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Variations in Plutonic Lithics at Goat Rock, Banks Peninsula, NZ

Abstract

At Goat Rock, Banks Peninsula, NZ, there is an abundance of plutonic lithics, with varying textures and alignments. While in most localities plutonic lithics are rare, they compromise about 2% of the dome, and have a normal distribution in size, ranging from <1 cm to 17 cm. These plutonic lithics have varying compositions, textures and grain sizes. The variations in the lithics suggest that they may have originated from multiple magma bodies, or possibly in a magma body that with chemically distinct layers.

Introduction

The connection between processes occurring in magma chambers and liquid erupted at the surface is poorly understood. A better understanding of the formation of eruptible liquid will lead to better predictions of volcanic activity. Plutonic lithics are fragments of plutonic igneous rock within volumes of volcanic rock (different from enclaves, which are intrusions into plutonic rocks) (Burt et al., 1998). By connecting plutonic rocks with volcanic rocks, plutonic lithics can provide insights into the process of crystallization in magma chambers, and insights into their relationship with the erupted liquid.

The magmatic evolution of the Akaroa Complex, Banks Peninsula, NZ, isn't completely understood, Although plutonic lithics are generally rare, there is an abundance of them at Goat Rock, Banks Peninsula (Figure 1), a basaltic trachy-andesitic dome (Bertolett, 2014). This large abundance is an opportunity to study the plutonic lithics in the field, looking at proportions, percentages, sizes, and clustering present in the lithics, where in other localities the scarcity of lithics makes this impossible. In addition, the plutonic lithics present at goat rock have a variety of compositions, textures, and fabrics present. These textures will illuminate the different magmatic processes that occurred beneath Banks Peninsula.

Geologic Setting

Two eroded composite shield volcanoes, Lyttelton and Akaroa, form Banks Peninsula, on the East Coast of New Zealand's South Island. Lyttelton formed first, between 12.3-10.4 Ma, and Akaroa formed after, between 9.4-6.8 Ma; both formed over 1 Myr, with smaller scale volcanism continuing for another 1.5 Myr

(Timm et al., 2009). Unlike most intraplate volcanoes, the Akaroa and Lyttleton complexes were not formed by a hotspot (Timm et al., 2009). Timm et al. (2009) suggest that delamination from the lower lithosphere generated upwelling from the upper asthenosphere, forming the Lyttleton volcano. Akaroa was formed by either a second delamination, or by a further propagation of the delamination that formed Lyttleton (Timm et al., 2009).

Akaroa had two major stages of volcanism, formed through fractional crystallization. The early stage consisted of basaltic magma that then evolved to a trachytic magma (Johnson, 2012), with a gap of intermediate compositions (Hartung, 2011), this trend is then repeated in the later stage (Johnson, 2012). Johnson (2012) proposed a model for Akaroa volcanism with a parental picrtic basalt magma at a depth of 15-20 km, which fed mid-crustal magma chambers where fractional crystallization occurred, creating the various chemistries seen in the Akaroa lavas.

Hartung (2011) found a gap in the compositions; the lava flows record mafic and trachytic compositions, but there is a significant lack of compositions between the two. This forms what Hartung (2011) calls the “Daly Gap”. Hartung (2011) proposes that this gap was caused by melt extraction from a cumulate melt, and that for this to occur the melt would have to be extracted after 50-70% of the crystals had formed. The trachytic compositions on Banks Peninsula could have been extracted from a melt with a hawaiite composition after 50-80% of the crystals had been formed (Hartung, 2011).

Within the Akaroa Volcanics is Goat Rock dome, in the northeast between Le Bons Bay and Okains Bay. It is a Pelean dome, intruded through an older basaltic scoria conduit (Tramontano, 2013). The dome is basaltic trachy-andesite (Bertolett, 2014), with abundant plutonic lithics. The composition of the dome shows the beginning of the transitional stage between basaltic and trachytic lavas on Akaroa (Tramontano, 2013).

Possible sources for plutonic lithics are: magma cooled in-situ along the edge of a reservoir; an unrelated plutonic, solidified before contact with host; or a solidified part of cumulate crystal mush (Graeter et al., in press). Bertolett (2014) collected plutonic lithic samples from Goat Rock with obvious schlieren fabrics, and determined that there is an alignment to the plagioclase laths, suggestive of a crystal mush, which can form during fractional crystallization and is supportive of Johnson’s (2012) hypothesis.

Methods

Samples were collected at Goat Rock from a recent rock fall where lithics are accessible and exposed. Five large boulders containing lithics were examined and photographed (Figure 2 shows on of the five boulders). All lithics greater than 1 cm in diameter were measured along their length, and labeled (Lithics smaller than 1 cm it was hard to distinguish if they were plutonic lithics or feldspar phenocrysts). Samples were collected as float, not from the boulders, as boulder material was less accessible due to the strength of the host rock. Field data was analyzed for variations in size, clustering and percentage.

Five thin sections were made from hand samples (Table 1). Each thin section was examined using petrographic microscopy to study mineral assemblages, textures, zoning, and clusters. The composition of zoned plagioclase was examined using energy dispersive spectroscopy (EDS) analysis on the JEOL scanning electron microscope (SEM) with the backscatter electron (BSE) dectector in two thin sections (GR2 and GR8). These thin sections were used because they contained both plutonic lithics and abundant phenocrysts. Data was taken from each sample from both the lithic and phenocrysts, with measurements from the core and rim of each crystal. An accelerating voltage of 20 kV and a spot size of 11 was used for the EDS analysis.

ImageJ (Image processing and analysis software from the National Institute of Health) was used for shape preferred orientation evaluation, to evaluate if the crystallographic axes of the plagioclase crystals are aligned in the same direction. ImageJ selected the crystals to be analyzed using a color threshold. Then the fit ellipses function was used to calculate orientation of the crystal and the angle. These angles were then compared on rose diagrams to see if the angles headed in a similar direction or if they were widely distributed.

Image J was also used to get a rough analysis of the percentage of plutonic lithics within the host. A picture of a boulder was taken, and all the plutonic lithics were highlighted in red. Image J then found the area of these, and compared it to the area of the boulder as a whole. Only one boulder was used, as the other photos were not high enough in quality, or spanned a large enough section of boulder.

Results

Overall 258 lithics were measured across the five boulders. The plutonic lithics have a normal distribution throughout the dome (Figure 3). The lithics make up roughly 1-2% of the outcrop. The average size of the lithics is 3.6 cm, with a maximum size of 17.3 cm. There were no clusters of plutonic lithics, however there was some clustering of phenocrysts within the groundmass. The boundary between the lithics and the host is a very sharp boundary. Many of the lithics have clear cooling fractures (Figures 4, 5 & 6). Using ImageJ, the plutonic lithics were found to compromise roughly 2% of the boulder.

The four plutonic lithic samples (GR1, GR17, and part of GR2 and GR8) have feldspar as the primary mineral (~67%-87%), between which the microcline and plagioclase feldspar is somewhat evenly split (Table 1). The feldspar in all four samples has albite, and pericline twinning. Almost all of the feldspar has patchy zoning. All four plutonic lithics contain olivine (10%-20%) and iddingsite (~3%), likely weathering products from olivine. Two of the more weathered samples (GR2 and GR17) contain clay minerals (10% and 20%) weathered from feldspars.

The host material (GR2, GR8, and GR9) is a dark aphenitic groundmass with abundant phenocrysts (7%-40%) (Table 1). There is prominent flow banding visible within the groundmass in each sample. The phenocrysts are mainly composed of plagioclase (5%-30%), many of which exhibit simple twinning. There are also olivine (2%-10%) and iddingsite (0%-3%) phenocrysts. Almost all of the phenocrysts are rounded along the edges.

There is patchy zoning within many of the plagioclase crystals, both in the lithics and in the phenocrysts, none of which is strong enough to be clearly visible in SEM BSE images. There is no consistent pattern of zoning. Most had minor differences in amounts of Na, Ca, and K, but only a few had more than 4-5 weight percent changes. The feldspar phenocrysts within the groundmass are plagioclase, closer to anorthite on the spectrum. There is no correlation or connection between the phenocrysts and the lithics.

Only one of the plutonic lithics (GR17) had a strong alignment of the plagioclase phase (Figures 7 & 8). The remaining three (GR1, GR2, GR8) had no alignment (Figure 8).

Discussion

The sharp boundaries and cooling fractures (Figures 5 & 6) visible between the plutonic lithics and the groundmass indicate that the plutonic lithics were solidified when they were incorporated into the basaltic magma. Some of the lithics have rounded edges (GR2) which suggests partial melting before eruption, while some are more jagged (GR8) which suggests partial melting of the lithic did not occur. As some lithics were partially melted and some were not, this suggests that there may have been more than one event where the plutonic lithics were incorporated into the magma. More than one event may explain the abundance of plutonic lithics within the dome.

The textures in the goat rock plutonic lithics are considerably variable. All lithics contain patchy zoning, which suggests early formation and multiple episodes of melting and regrowth (Grater, 2015). GR17 has the largest feldspars, ranging from 2-10 mm. It is also the only sample with aligned plagioclase (Figure 7), it seems similar to the lithics described by Bartlett (2014), (with both interstitial olivine and clinopyroxene) and likely formed as a cumulate under compaction. GR1 and GR2 plutonic lithics have mainly <1mm feldspars, up to 2mm, and are less tabular than those in GR8 and GR17. However they are still the largest grains in the thin sections, with interstitial olivine between them. It seems likely they formed as a cumulate as well, but not under compaction as with GR17, due to the lack of plagioclase alignment.

The variation in these lithics supports Johnson's (2012) magmatic model of Akaroa Volcano: small magma batches with episodic magma injection that feed multiple eruption centers. The variability in the textures the likely came from different magma batches.

Conclusion

The plutonic lithics are further evidence for Johnson's (2012) Magmatic Model, with both compacted and not compacted cumulates. The variation in cumulates represent possible separate small magma batches.

Although previously all plutonic lithics seen had a strongly aligned plagioclase phase (Bertolett, 2014), which represented compaction of cumulate material, there are many lithics without this fabric. These likely represent cumulates that did not undergo compaction.

There has never been an in depth analysis of plutonic lithic distribution. The data presented here is a starting point, but a more complete geophysical analysis needs to be done. Fractals are used in many analyses of enclave distribution; perhaps the goat rock plutonic lithics can be investigated with this technique. Additionally, other field sites with abundant plutonic lithics should be examined for comparison.

Geochemical data has been done on the schlieren rich plutonic lithics and the host material, but not on the lithics without a distinct alignment of plagioclase. These should be analyzed for comparison with the previous geochemical data to investigate further the possibility of separate magma bodies.

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Figures

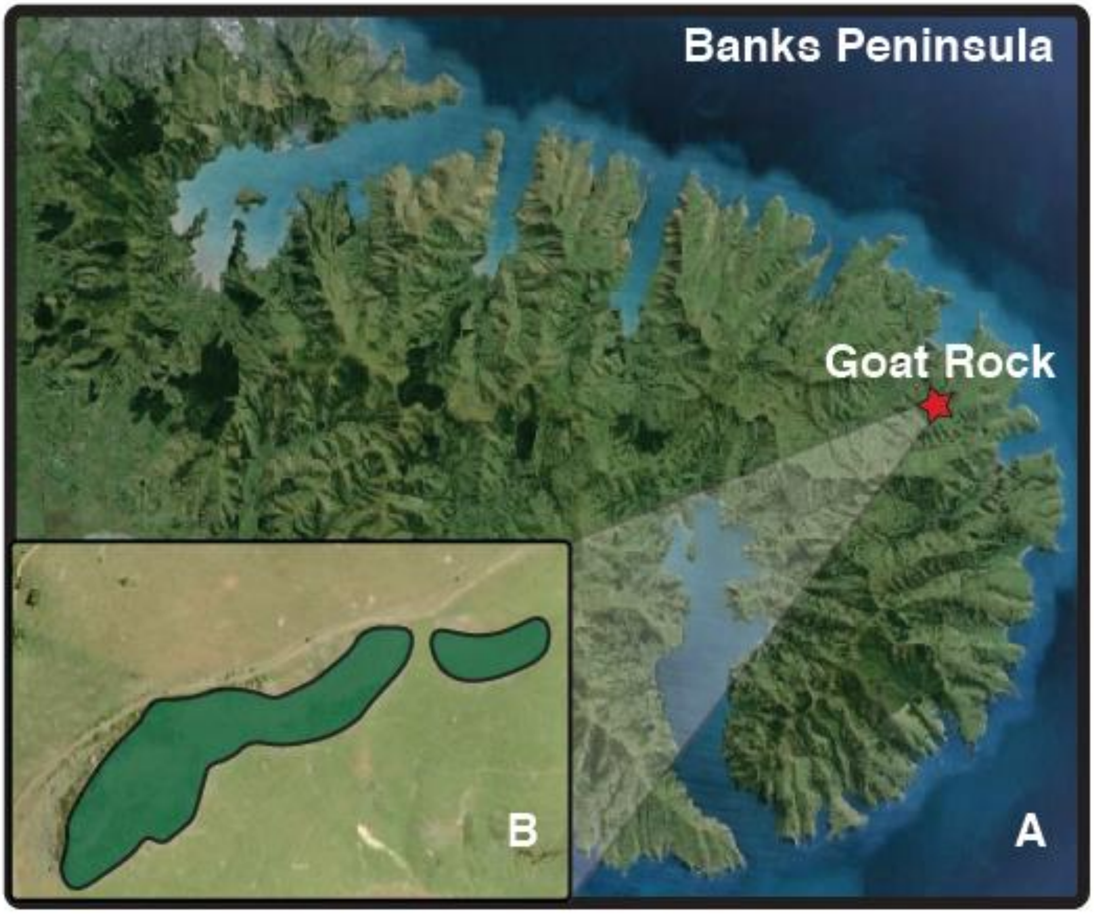

Figure 1: A) Map of Banks Peninsula showing the location of Goat Rock dome; B) Goat Rock dome

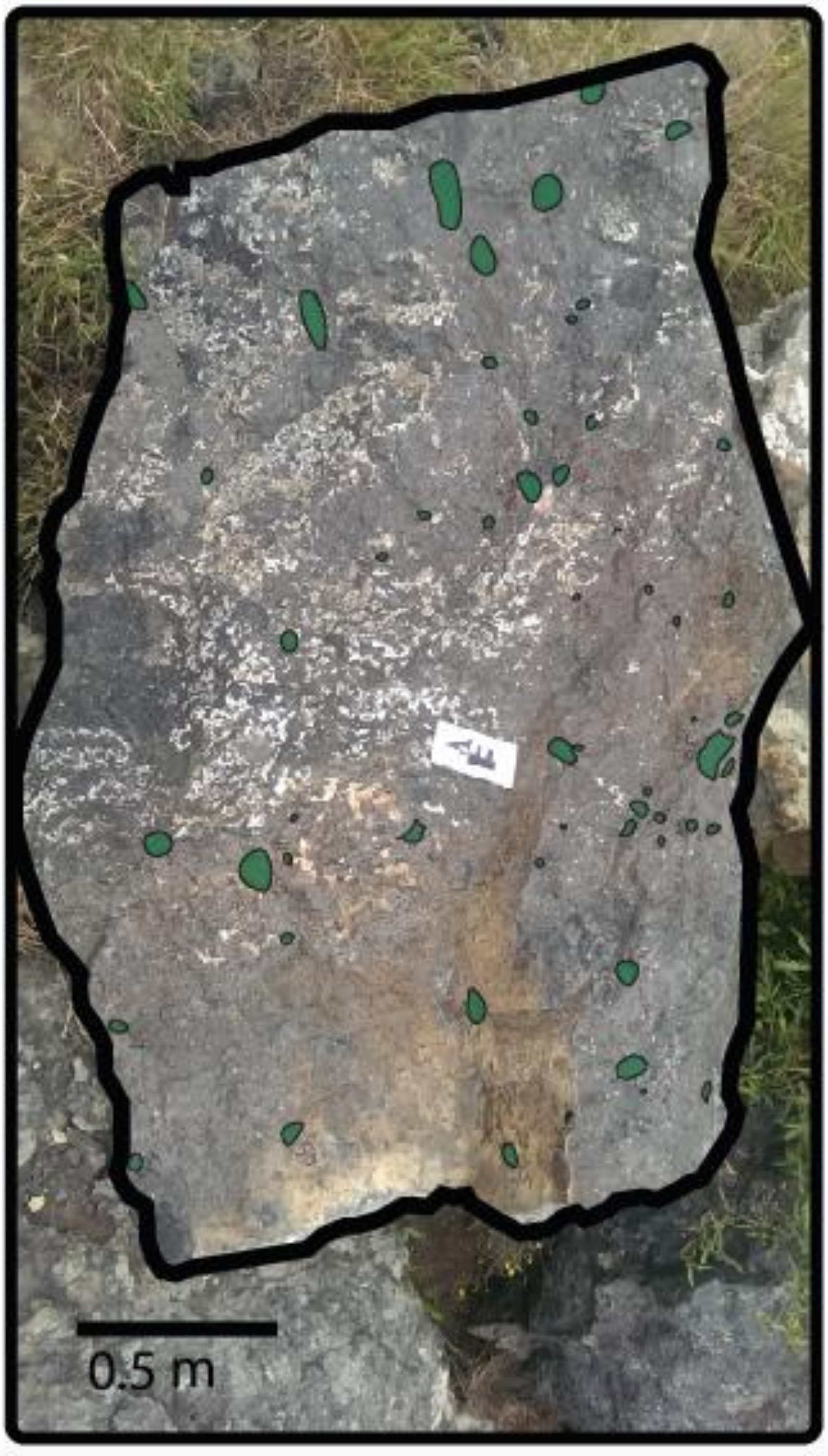

Figure 2: Photograph of Boulder D showing the distribution of plutonic lithics (green)

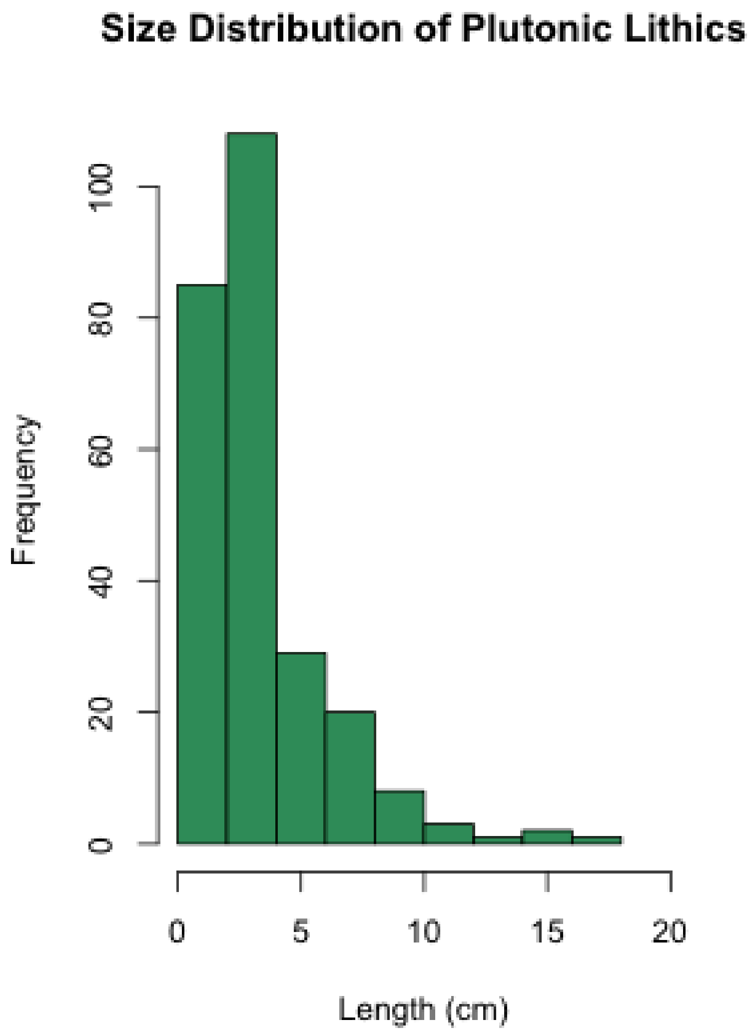

Figure 3: Size distribution of plutonic lithics show a normal distribution. Lithics smaller than 1 cm were not measured

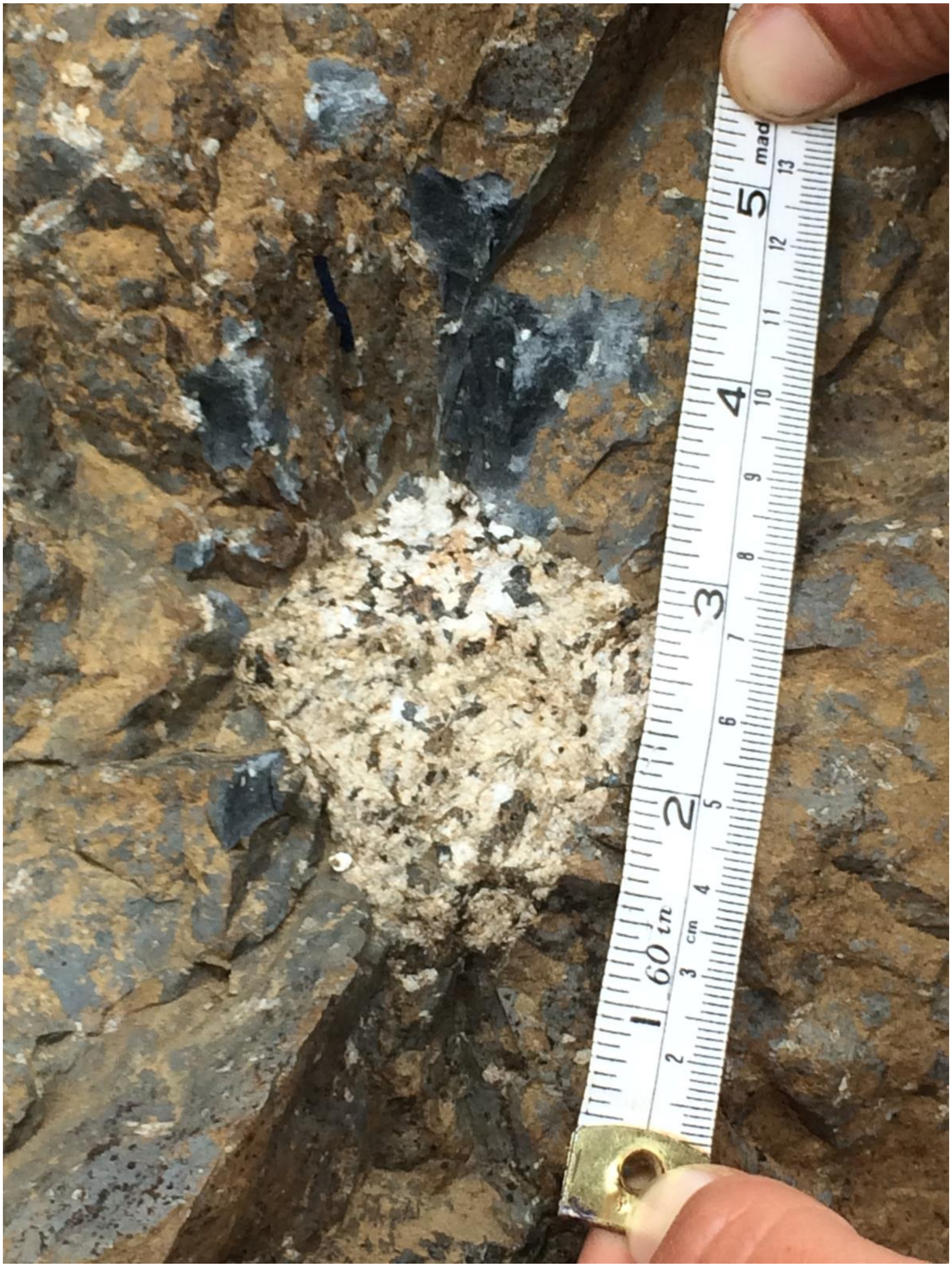

Figure 4: Plutonic lithic in the field. Photo show radiating cooling fractures

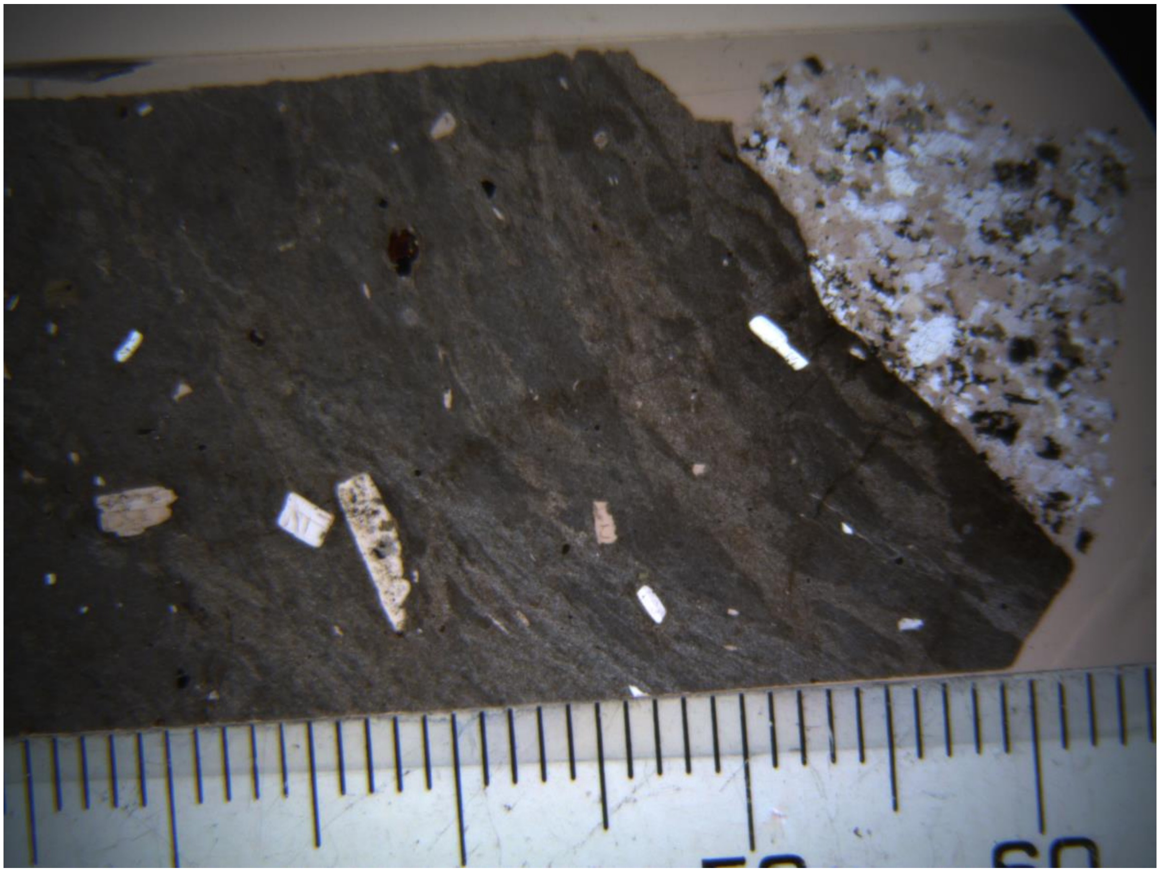

Figure 5: Photomicrograph of GR2 in PPL, showing sharp boundary between lithic and host rock, as well as cooling fractures. Shows rounded edge.

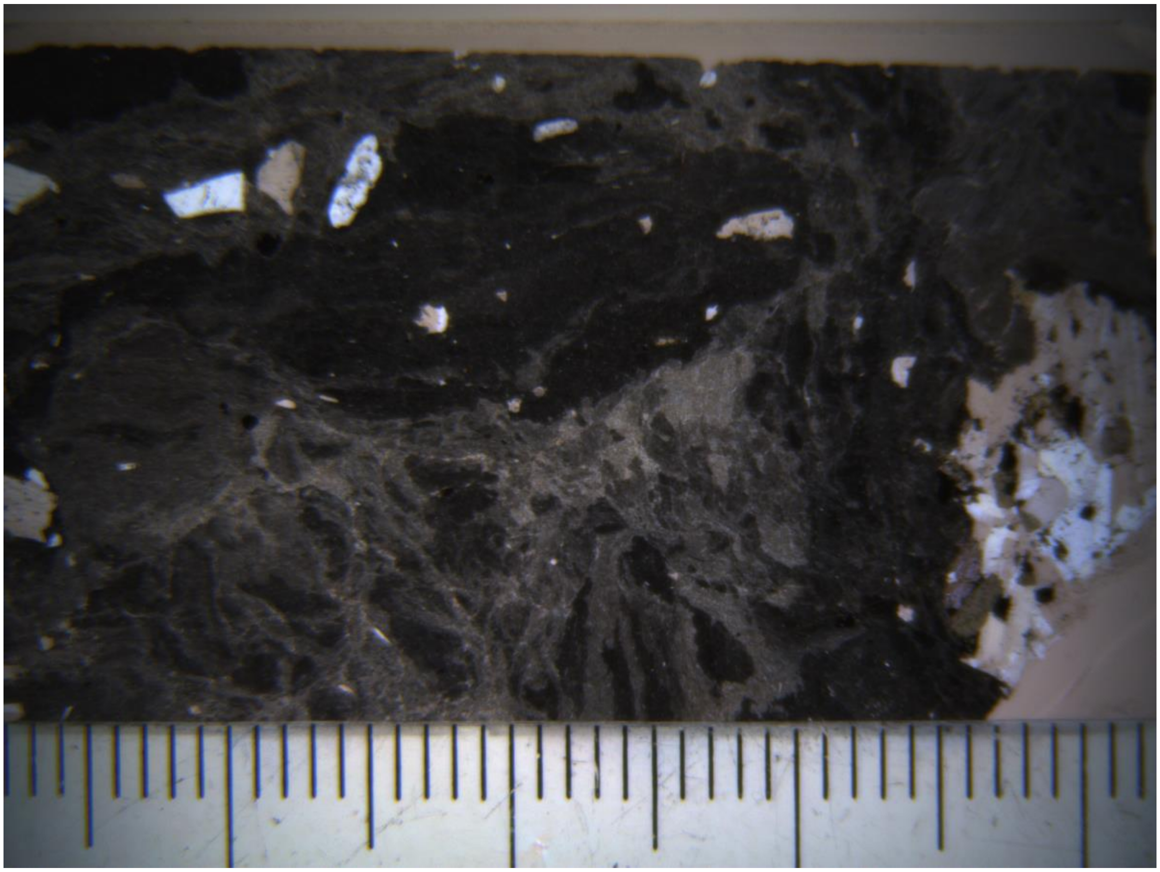

Figure 6: Photomicrograph of GR8 showing the sharp jagged boundary between lithic and the host rock

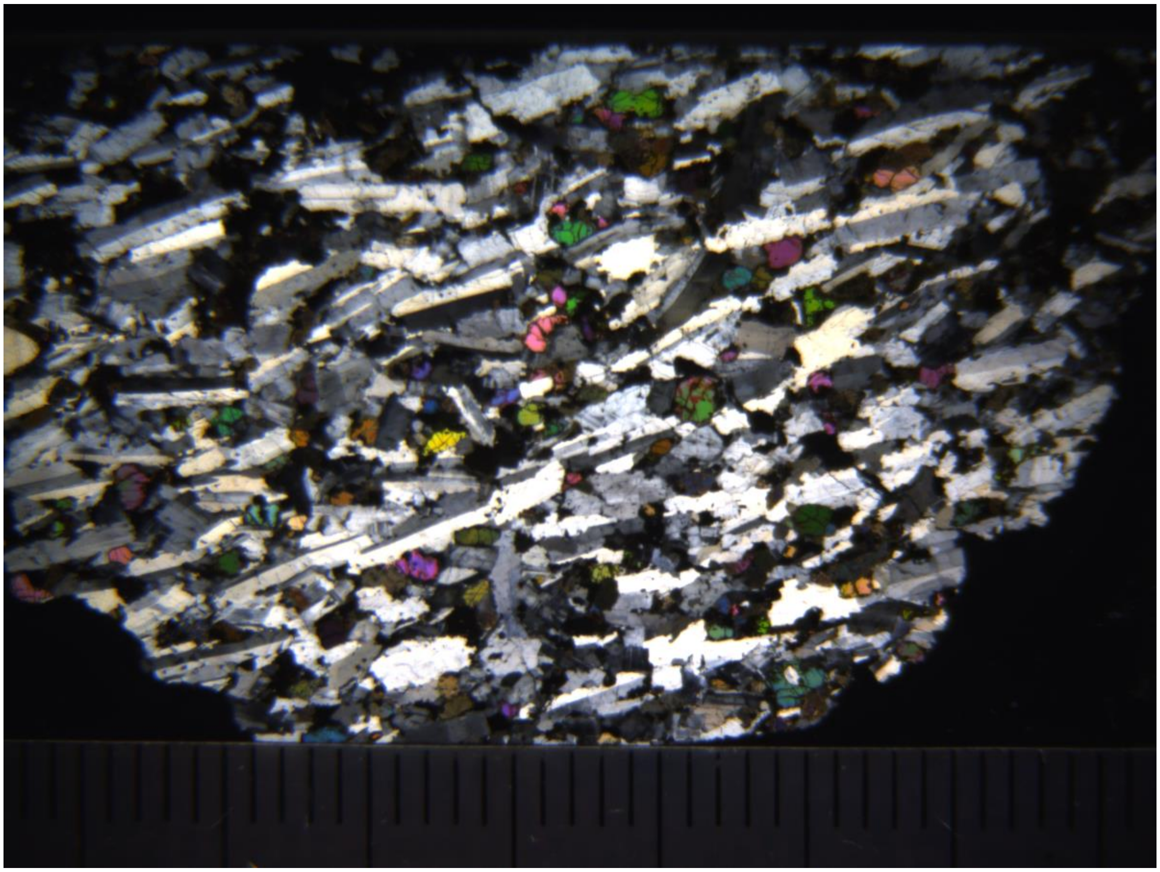

Figure 7: Photomicrograph of GR17 in XPL, showing alignment of feldspar crystals

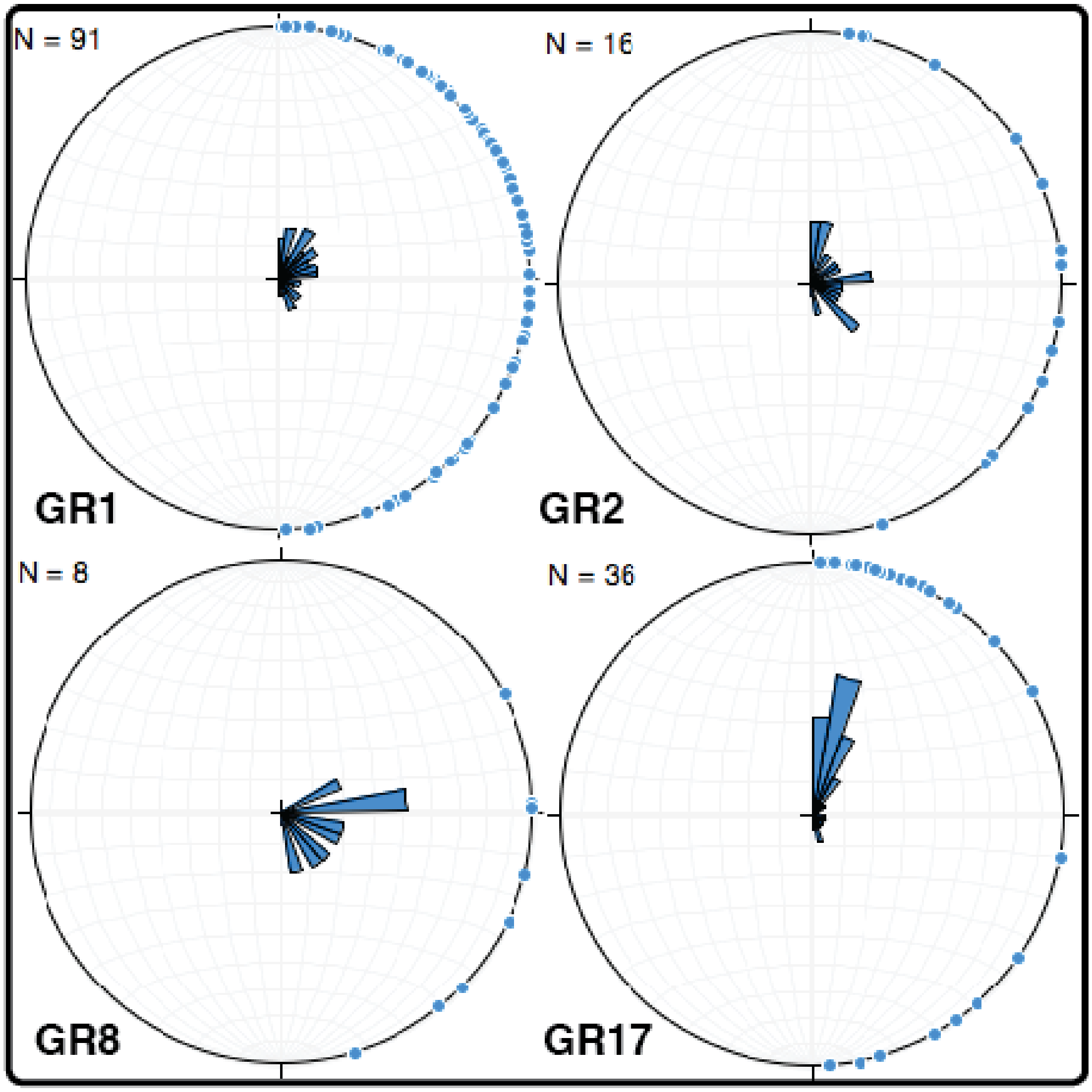

Figure 8: Rose diagrams showing the alignment of feldspar crystals in thin section. Samples GR1 and GR17 are full thin sections of plutonic lithics. Samples GR2 and GR8 are smaller plutonic lithics from a thin section with a groundmass

Tables

Table 1: Field descriptions and estimated modal mineralogy for each of the plutonic lithics. Due to the extremely small grain size, the groundmass could not be estimated and isn't included in the modal mineralogy. Phenocrysts are noted as percentage of the host rock.

Sample	Type	Field Description	Microcline	Plagioclase	Olivine	Iddingsite	Clay Mins.	Cpx.	Notes
GR1	Plutonic Lithic	5-10 cm plutonic lithic, with feldspar and mafics	47%	40%	10%	3%	0%	0%	
GR2	Plutonic Lithic	10-15 cm black aphenitic host with limited feldpsar phenocrysts and one cm-scale plutonic lithic	40%	37%	10%	3%	10%	N/A	
	Phenocrysts (total 7%)		N/A	5%	2%	N/A	N/A	N/A	7% phenocrysts; 93% aphenitic host
GR8	Plutonic Lithic	20 cm black aphenitic host with small, a small cm-scale plutonic lithic and feldspar crysts	35%	40%	20%	3%	N/A	N/A	
	Phenocrysts (total 10%)		N/A	7%	3%	N/A	N/A	N/A	10% phenocrysts; 90% aphenitic host
GR9	Phenocrysts (Total 40%)	aphenitic host with 5-10% feldspar phenocrysts	N/A	30%	10%	3%	N/A	N/A	40% phenocrysts; 60% aphenitic host
GR17	Plutonic Lithic	5-10 cm plutonic lithic with clear schlieren fabric	37%	30%	20%	2%	20%	<1%	