rb error	0.082	0.048	0.023	0.026	0.031	0.022	0.022	0.27	0.31	1.1	0.088	0.62	0.092
Sr (ppm)	1007.9	1041.1	1003.9	945.3	899.2	944	918.7	992.9	1124	528	1059	245.7	558.8
Sr error	7.7	7.8	7	6.8	7.1	7.1	7.3	8.2	19	11	11	5.9	5.8
Ba (ppm)	303.4	318	291.8	318.6	345.3	346.5	251.6	289.4	72.7	282.4	518.3	87.6	165.5
Ba error	2.8	3	2.3	3.1	3.1	3.2	2.9	3.8	2.2	5.1	5.7	2.7	2.4
La (ppm)	4.257	4.502	3.649	5.284	4.716	5.526	3.861	4.75	8.51	7.81	16.41	12.33	11.65
La error	0.041	0.045	0.036	0.06	0.057	0.058	0.056	0.11	0.17	0.16	0.89	0.24	0.11
Ce (ppm)	6.418	6.82	5.681	8.333	7.869	8.97	6.13	7.81	13.23	11.7	22	18.08	18.11
Ce error	0.069	0.075	0.055	0.099	0.09	0.1	0.094	0.27	0.22	0.24	1	0.31	0.2
Pr (ppm)	0.6681	0.707	0.6078	0.889	0.862	0.983	0.662	0.875	1.382	1.194	2.011	1.877	1.899
Pr error	0.0098	0.0095	0.0081	0.013	0.012	0.015	0.012	0.039	0.025	0.026	0.077	0.031	0.021
Nd (ppm)	2.462	2.646	2.307	3.313	3.316	3.669	2.535	3.5	5.141	4.458	6.76	6.8	6.952
Nd error	0.037	0.048	0.035	0.053	0.056	0.055	0.049	0.18	0.088	0.094	0.2	0.11	0.084
Sm (ppm)	0.314	0.337	0.31	0.436	0.476	0.503	0.345	0.526	0.879	0.732	0.872	0.99	0.959
Sm error	0.011	0.012	0.011	0.013	0.015	0.016	0.011	0.04	0.021	0.021	0.029	0.022	0.019
Eu (ppm)	1.204	1.164	1.458	1.788	1.704	1.643	1.208	1.129	0.78	0.62	1.808	0.79	1.055
Eu error	0.017	0.016	0.018	0.028	0.025	0.024	0.022	0.019	0.017	0.013	0.026	0.016	0.016
Gd (ppm)	0.1988	0.1989	0.1914	0.2663	0.299	0.294	0.2046	0.372	0.615	0.531	0.5	0.615	0.581
Gd error	0.0083	0.0088	0.0081	0.0094	0.011	0.01	0.0087	0.033	0.021	0.016	0.016	0.018	0.014
Dy (ppm)	0.0833	0.0857	0.0861	0.1253	0.1443	0.1357	0.0941	0.243	0.417	0.328	0.2308	0.32	0.2683
Dy error	0.0043	0.0048	0.0041	0.005	0.0059	0.0057	0.0045	0.03	0.017	0.011	0.0087	0.011	0.0074
Er (ppm)	0.0281	0.0266	0.0263	0.0362	0.0395	0.0372	0.0262	0.103	0.1481	0.0999	0.0624	0.0968	0.0685
Er error	0.0025	0.0024	0.0021	0.0026	0.0026	0.0026	0.0022	0.014	0.0083	0.0049	0.0039	0.0044	0.0032
Yb (ppm)	0.0158	0.012	0.0137	0.0193	0.0188	0.0167	0.0109	0.077	0.0855	0.0529	0.0249	0.0515	0.0299
Yb error	0.002	0.0017	0.0018	0.002	0.002	0.002	0.0017	0.012	0.0054	0.0037	0.0026	0.0029	0.0024
⁸⁷ Sr/ ⁸⁶ Sr	0.70509	0.70509	0.70505	0.70505	0.70497	0.70497	0.70505	0.70505					

AGSKSE08: IRL with inclusion. MA: matrix INC: inclusion. ⁸⁶Sr data taken from Glommé (2015)

Appendix I 10(13)

AGSKSE08

Analytical point	14	15	16	17	18	19	20	21	22	23	24	25	26
context	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Wt %	96.81	96.81	96.81	96.81	96.81	96.81	96.81	96.16	96.16	96.76	96.76	96.76	96.76
An (mol %)	53.76	53.76	56.12	56.12	56.12	53.42	53.42	53.42	53.42	52.85	52.85	52.85	52.85
Rb (ppm)	0.924	1.259	6.5	4.002	0.239	2.02	37.9	44.13	0.886	2.944	2.12	2.277	2.112
Rb error	0.038	0.033	0.12	0.094	0.018	0.17	1	0.59	0.03	0.087	0.022	0.026	0.026
Sr (ppm)	916.8	905.6	627.3	649.5	985.9	922.4	1367	1127.9	931.7	1031.9	968.7	997.4	1028.6
Sr error	7.3	7	4.6	5.9	6.8	6.9	13	9.1	7.5	7.5	7.3	8	7.3
Ba (ppm)	398.4	370.1	223.8	291.8	483.9	522.5	568.8	844.4	420.9	325.8	285.5	383.3	317.4
Ba error	3.4	3	2.3	3.1	4	4.6	8.4	7.5	3	3.8	2.5	3.3	2.4
La (ppm)	11.07	6.132	15.31	18.23	10.12	25.98	18.35	16.15	10.123	6.963	4.42	4.554	4.218
La error	0.11	0.078	0.13	0.84	0.12	0.66	0.27	0.16	0.079	0.08	0.046	0.048	0.043
Ce (ppm)	17.36	10.19	23.08	28.1	18.41	40.5	29.17	27.4	16.7	11.71	6.945	7.408	6.913
Ce error	0.19	0.13	0.22	1.4	0.22	1.3	0.38	0.29	0.13	0.12	0.073	0.084	0.079
Pr (ppm)	1.848	1.106	2.43	3.02	2.015	4.09	2.902	2.811	1.768	1.282	0.742	0.814	0.738
Pr error	0.025	0.018	0.025	0.17	0.026	0.15	0.042	0.033	0.018	0.016	0.01	0.012	0.011
Nd (ppm)	6.81	4.126	9.01	11.45	7.56	14.93	10.13	9.95	6.367	4.852	2.824	3.113	2.756
Nd error	0.13	0.065	0.11	0.7	0.11	0.59	0.16	0.11	0.069	0.064	0.039	0.049	0.047
Sm (ppm)	1.049	0.564	1.246	1.71	1.114	2.06	1.337	1.392	0.93	0.708	0.388	0.435	0.37
Sm error	0.036	0.017	0.023	0.13	0.024	0.1	0.029	0.027	0.021	0.017	0.012	0.014	0.013
Eu (ppm)	1.584	1.536	1.182	1.355	1.82	1.673	2.197	2.211	1.727	1.518	1.491	1.739	1.617
Eu error	0.019	0.02	0.017	0.046	0.026	0.02	0.032	0.025	0.018	0.02	0.02	0.023	0.022
Gd (ppm)	0.694	0.357	0.753	1.22	0.655	1.412	0.766	0.808	0.567	0.423	0.2347	0.272	0.23
Gd error	0.042	0.013	0.016	0.11	0.017	0.083	0.022	0.018	0.017	0.015	0.0083	0.011	0.01
Dy (ppm)	0.387	0.173	0.3342	0.721	0.2865	0.839	0.341	0.359	0.2631	0.2121	0.1101	0.1318	0.1021
Dy error	0.032	0.0071	0.0086	0.083	0.0086	0.06	0.01	0.011	0.0085	0.0083	0.0055	0.006	0.0054
Er (ppm)	0.127	0.052	0.0873	0.28	0.0715	0.349	0.0915	0.0908	0.0664	0.0672	0.0312	0.0394	0.0301
Er error	0.014	0.0034	0.004	0.039	0.0042	0.029	0.0046	0.0048	0.0038	0.0044	0.0025	0.0028	0.0026
Yb (ppm)	0.077	0.0275	0.0366	0.187	0.0238	0.268	0.0468	0.0398	0.0275	0.0392	0.0162	0.0177	0.0149
Yb error	0.011	0.0031	0.0026	0.031	0.0026	0.024	0.0037	0.0033	0.0026	0.0035	0.0019	0.0024	0.0019
87Sr/86Sr	0.70515	0.70515						0.70530	0.70530	0.70519	0.70519	0.70509	

Continuation of AGSKSE08: IRL with inclusion. INC: inclusion. ⁸⁶Sr data taken from Glommé (2015)

Appendix I 11(13)

AGSKSE03(1)

Analytical point	1	2	3	4	5	6	7	8	9	10	11	12
context	MI	MI	MI	MI	MA	MA	MA	MA	MO	MO	MO	MO
Wt %	98.35	98.35	98.35	98.35	98.20	98.20	98.20	98.20	98.20	98.20	98.20	98.20
An (mol %)	52.26	52.26	52.26	52.26	53.79	53.79	53.79	53.79	53.79	53.79	53.79	53.79
Rb (ppm)	3.215	1.957	1.245	1.743	0.83	1.435	1.993	2.138	1.79	1.809	7.39	12.2
Rb error	0.061	0.053	0.03	0.052	0.02	0.022	0.073	0.053	0.035	0.032	0.088	1
Sr (ppm)	1024.9	1027.6	989.8	1017.6	1001.3	1022.1	1051.4	1049.5	990.9	1024.1	1020	1153.3
Sr error	7.2	7.1	5.9	7	6.2	7.3	6.1	7.5	6.6	6.7	9.9	7.2
Ba (ppm)	590	566.9	523	541	436.2	463	541.9	489.4	526.5	575.9	1015.4	456.7
Ba error	12	4	3.9	5.6	3.9	3.3	3.9	3.8	5.4	5.3	9.1	4.3
La (ppm)	12.68	16.35	13.911	15.24	12.92	14.1	16.9	15.82	11.97	16.37	16.51	24.33
La error	0.13	0.12	0.095	0.12	0.13	0.11	0.13	0.14	0.1	0.15	0.17	0.16
Ce (ppm)	20.84	26.64	22.75	25.04	21.62	24.46	28.25	26.95	20.17	26.68	27.57	37.27
Ce error	0.2	0.21	0.15	0.2	0.2	0.18	0.21	0.28	0.16	0.25	0.3	0.28
Pr (ppm)	2.132	2.661	2.325	2.562	2.221	2.545	2.899	2.786	2.123	2.732	2.858	3.641
Pr error	0.027	0.027	0.022	0.026	0.025	0.027	0.028	0.032	0.025	0.03	0.043	0.034
Nd (ppm)	7.698	9.39	8.346	9.09	8.006	9.18	10.24	9.84	7.749	9.74	10.05	12.48
Nd error	0.095	0.11	0.087	0.11	0.089	0.11	0.11	0.13	0.095	0.12	0.16	0.13
Sm (ppm)	1.016	1.21	1.121	1.209	1.113	1.285	1.397	1.368	1.087	1.31	1.381	1.562
Sm error	0.026	0.029	0.027	0.028	0.024	0.029	0.03	0.031	0.025	0.033	0.048	0.035
Eu (ppm)	1.875	2.128	1.918	1.945	2.141	2.169	2.266	2.3	1.812	2.037	2.292	2.486
Eu error	0.025	0.029	0.022	0.026	0.023	0.027	0.026	0.029	0.024	0.026	0.04	0.027
Gd (ppm)	0.587	0.676	0.653	0.704	0.657	0.747	0.814	0.82	0.675	0.765	0.802	0.866
Gd error	0.018	0.019	0.019	0.022	0.018	0.023	0.022	0.025	0.021	0.023	0.033	0.024
Dy (ppm)	0.298	0.316	0.315	0.357	0.3221	0.374	0.392	0.446	0.372	0.368	0.38	0.386
Dy error	0.011	0.01	0.011	0.012	0.0097	0.012	0.014	0.015	0.014	0.012	0.017	0.013
Er (ppm)	0.0853	0.0874	0.0898	0.1065	0.0863	0.0955	0.1118	0.1411	0.163	0.0995	0.1041	0.1004
Er error	0.0049	0.0049	0.0054	0.0061	0.005	0.0052	0.0065	0.0081	0.012	0.0062	0.0093	0.0057
Yb (ppm)	0.0397	0.0379	0.0345	0.0524	0.0338	0.0375	0.0431	0.0816	0.107	0.0375	0.0384	0.0403
Yb error	0.0042	0.0039	0.004	0.005	0.0036	0.004	0.0044	0.0075	0.012	0.004	0.0062	0.0049
87Sr/86Sr	0.70502	0.70502	0.70512	0.70512	0.70525	0.70525			0.70519	0.70519	0.70528	0.70528

AGSKSE03(1): IRL with plagioclase phenocryst. MI: megacryst inner MA: matrix MO: megacryst outer. ⁸⁶Sr data taken from Glommé (2015)

Appendix I 12(13)

AGSKSE03(1)

Analytical point	13	14	15	16	17	18	19	20	21	22	23	24
context	MA	MA	MA	MA	MA	MA	MA	MA	MA	MA	MO	MO
Wt %	97.48	97.48	95.66	95.66	95.66	95.66	96.12	96.12	96.02	96.02	95.55	95.55
An (mol %)	52.95	52.95	51.87	51.87	51.87	51.87	51.57	51.57	50.57	50.57	52.32	52.32
Rb (ppm)	19.1	1.397	4.58	3.534	2.51	1.459	1.321	9.7	1.293	1.621	1.712	2.166
Rb error	1	0.026	0.25	0.054	0.03	0.02	0.024	1.1	0.023	0.018	0.032	0.026
Sr (ppm)	1096.6	990.1	1019	1007	1062.6	1027.7	938.8	957.9	981.1	943.1	1011.3	1016
Sr error	9.1	6.1	12	10	8	8	6.1	9.1	6.4	7.2	6.4	7.2
Ba (ppm)	532	398.7	334.2	468.2	761.3	516.5	406.9	454	515	418.9	415.2	318.5
Ba error	14	3.1	5.8	5.7	5.6	4.2	2.8	17	4.1	3.3	2.9	2.4
La (ppm)	17.68	4.185	5.71	5.168	21.23	8.055	7.84	8.7	8.75	5.682	6.8	4.209
La error	0.15	0.04	0.1	0.079	0.21	0.083	0.12	0.17	0.17	0.068	0.17	0.045
Ce (ppm)	28.07	6.683	9	8.46	31.24	13.31	13.28	14.23	14.55	9.36	11.47	6.549
Ce error	0.23	0.066	0.15	0.13	0.3	0.14	0.19	0.25	0.27	0.12	0.27	0.071
Pr (ppm)	2.765	0.688	0.915	0.882	2.998	1.374	1.414	1.455	1.504	0.982	1.194	0.673
Pr error	0.027	0.011	0.026	0.019	0.034	0.02	0.022	0.023	0.027	0.015	0.028	0.01
Nd (ppm)	9.51	2.626	3.284	3.244	10.28	5.062	5.287	5.317	5.445	3.62	4.327	2.566
Nd error	0.1	0.046	0.094	0.07	0.13	0.077	0.085	0.086	0.094	0.062	0.092	0.047
Sm (ppm)	1.19	0.348	0.425	0.422	1.223	0.681	0.746	0.71	0.769	0.514	0.618	0.319
Sm error	0.029	0.013	0.031	0.023	0.029	0.021	0.023	0.022	0.021	0.018	0.021	0.013
Eu (ppm)	1.985	1.855	1.637	2.035	2.797	2.192	2.477	2.053	2.264	1.918	2.245	1.314
Eu error	0.027	0.024	0.04	0.039	0.032	0.027	0.032	0.032	0.026	0.025	0.027	0.021
Gd (ppm)	0.693	0.202	0.259	0.258	0.684	0.403	0.433	0.426	0.427	0.3	0.35	0.197
Gd error	0.021	0.011	0.026	0.016	0.019	0.015	0.016	0.018	0.016	0.012	0.015	0.011
Dy (ppm)	0.333	0.0999	0.118	0.1287	0.329	0.1886	0.218	0.221	0.2132	0.1426	0.1744	0.0895
Dy error	0.012	0.0068	0.013	0.0096	0.012	0.0089	0.01	0.01	0.0083	0.0071	0.008	0.0057
Er (ppm)	0.0995	0.0315	0.0442	0.0384	0.1	0.0588	0.0581	0.065	0.0601	0.0394	0.0548	0.0289
Er error	0.0066	0.0031	0.0082	0.0047	0.0065	0.0041	0.0045	0.0046	0.0046	0.0035	0.0042	0.0031
Yb (ppm)	0.0504	0.0192	0.0321	0.0225	0.0596	0.0256	0.0303	0.0351	0.0233	0.0231	0.0397	0.0141
Yb error	0.005	0.0029	0.0063	0.0043	0.0049	0.0032	0.0037	0.0042	0.0033	0.0029	0.0044	0.0028
87Sr/86Sr	0.70501	0.70501	0.70494	0.70494	0.70497	0.70497	0.70508	0.70508			0.70508	0.70508

Continuation of AGSKSE03(1): IRL with plagioclase phenocryst. AGSKSE11: IRL matrix. ⁸⁶Sr data taken from Glommé (2015)

Appendix I 13(13)

AGSKSE11

Analytical point	1	2	3	4	5	6	7	8	9	10	11	12	13
context	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR
Wt %	96.39	96.39	95.93	95.93	97.51	97.51	97.84	97.84	97.06	97.06	97.06	96.02	96.02
An (mol %)	52.91	52.91	52.45	52.45	52.23	52.23	51.94	51.94	53.90	53.90	53.90	54.52	54.52
Rb (ppm)	2.372	2.094	3.82	5.508	1.004	1.995	0.818	1.764	1.946	4.84	5.04	3.159	2.251
Rb error	0.033	0.037	0.11	0.067	0.024	0.033	0.027	0.024	0.033	0.11	0.16	0.061	0.028
Sr (ppm)	991.9	1010.5	1077.2	904.2	1001.7	926.4	939.9	934.3	1013.8	1002.1	995.2	982.6	959.7
Sr error	7.4	7.8	7.9	9.1	7.2	7	7.8	6.6	6.7	7.6	6.7	5.8	6.7
Ba (ppm)	354.9	349.2	607.1	264.9	518.5	431.8	421.1	337.3	296.1	372.3	325	270	276.6
Ba error	2.5	3	3.5	2.8	3.2	3.2	3.9	2.5	1.7	3.3	2.3	1.6	1.9
La (ppm)	3.96	3.671	17.88	6.422	5.053	3.565	5.241	3.261	3.32	3.599	4.233	2.94	3.159
La error	0.034	0.041	0.13	0.096	0.042	0.04	0.058	0.032	0.028	0.04	0.033	0.024	0.029
Ce (ppm)	6.307	5.898	26	10.78	8.54	5.882	9.16	5.453	5.436	6.051	6.593	4.753	5.313
Ce error	0.056	0.065	0.17	0.17	0.055	0.062	0.11	0.053	0.042	0.058	0.047	0.038	0.042
Pr (ppm)	0.6595	0.623	2.511	1.143	0.93	0.633	0.992	0.5916	0.5934	0.666	0.685	0.5116	0.5776
Pr error	0.0098	0.01	0.024	0.024	0.011	0.01	0.016	0.0096	0.008	0.011	0.0092	0.0074	0.0077
Nd (ppm)	2.486	2.355	8.8	4.2	3.528	2.496	3.832	2.278	2.298	2.608	2.638	2.015	2.263
Nd error	0.038	0.039	0.096	0.11	0.05	0.045	0.074	0.038	0.036	0.052	0.043	0.034	0.037
Sm (ppm)	0.327	0.305	1.056	0.571	0.543	0.359	0.551	0.33	0.33	0.415	0.356	0.271	0.324
Sm error	0.014	0.014	0.024	0.029	0.018	0.015	0.029	0.014	0.015	0.019	0.016	0.012	0.013
Eu (ppm)	1.967	1.822	2.453	1.437	2.3	2.161	2.099	1.815	1.808	2.113	1.87	1.497	1.562
Eu error	0.021	0.026	0.027	0.034	0.028	0.028	0.033	0.024	0.021	0.029	0.021	0.017	0.018
Gd (ppm)	0.1947	0.1919	0.592	0.349	0.349	0.232	0.338	0.215	0.219	0.268	0.235	0.186	0.217
Gd error	0.0098	0.0099	0.021	0.022	0.015	0.012	0.02	0.012	0.013	0.016	0.012	0.01	0.011
Dy (ppm)	0.0901	0.0858	0.244	0.185	0.1913	0.134	0.179	0.1073	0.0988	0.1393	0.1129	0.096	0.0999
Dy error	0.0053	0.0057	0.01	0.015	0.0089	0.0077	0.012	0.0061	0.0063	0.0091	0.0069	0.0061	0.0058
Er (ppm)	0.0275	0.0256	0.0565	0.0725	0.0591	0.044	0.0506	0.0338	0.0308	0.0438	0.0347	0.0308	0.0283
Er error	0.003	0.0028	0.004	0.0076	0.0049	0.0039	0.0058	0.0038	0.0032	0.0046	0.0034	0.0036	0.0031
Yb (ppm)	0.0155	0.0136	0.0278	0.0464	0.0268	0.0273	0.0291	0.0225	0.014	0.033	0.0206	0.0165	0.0131
Yb error	0.003	0.0028	0.0039	0.0076	0.0041	0.0035	0.0057	0.0034	0.0031	0.0053	0.0032	0.0032	0.0026
87Sr/86Sr	0.70519	0.70519	0.70505	0.70505	0.70508	0.70508	0.70511	0.70511	0.70501	0.70501	0.70501	0.70511	0.70511

AGSKSE11: IRL matrix. GR: grain. ⁸⁶Sr data taken from Glommé (2015)

Appendix II 1(4)

	Standard sample	Na	error	LOD_Na	Si	error	LOD_Si	Rb	error	LOD_Rb
	NIST614-1	104490	870	55	3.37E+05	2.40E+03	270	0.8459	0.0086	0.0029
	NIST614-2	103170	790	57	3.36E+05	2.00E+03	300	0.8493	0.0085	0.0033
	NIST614-3	1.05E+05	1.10E+03	59	3.39E+05	3.00E+03	320	0.846	0.01	0.0035
	NIST614-4	1.02E+05	1.00E+03	51	3.29E+05	2.60E+03	260	0.8357	0.0087	0.0025
	NIST614-5	104240	970	64	3.40E+05	2.50E+03	270	0.8568	0.0085	0.0029
	NIST614-6	104300	730	130	3.38E+05	2.40E+03	290	0.8514	0.0097	0.0065
	NIST614-7	102320	840	150	3.31E+05	2.50E+03	330	0.846	0.01	0.0074
	NIST614-8	103250	820	130	3.33E+05	2.20E+03	360	0.8479	0.0096	0.0072
	NIST614-9	103320	870	130	3.35E+05	2.60E+03	310	0.8375	0.0094	0.0066
	NIST614-10	101790	950	130	3.32E+05	2.60E+03	290	0.836	0.01	0.007
	NIST614-11	101060	800	140	3.31E+05	2.50E+03	290	0.848	0.01	0.0062
Mean & standard deviation		103104	1231		334555	3641		0.846	0.007	
Coefficient of variation			1.2%			1.1%			0.8%	
NIST614 reference values and error								0.855	0.005	
Secondary std vs ref value								0.989	1.0%	
2 standard deviations									2.0%±2SD	

Appendix II 2(4)

	Standard sample	Sr	error	LOD_Sr	Ba	error	LOD_Ba	La	error	LOD_La	Ce	error	LOD_Ce
	NIST614-1	45.77	0.54	0.017	3.26	0.04	0.0031	0.7109	0.0074	0.00019	0.7921	0.0081	0.00021
	NIST614-2	45.26	0.55	0.014	3.176	0.039	0.003	0.7136	0.0083	0.00021	0.7929	0.0095	0.00022
	NIST614-3	45.08	0.56	0.019	3.179	0.042	0.0028	0.7136	0.0073	0.00024	0.7934	0.0099	0.00025
	NIST614-4	45.35	0.5	0.014	3.204	0.041	0.0022	0.714	0.01	0.0002	0.782	0.012	0.0002
	NIST614-5	46.07	0.61	0.02	3.247	0.044	0.0026	0.7225	0.0079	0.00019	0.7897	0.0085	0.00022
	NIST614-6	45.55	0.58	0.021	3.233	0.045	0.0037	0.7236	0.0084	0.00034	0.7889	0.0096	0.00045
	NIST614-7	46.17	0.72	0.023	3.209	0.042	0.0048	0.7196	0.008	0.00038	0.7839	0.0092	0.00042
	NIST614-8	45.98	0.64	0.033	3.188	0.045	0.0049	0.7151	0.0085	0.00036	0.7809	0.0093	0.00038
	NIST614-9	45.78	0.63	0.027	3.226	0.045	0.0037	0.7182	0.0088	0.00036	0.784	0.01	0.00042
	NIST614-10	45.43	0.57	0.024	3.213	0.044	0.0035	0.7142	0.009	0.0004	0.787	0.011	0.00035
	NIST614-11	45.53	0.59	0.027	3.166	0.041	0.004	0.7198	0.0081	0.00039	0.7813	0.0098	0.00038
Mean & standard deviation		45.634	0.350		3.209	0.030		0.717	0.004		0.787	0.005	
Coefficient of variation			0.8%			0.9%			0.6%			0.6%	
NIST614 reference values and error		45.8	0.1		3.2	0.09		0.72	0.013		0.813	0.025	
Secondary std vs ref value		0.996	0.8%		1.003	3.0%		0.996	1.9%		0.968	3.1%	
2 standard deviations			1.6%±2SD			5.9%±2SD			3.8%±2SD			6.3%±2SD	

Appendix II 3(4)

	Standard sample	Pr	error	LOD_Pr	Nd	error	LOD_Nd	Sm	error	LOD_Sm	Eu	error	LOD_Eu
	NIST614-1	0.7537	0.0083	0.00019	0.746	0.011	0.00092	0.776	0.014	0.0012	0.7621	0.0095	0.00034
	NIST614-2	0.7562	0.0086	0.00023	0.754	0.012	0.00095	0.765	0.013	0.0014	0.7593	0.0097	0.00035
	NIST614-3	0.7582	0.0092	0.00019	0.74	0.013	0.0011	0.77	0.014	0.0013	0.757	0.01	0.0003
	NIST614-4	0.754	0.012	0.00015	0.747	0.015	0.00087	0.778	0.016	0.0012	0.76	0.013	0.00028
	NIST614-5	0.7672	0.0084	0.00018	0.745	0.013	0.001	0.782	0.013	0.0014	0.7699	0.0097	0.00032
	NIST614-6	0.7687	0.0098	0.0003	0.764	0.015	0.0015	0.782	0.016	0.0018	0.771	0.012	0.00055
	NIST614-7	0.7561	0.0073	0.00034	0.748	0.015	0.0019	0.784	0.018	0.0025	0.7645	0.0099	0.00063
	NIST614-8	0.7535	0.0084	0.00034	0.759	0.014	0.0016	0.795	0.016	0.0022	0.7686	0.0095	0.00064
	NIST614-9	0.759	0.01	0.00027	0.749	0.014	0.0017	0.791	0.017	0.002	0.771	0.012	0.0005
	NIST614-10	0.757	0.01	0.00032	0.749	0.015	0.0017	0.786	0.017	0.0017	0.766	0.011	0.00049
	NIST614-11	0.7604	0.0099	0.00029	0.753	0.015	0.0017	0.796	0.015	0.0025	0.764	0.011	0.00061
Mean & standard deviation		0.759	0.005		0.750	0.007		0.782	0.010		0.765	0.005	
Coefficient of variation			0.7%			0.9%			1.2%			0.6%	
NIST614 reference values and error		0.768	0.015		0.752	0.014		0.754	0.013		0.77	0.016	
Secondary std normalised to ref value		0.988	2.1%		0.998	2.1%		1.037	2.1%		0.993	2.2%	
2 standard deviations			4.1%±2SD			4.1%±2SD			4.3%±2SD			4.3%±2SD	

Appendix II 4(4)

	Standard sample	Gd	error	LOD_Gd	Dy	error	LOD_Dy	Er	error	LOD_Er	Yb	error	LOD_Yb
	NIST614-1	0.747	0.013	0.0011	0.753	0.01	0.0008	0.743	0.01	0.00057	0.77	0.011	0.00087
	NIST614-2	0.75	0.012	0.0013	0.767	0.012	0.00069	0.755	0.011	0.00065	0.769	0.011	0.00085
	NIST614-3	0.746	0.013	0.0013	0.755	0.011	0.0007	0.755	0.011	0.00062	0.766	0.011	0.00092
	NIST614-4	0.738	0.014	0.00096	0.761	0.014	0.00069	0.752	0.012	0.00059	0.769	0.012	0.00072
	NIST614-5	0.748	0.013	0.0011	0.762	0.011	0.00067	0.759	0.011	0.0006	0.776	0.011	0.00096
	NIST614-6	0.762	0.016	0.0021	0.766	0.014	0.0012	0.766	0.013	0.00089	0.776	0.014	0.0011
	NIST614-7	0.755	0.015	0.0021	0.761	0.014	0.0014	0.779	0.012	0.00098	0.788	0.014	0.0015
	NIST614-8	0.76	0.014	0.0022	0.77	0.013	0.0012	0.768	0.013	0.001	0.785	0.013	0.0014
	NIST614-9	0.741	0.015	0.0019	0.764	0.013	0.0011	0.76	0.013	0.00098	0.785	0.013	0.0013
	NIST614-10	0.758	0.017	0.002	0.778	0.015	0.0014	0.76	0.014	0.001	0.78	0.015	0.0015
	NIST614-11	0.772	0.015	0.0024	0.792	0.013	0.0012	0.777	0.013	0.00089	0.786	0.014	0.0014
Mean & standard deviation		0.752	0.010		0.766	0.011		0.761	0.011		0.777	0.008	
Coefficient of variation			1.3%			1.4%			1.4%			1.0%	
NIST614 reference values and error		0.763	0.021		0.746	0.022		0.74	0.017		0.777	0.021	
Secondary std normalised to ref value		0.986	3.1%		1.027	3.3%		1.029	2.7%		1.000	2.9%	
2 standard deviations			6.1%±2SD			6.6%±2SD			5.4%±2SD			5.8%±2SD	

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