A PHYSICAL ANALYSIS OF ICELANDIC LAVAS: WHAT CLINOPYROXENES REVEAL ABOUT THE SOUTHWEST REYKJANES PENINSULA

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Geologic Setting

Methods

Results

Discussion

ABSTRACT

The geology of Iceland’s Southwest Reykjanes Peninsula is unique and not fully understood, and volcanic activity persists into modern times. It is a special location where a plate boundary is pulling apart, creating rift volcanism. To get a better foothold in understanding this complex geology, petrographic analyses were performed. Samples were collected from areas of high volcanism, namely Midfell, Litla Sandfell, and to a lesser degree Fagradalsfjall, Geitafell, and the southwestern tip of the Reykjanes Peninsula.

Most of these samples were basaltic lavas or glasses erupted from nearby volcanic features. Detailed visual analyses were conducted on thin sections made from these igneous samples. Mineral makeup and volcanic textures present in these minerals were documented. Clinopyroxenes were studied in more detail, due to their common occurrence and ideal textures such as zoning that can tell a lot about magmatic processes. Due to the distribution of clinopyroxenes at these locations, Midfell and Sandfell were able to be analyzed in more depth than the other three localities.

ACKNOWLEDGEMENTS

I would like to thank Dr. Barton for allowing me to be a part of the research opportunities that he has been working on, and for awarding me money to further conduct my research.

Special thanks to Ken Peterman for supporting this research and teaching me the ropes on this topic.

I would also like to thank Owen McNeill. Even though I was not able to utilize the data he is gathering from the samples by using the electron microprobe, it will be used to conduct further research and keep this project going.

Lastly, I would like to thank Dr. Sawyer for being willing to attend my thesis defense on such short notice.

LIST OF FIGURES

INTRODUCTION

Areas such as Midfell have been documented before, and with the growing media attention due to current eruptions, so has Fagradalsfjall. However, areas such as Litla Sandfell have little to no documentation, and have yet to be explored in depth. Comparing what is present in known areas like Midfell to the unknown Sandfell can help further understanding of magmatic processes in various areas of the Southwest Reykjanes Peninsula.

A paper written by Thordarson and Larsen in 2007 explored the eruptive events in the Southwest Reykjanes Peninsula. The goal of their paper was to get a better understanding of the magmatic behaviors of known volcanic sites. Thordarson and Larsen successfully explored the volcanism and eruptive environments of Iceland, and documented the types of volcanism in the different rift zones along the plate boundary that runs through Iceland. They also started to scratch the surface of rock compositions in the area, documenting various igneous formations and how they formed.

This paper aims to go further than Thordarson and Larsen, and dive into the actual composition and makeup of different volcanic areas in the Southwest Reykjanes Peninsula. Understanding the physical makeup of the rocks and the minerals that compose them is a key step in comprehending magmatic processes. Physical petrographic information is an important step in understanding igneous rocks. Minerals and their physical states can reveal a lot about the process a rock has been through. This paper specifically looks in-depth at clinopyroxenes. Clinopyroxenes are a common igneous mineral and can display distinguishing features such as zoning.

GEOLOGIC SETTING

Background

Iceland lies along the mid-Atlantic ocean ridge. Due to this, earthquakes and volcanism are a consistent occurrence on the island. Fault systems riddle the island, making rift volcanism a common occurrence. Many volcanoes such as Fagradalsfjall have garnered media attention over the past 5-10 years due to their eruptive activity. However, some of these volcanoes pose a risk to human populations in the area, due to their locations. Active volcanoes like Fagradasfjall are only a couple hours' drive or less from the capital city Reykjavík. Getting a better understanding of volcanism in Iceland can help predict volcanic activity and better prepare citizens of Iceland for when an event does occur.

The samples for the petrographic analyses were collected from various places around Iceland. The two major areas of interest are the mountains of Midfell and Sandfell. Other minor areas also include the well-known volcano Fagradalsfjall, and some other localities such as Geitafell and other parts of the Southwest Reykjanes Peninsula. **Figure 1** shows a map of where these samples were taken from along the peninsula. Samples of erupted material were collected, and ground into thin sections, which were then analyzed under a microscope.

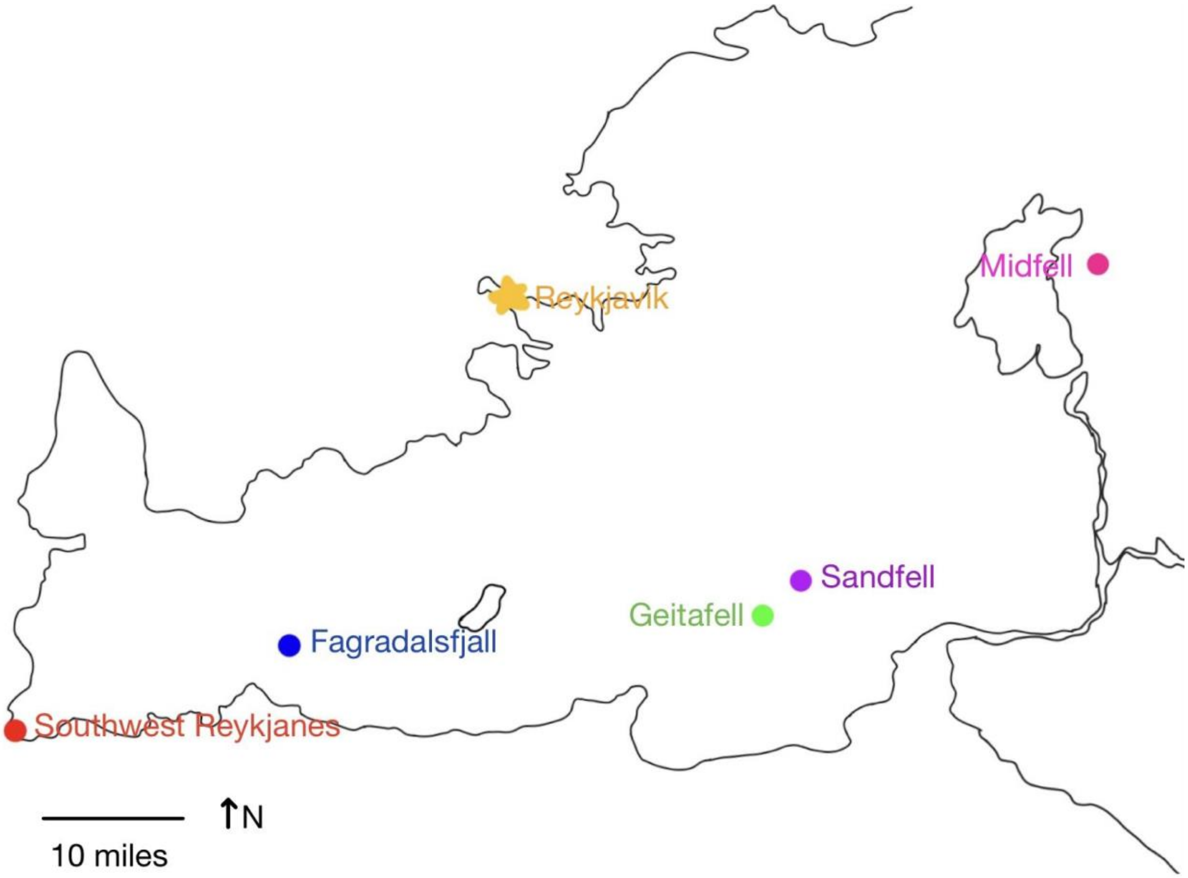

Figure 1 - Map of locations samples were taken from. The capital of Iceland, Reykjavik, is marked for spatial reference.

Almost all these locations are directly located along the plate boundary that runs through the country of Iceland. The North American and the Eurasian plates are separating from each other. This opens up rift zones that allow for magma to reach the surface and ultimately causes the volcanism throughout Iceland. The rift that is located along the plate boundary has multiple rift swarms that stem from the main path. It is along these swarms that high volcanic activity is present (Einarsson et al., 2023).

Midfell and Sandfell

Midfell is a mountain on the Reykjanes Peninsula that stands at around 320 m high and 3 km in length. As with most of the locations samples were taken, Midfell lies directly along the rift zone created by the separating North American and Eurasian plates. It was formed from a subglacial eruption The samples from the Midfell region were collected from pillow basalt formations that are present in the southwest of the mountain. These pillow basalts often contain fragmented gabbro xenoliths (Gurenko & Sobolev, 2006).

Not to be confused with the Sandfell laccolith to the east of the rift zone, the samples from Sandfell were collected from the mountain "Litla Sandfell". Litla Sandfell lies along the Icelandic rift zone along a rift swarm, just southwest of Midfell. Unfortunately, not much has been documented about this small mountain, but based on its location on the rift swarm, it is safe to assume that this mountain formed from subglacial volcanism similar to Midfell. The samples analyzed from this location are all pillow basalt samples, but Sandfell contains both pillow basalts and hyaloclastites.

Other Locations

The first of these other minor locations is the Fagradalsfjall volcano. A few samples of the recent 2021 eruption were collected. Only one thin section of these samples was analyzed. This volcano lies along the plate boundary that separates Iceland and is located on a rift swarm. Fagradalsfjall is fed by dikes that result from rifting (Einarsson et al., 2023). It contains a main cone, but also erupts from long fissures in the ground.

Geitafell is a location just to the southwest of Sandfell. This location is not to be confused with the Geitafell volcano that is in southeastern Iceland. The Geitafell from this study is in a similar geologic environment to Sandfell and Midfell on the Southwest Reykjanes Peninsula. Pillow basalts and hyaloclastites were collected from this location.

The samples from the Southwest Reykjanes Peninsula were collected from a location at the southwestern tip of the peninsula, near the Reykjanes Lighthouse. From this location, various pillow basalts were collected. These samples are within the vicinity of the Haleyjarbungar lava shield, located just to the east of where the samples were collected. This area is just to the west of the active Grindavik volcano. Grindavik and the other volcanoes in the area are geologically linked and affect each other due to their proximity. Eruptions and seismic activity from the Fagradalsfjall area create chain reactions that cause eruptions further southwest on the Reykjanes Peninsula (Hernández-Aguirre et al., 2023).

METHODS

Samples

These samples were all collected over the past few years. Locations with volcanic activity and accessibility along the Reykjanes Peninsula were selected. An ideal lava sample is one that has not been weathered and is large enough to be ground into a thin section. After grinding several samples into thin sections, they were documented by location and type of material. For example, xenolith-containing samples from Midfell were grouped separately than the normal pillow basalt samples. These samples were then carefully analyzed under a microscope.

At first, a broad understanding of each thin section was required. These thin sections were analyzed at a broad level to determine overall composition and textures present in each one. Minerals such as olivine, plagioclase, and opaques were noted. The next step was to find clinopyroxene phenocrysts and document each one. Phenocrysts were located and identified by their distinct cleavage and darker coloration in plain polarized light. Each pyroxene located would be documented and studied, looking for things such as melt inclusions or abnormal zoning. Despite many clinopyroxenes being present, only the highest quality and easiest to distinguish were picked out. Clinopyroxenes that could not be seen on 4x or 10x magnification in the microscope were not analyzed, and therefore not described in this paper.

RESULTS

Midfell Samples

As mentioned prior, the Midfell samples are thin sections taken from pillow basalts. The thin sections contain both the surrounding basalt lithic composition and the interior pillow glass. The composition of the surrounding basalt is made mostly of microphenocrysts of plagioclase and glassy material. The plagioclase crystals appear stubby and subhedral, and do not exceed 0.1 mm. Overall, the coloration appears dark gray-brown, and the zoning in the plagioclase can be seen at more precise microscope lens sizes. Vesicles that are 0.2 - 1 mm in size occur in this portion of the basalt. The pillow glass composition is a lighter brown coloration. It contains vesicles that range from 0.1 - 9.8 mm in size. Large xenoliths are also present in a couple of samples and are dominated mostly by plagioclase and clinopyroxene (**Figure 2**).

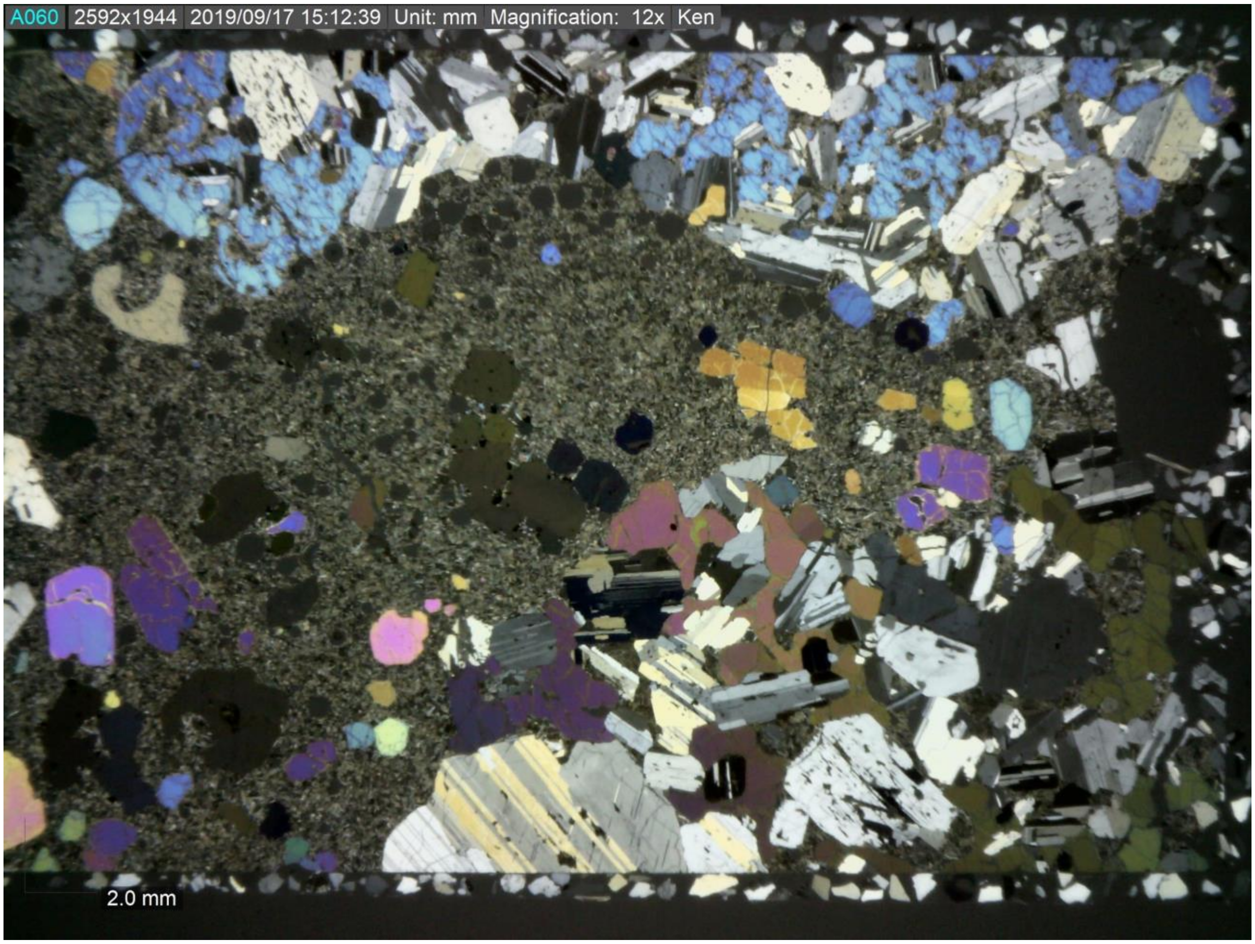

Figure 2 - A full view of a Midfell xenolith thin section. Photo taken by Ken Peterman, 2017.

Throughout both the exterior basalt and the glass formations, phenocrysts of olivine, plagioclase, and clinopyroxene are present. The olivines are mostly euhedral, but some skeletal texturing is present (**Figure 3**), indicating a very quick formation time. These olivine phenocrysts range in size anywhere from 0.3 mm to around 4 mm in size. While most commonly occurring by themselves, olivine phenocrysts are also present in some of the xenoliths. Occasionally, these olivines would contain melt inclusions or inclusions of opaque minerals such as magnetite or chromite (**Figure 4**).

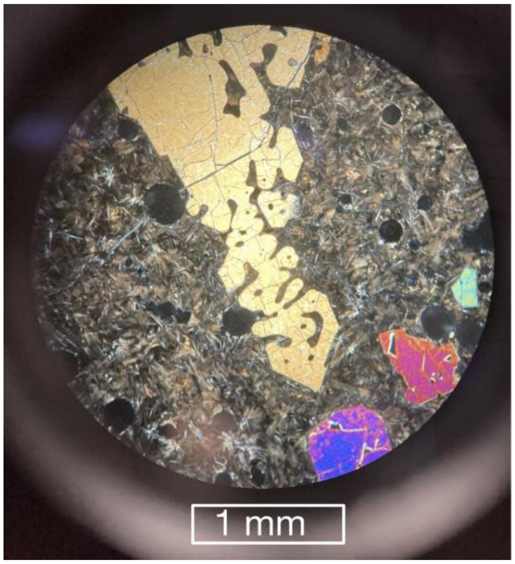

Figure 3 - Skeletal olivine.

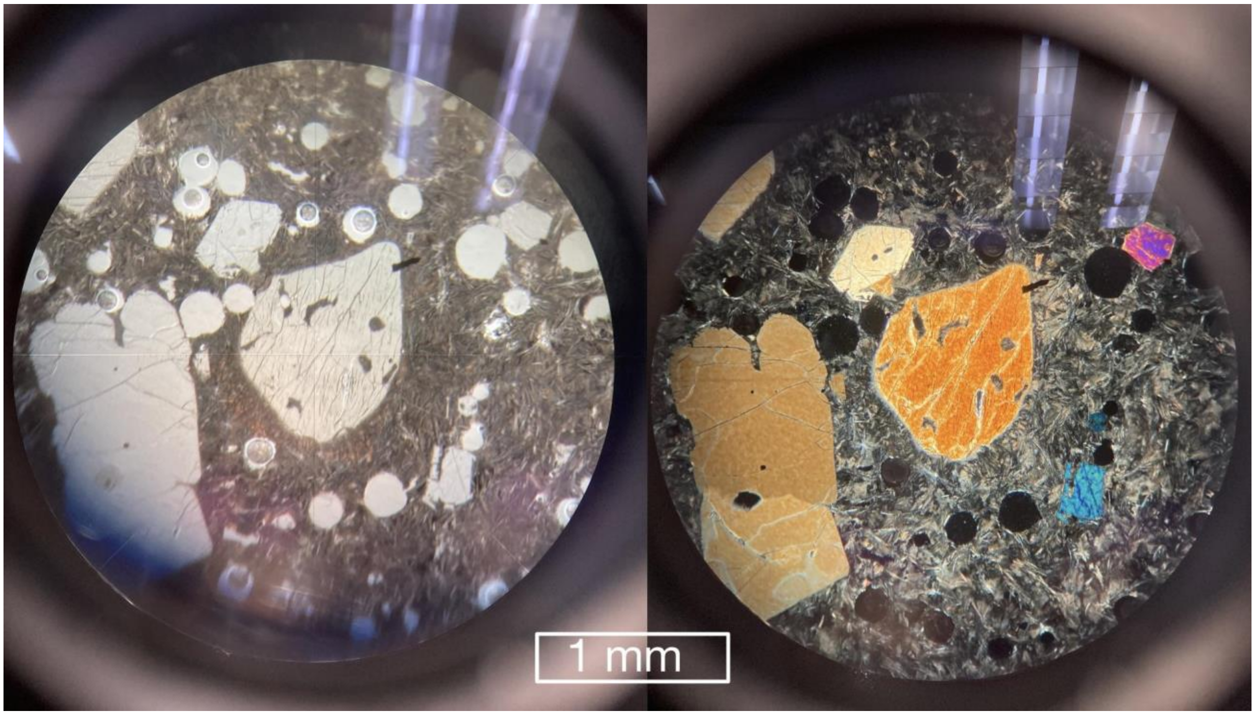

Figure 4 - A clinopyroxene with first order orange birefringence is shown in the middle. Surrounding it are olivines. The olivine to the northwest of the clinopyroxene contains small melt inclusions.

Despite composing most of the matrix, there are also isolated plagioclase phenocrysts present in the Midfell samples. These occur as stand-alone phenocrysts, or commonly part of xenolith fragments. As stand-alone phenocrysts, the plagioclase range in size from 0.5 - 2.5 mm, are euhedral, and exhibit polysynthetic twinning. However, these isolated phenocrysts are uncommon. In the xenoliths, plagioclase sizes range from 0.5 - 4 mm and are euhedral. These can contain melt inclusions and exhibit polysynthetic twinning (**Figure 5**).

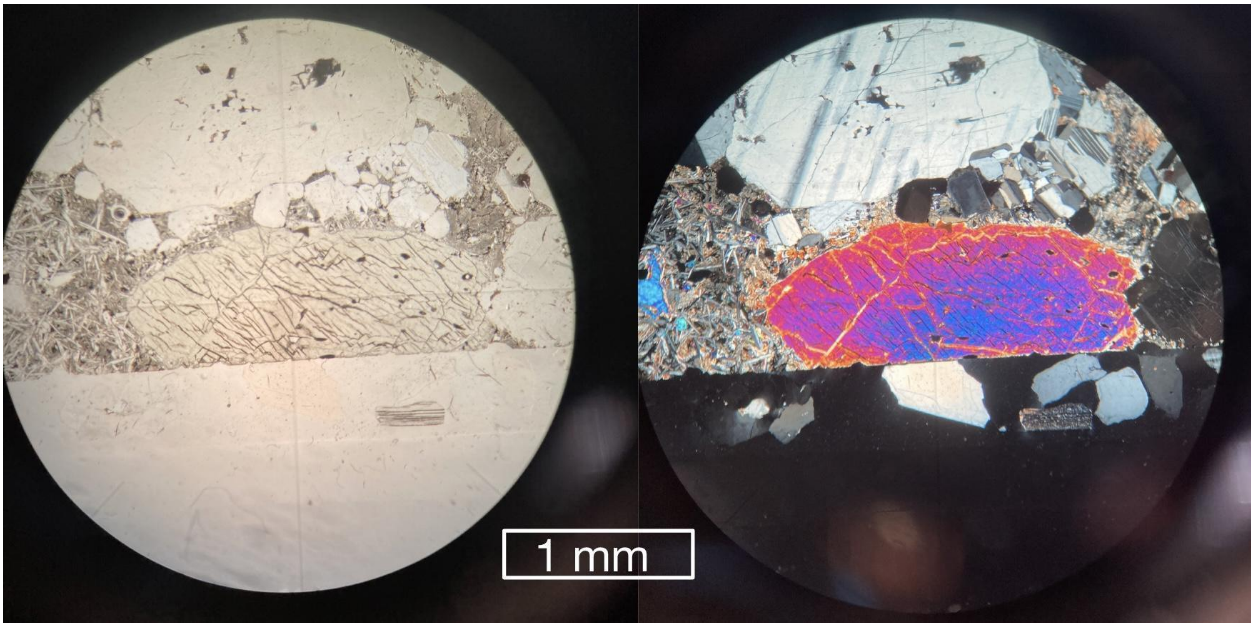

Figure 5 - A clinopyroxene with first order red and purple birefringence is shown at the bottom. Surrounding it are plagioclase phenocrysts.

The clinopyroxenes in the Midfell samples occur both stand-alone and present in xenolithic fragments. Many of the phenocrysts are present within the basaltic matrix, rather than the glass matrix. Only one phenocryst was documented to have appeared in the pillow glass portion of the samples. Clinopyroxenes that occur on their own in matrix tend to be broken and display a fractured texture (**Figure 6**). The average size of these independent clinopyroxenes is between 1 to 6 mm. Most phenocrysts are subhedral, with an unusual roundness that is unexpected from clinopyroxene structure. Some contain what look to be melt inclusions, but due to the number of breaks in the phenocrysts it is hard to determine whether they are true melt inclusions or glass that has been fed through channels leading outside the phenocryst (**Figure 7**). However, every clinopyroxene has very distinct cleavage planes visible, despite the fractured appearance. Some phenocrysts are twinned, but distinct zoning is not present in any of the Midfell samples (**Figure 8**). Occasionally, clinopyroxenes contain olivine or opaque mineral inclusions (**Figure 9**).

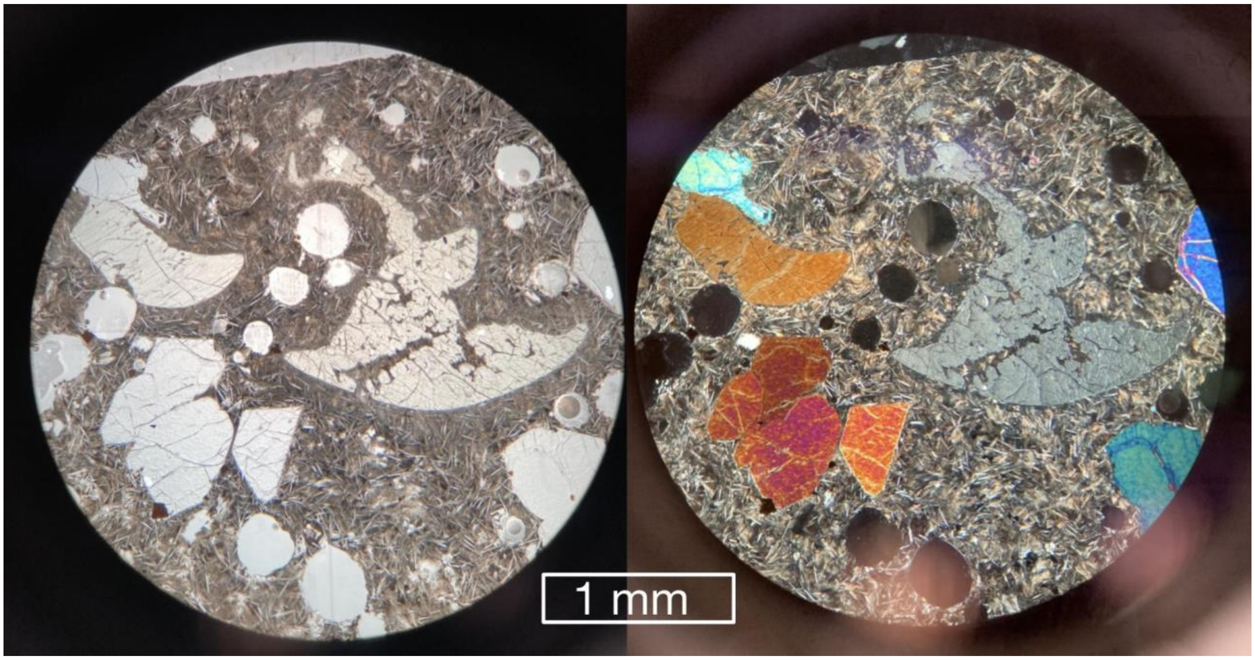

Figure 6 - A clinopyroxene displaying gray birefringence is located in the center right, surrounded by olivine phenocrysts.

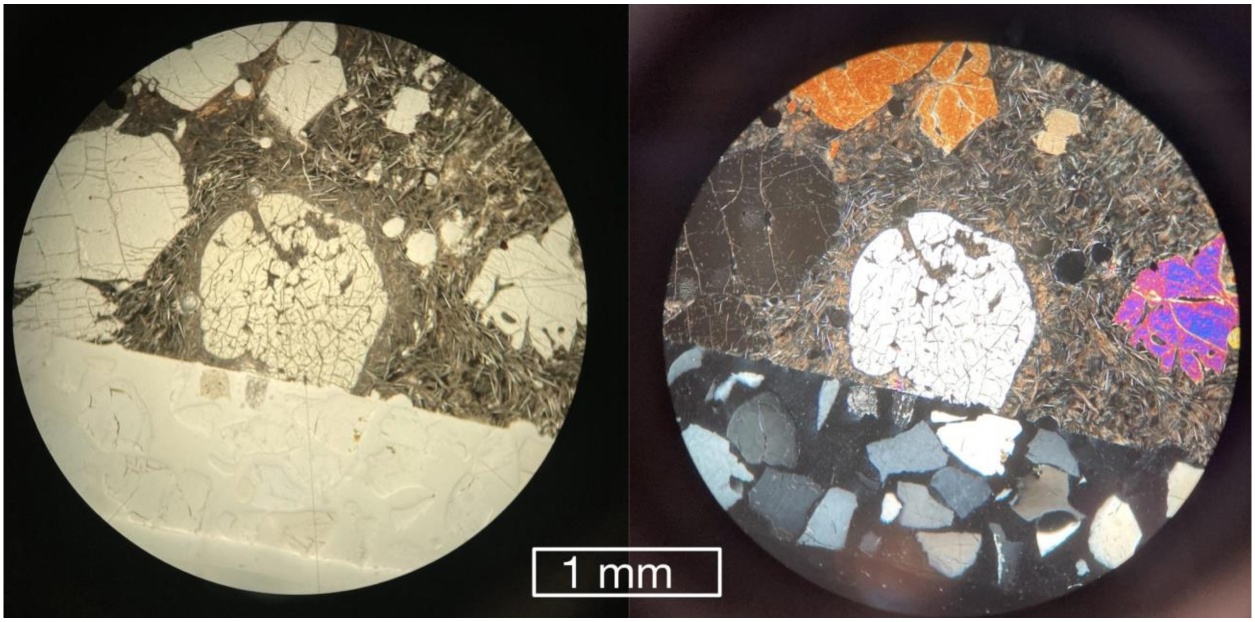

Figure 7 - A clinopyroxene with gray birefringence and matrix-filled fractures.

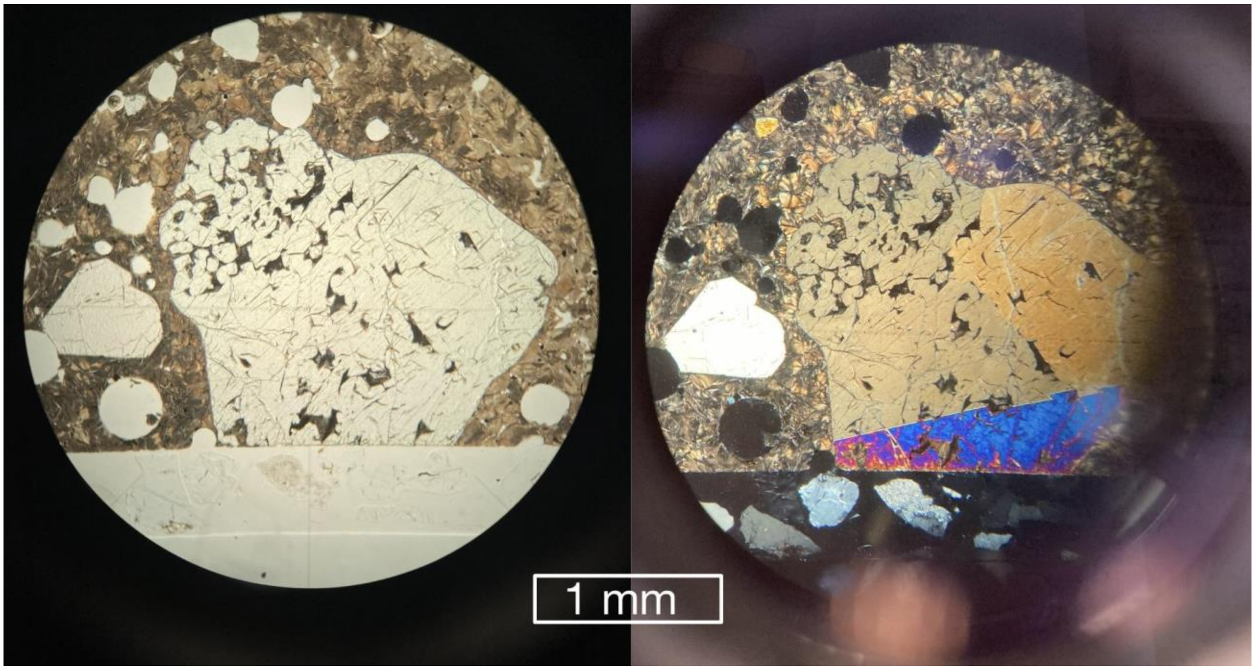

Figure 8 - A clinopyroxene with first order interference and twinning.

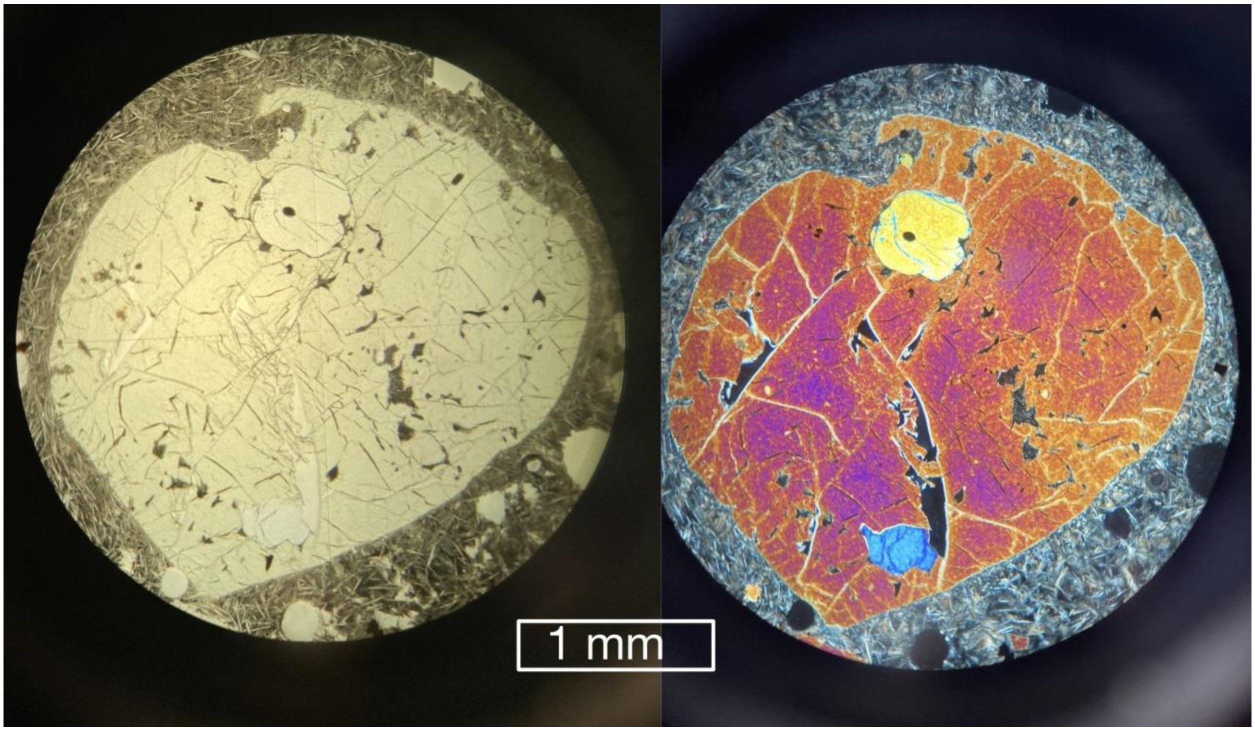

Figure 9 - A clinopyroxene with first order orange interference and an olivine inclusion.

In the xenoliths, the clinopyroxenes are less fractured. Most of them are fully in-tact and euhedral, but still display a partial roundness, much like the independent clinopyroxenes. They also tend to occur as massive formations, rather than isolated phenocrysts. It appears that they fill the gaps between large plagioclase phenocrysts in the sample (**Figure 10**). Non-massive phenocrysts range between 0.5 - 1.5 mm. As per usual, they tend to display distinct cleavage planes.

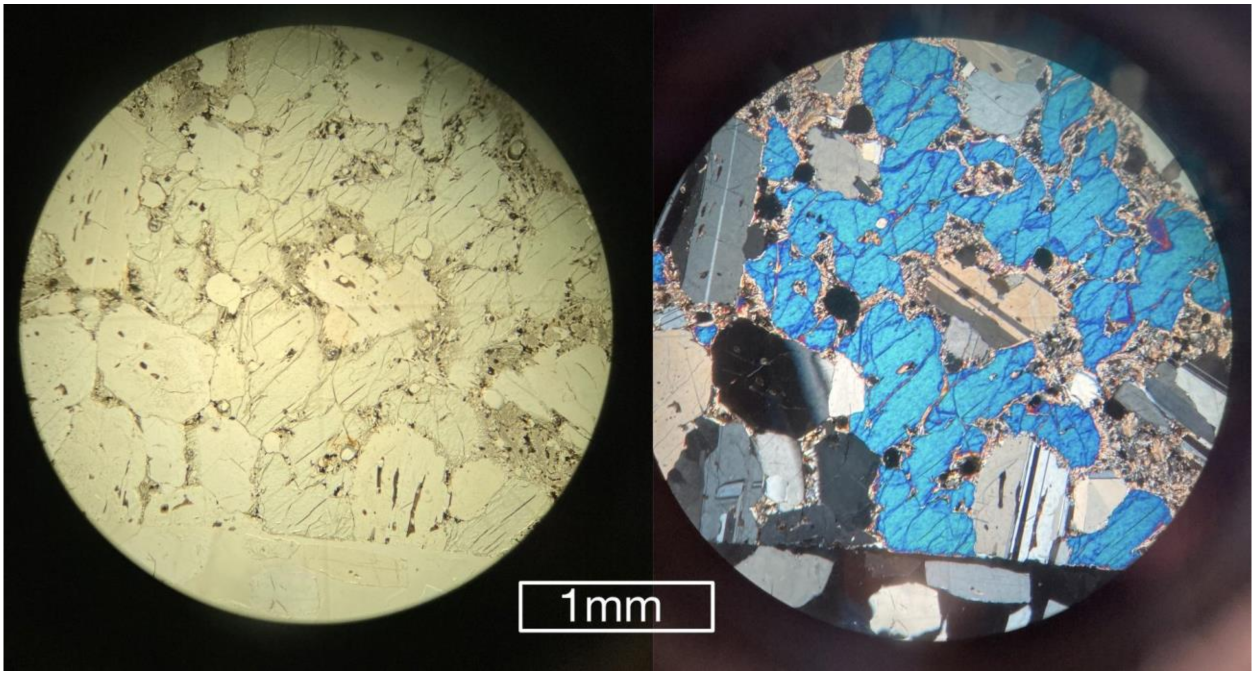

Figure 10 - Massive clinopyroxene with first order blue interference is shown in the center. It is surrounded by plagioclase phenocrysts.

Sandfell Samples

The samples from Sandfell are quite different compared to the Midfell samples. Despite being in quite a similar tectonic setting, these samples are much glassier than the Midfell samples. The overall appearance is quite like the pillow glass seen in the former samples, but the phenocrysts are not nearly as large, and vesicles are present in great numbers. These vesicles range in size from 0.5 - 3 mm in size. Microphenocrysts of plagioclase are present in the sample and do not exceed 0.1 mm in size. Glomeroporphs are common in these samples, usually centered around plagioclase phenocrysts (**Figure 11**).

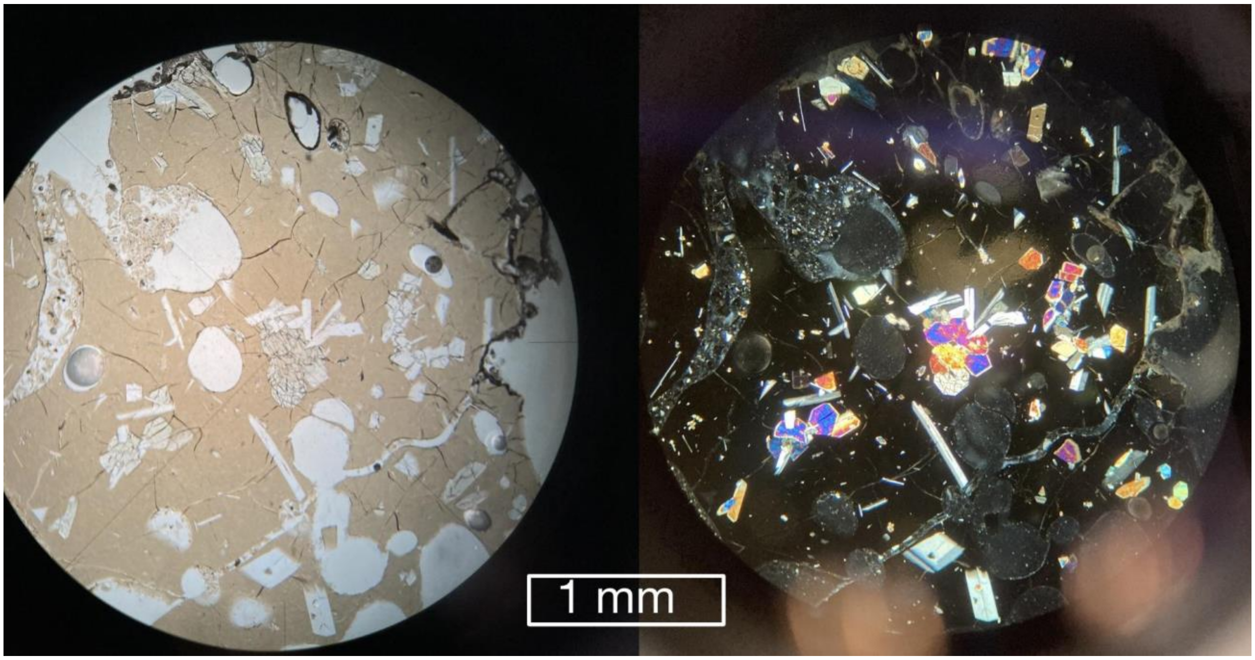

Figure 11 - Multiple glomeroporphs present, consisting of plagioclase and clinopyroxene.

Olivines present in this sample tend to be euhedral and range from 0.1 - 0.8 mm. They tend to be very euhedral and can contain melt inclusions up to 0.05 mm and small opaques within them. While most commonly occurring on their own, occasionally they will be present in the glomeroporphs.

Plagioclase are most commonly present as individual phenocrysts, many of which contain unique texturing. Most plagioclase contain polysynthetic twinning. Some of the plagioclase contain distinct zoning cores that are separated from a rim, and sometimes there are multiple rim layers (**Figure 12**). Plagioclase phenocrysts also commonly contain melt inclusions (**Figure 13**).

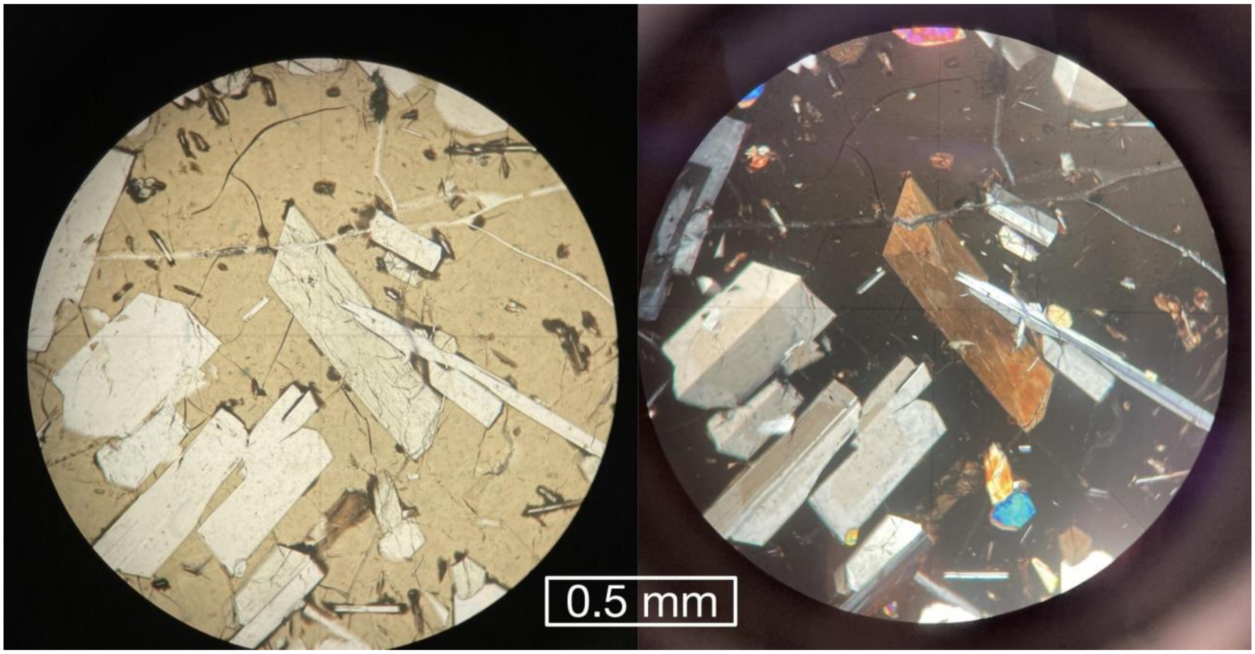

Figure 12 - Hourglass zoned clinopyroxene surrounded by zoned plagioclase phenocrysts.

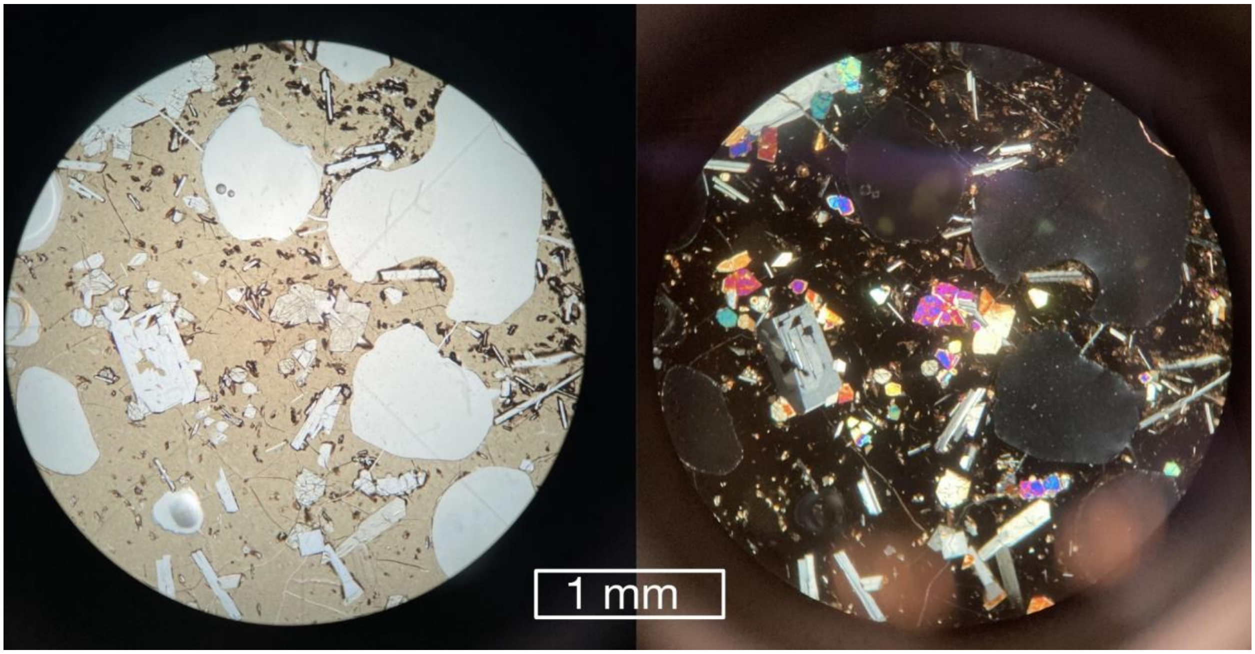

Figure 13 - Glomeroporph next to a plagioclase phenocryst containing multiple melt inclusions, as well as zoning.

The clinopyroxenes in this sample are quite diverse. Their size range is between 0.1 - 0.5 mm and are euhedral. They occur as individual phenocrysts, but also are the primary mineral present within the glomeroporphs. These are usually quite small, and do not exceed 0.2 - 0.3

mm. The clinopyroxenes in the glomeroporphs do not display any textures, such as zoning or twinning.

Most individual clinopyroxenes have distinct cleavage visible and are distinctly darker colored than the olivines in plain polarized light. Some of the phenocrysts present in the samples are twinned (**Figure 14**), and some contain plagioclase phenocrysts that cut through the clinopyroxenes (**Figure 15**). Nearly all the phenocrysts contain some form of zoning, and some clinopyroxenes have a distinct separation between a core and a rim (**Figure 16**). Occasionally, the phenocrysts exhibit hourglass zoning, but it is sometimes only partial (**Figure 17**).

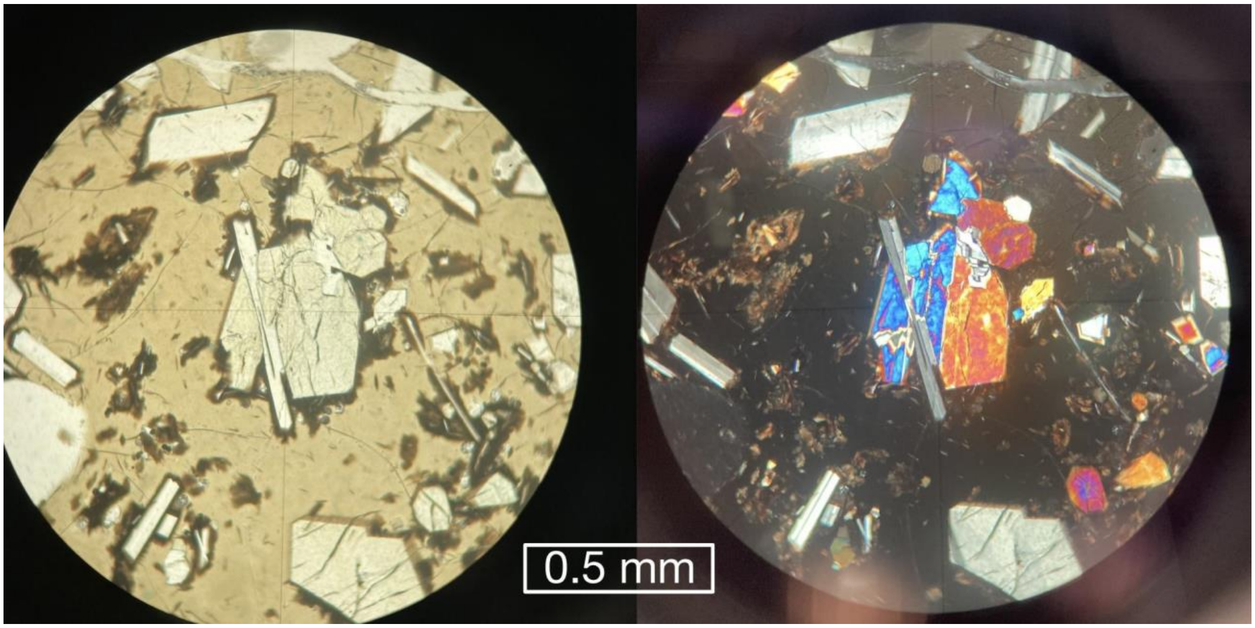

Figure 14 - Twinned clinopyroxene phenocryst with a plagioclase inclusion.

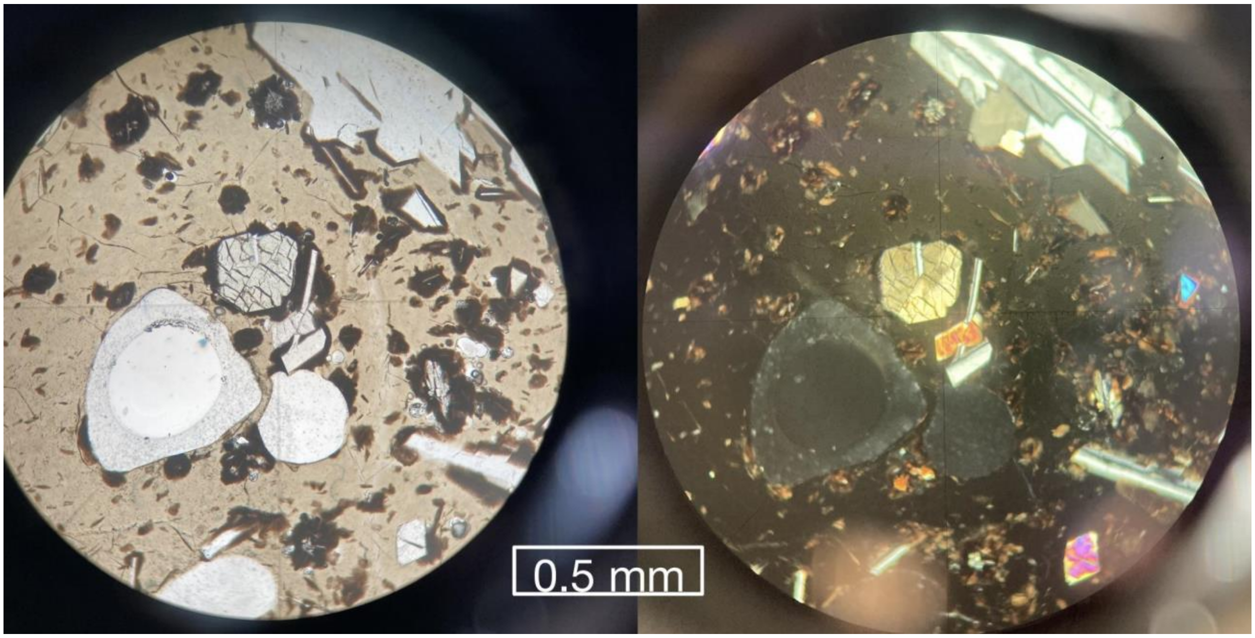

Figure 15 - Clinopyroxene phenocryst with a plagioclase inclusion.

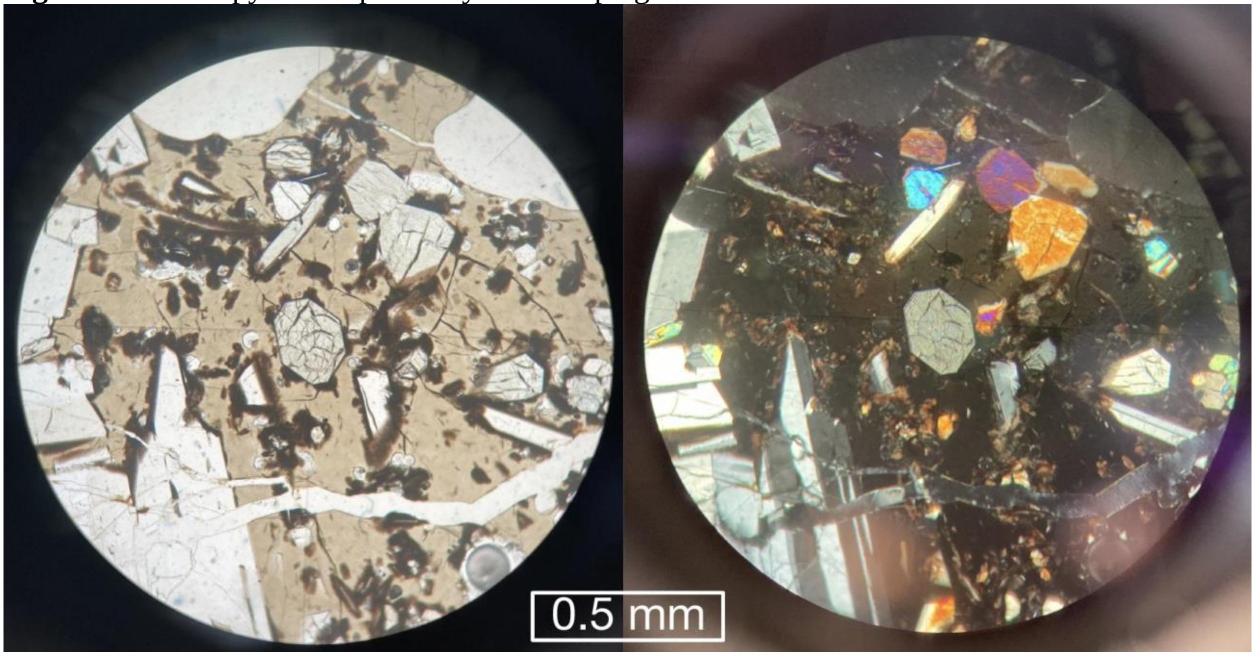

Figure 16 - Clinopyroxene phenocryst containing zoning. While subtle, the interior birefringence is a slightly different color than the rim.

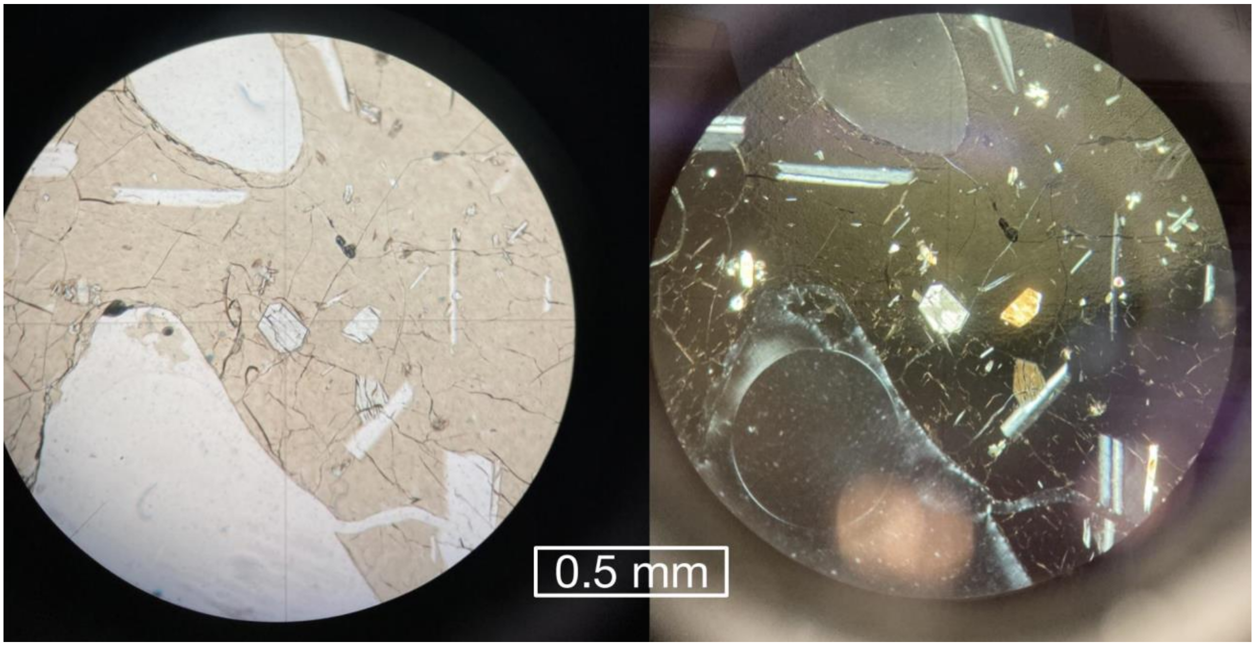

Figure 17 - Clinopyroxene phenocryst exhibiting hourglass zoning.

Other Location Samples

The sample from Fagradalsfjall was a basalt sample that contained a xenolith in it (**Figure 18**). The surrounding matrix is much like that of Midfell, with plagioclase microphenocrysts no larger than 0.1 mm. Some individual phenocrysts of plagioclase between 0.7 - 1 mm are present in the matrix. There is also a 1 mm glomeroporph composed of plagioclase and olivine. The xenolith itself is composed primarily of plagioclase, with some phenocrysts of olivine and clinopyroxene present (**Figure 19**).

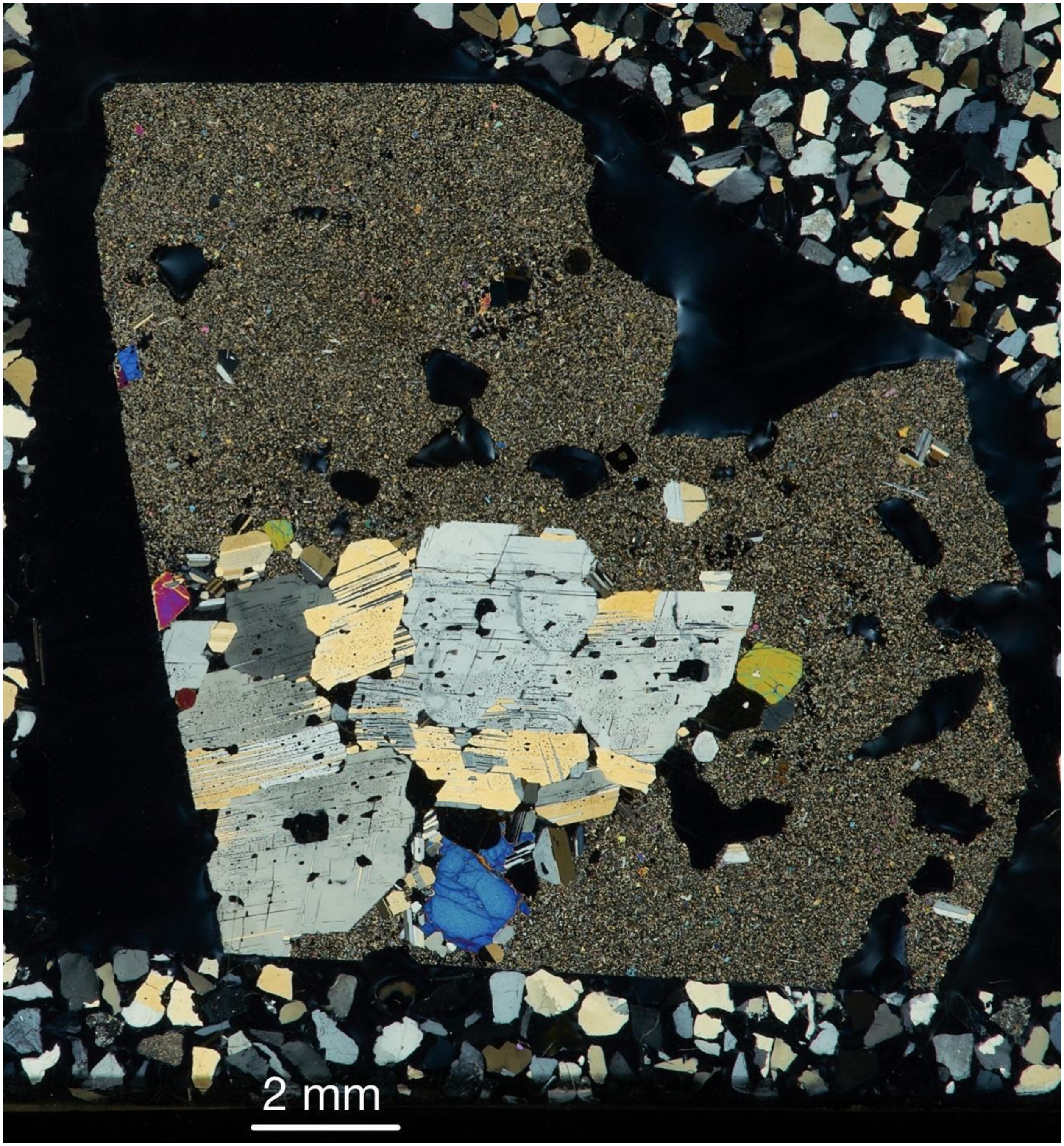

Figure 18 - Thin section view of the Fagradalsfjall basalt sample. Photo taken by Ken Peterman, 2023.

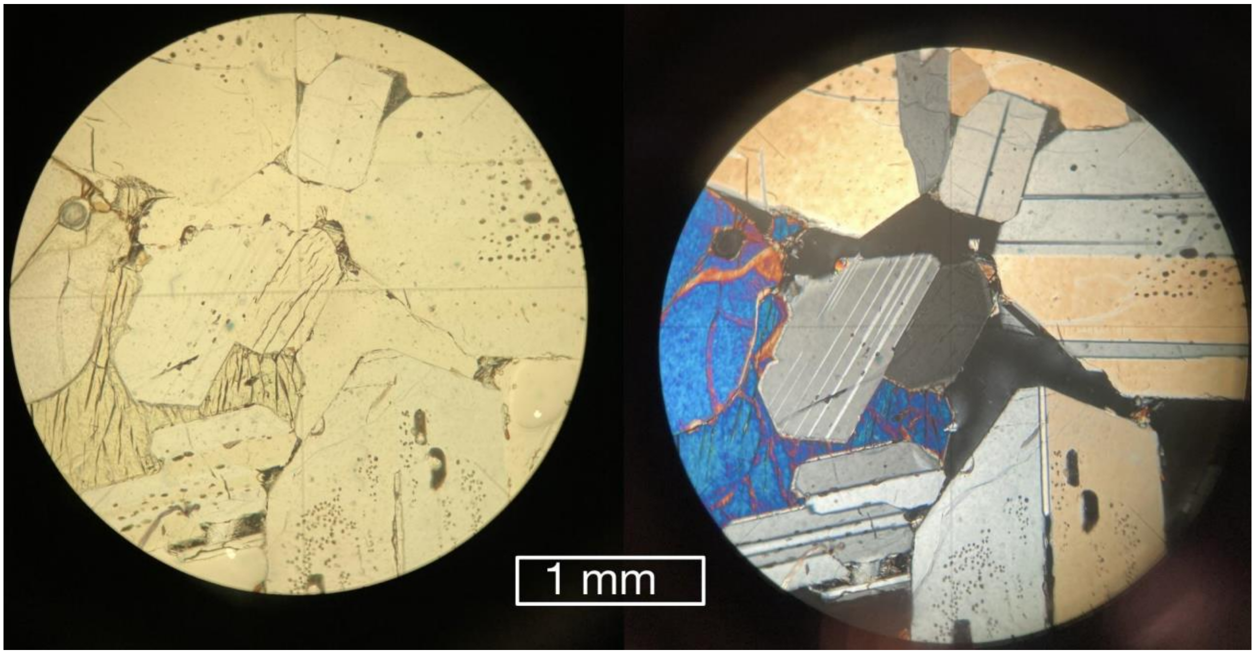

Figure 19 - Close-up view of the composition of the xenolith. Clinopyroxene and plagioclase can be seen in this view.

In the xenolithic olivines, inclusions of plagioclase can be seen. These olivines range from 0.5 - 1.2 mm in size and are euhedral. The plagioclase present in the xenolith is much larger, ranging from 0.3 - 6 mm in size. These phenocrysts contain large melt inclusions, as well as polysynthetic twinning. Inclusions of olivine are also present inside of the larger plagioclase phenocrysts. These plagioclase crystals also contain first order orange birefringence colors.

Clinopyroxene phenocrysts occur individually, but also as massive formations in this xenolith. The individual phenocrysts measure between 0.5 - 1 mm and have visible cleavage planes. They contain inclusions of olivine and plagioclase (**Figure 20**). The massive clinopyroxene formation also displays visible cleavage planes to a lesser degree. Contrary to the individual phenocrysts, it does not contain any inclusions.

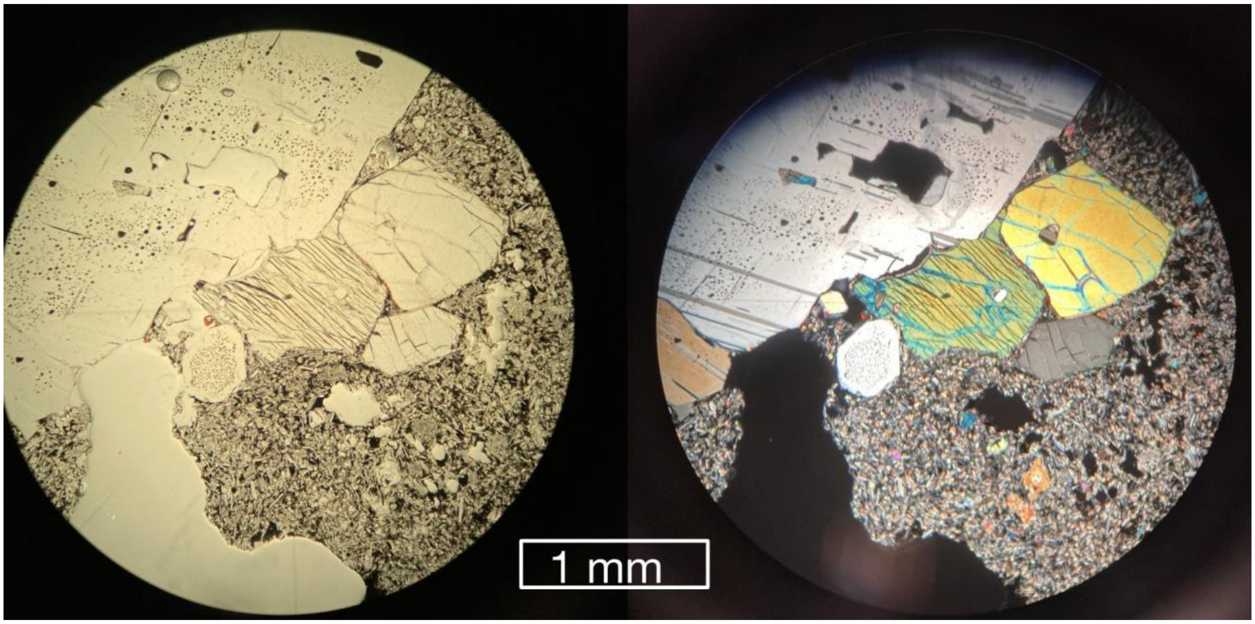

Figure 20 - Clinopyroxene present in the center, exhibiting first order yellow and green birefringence, with distinct cleavage planes visible. The plagioclase to the northwest contains many melt inclusions, and the olivine to the east contains a plagioclase inclusion.

The pillow basalt sample from Geitafell is a lot sparser and does not contain xenoliths. The matrix is mostly glassy, with many microphenocrysts and phenocrysts of plagioclase. The microphenocrysts do not exceed 0.01 mm, and the matrix phenocrysts range from 0.03 - 0.6 mm in size. Most of these crystals are euhedral and very elongated. Many vesicles that range from 0.3 mm - 4 mm are present throughout the sample.

There are no large standalone plagioclase phenocrysts outside of the matrix, but olivine phenocrysts are plentiful. They range from 0.3 - 1 mm in size, and often contain melt inclusions. They are also present as microphenocrysts within the matrix, at sizes less than 0.01 mm. The only clinopyroxenes present in the Geitafell sample are present within a glomeroporph. Subhedral clinopyroxene phenocrysts are surrounding some smaller plagioclase phenocrysts (**Figure 21**).

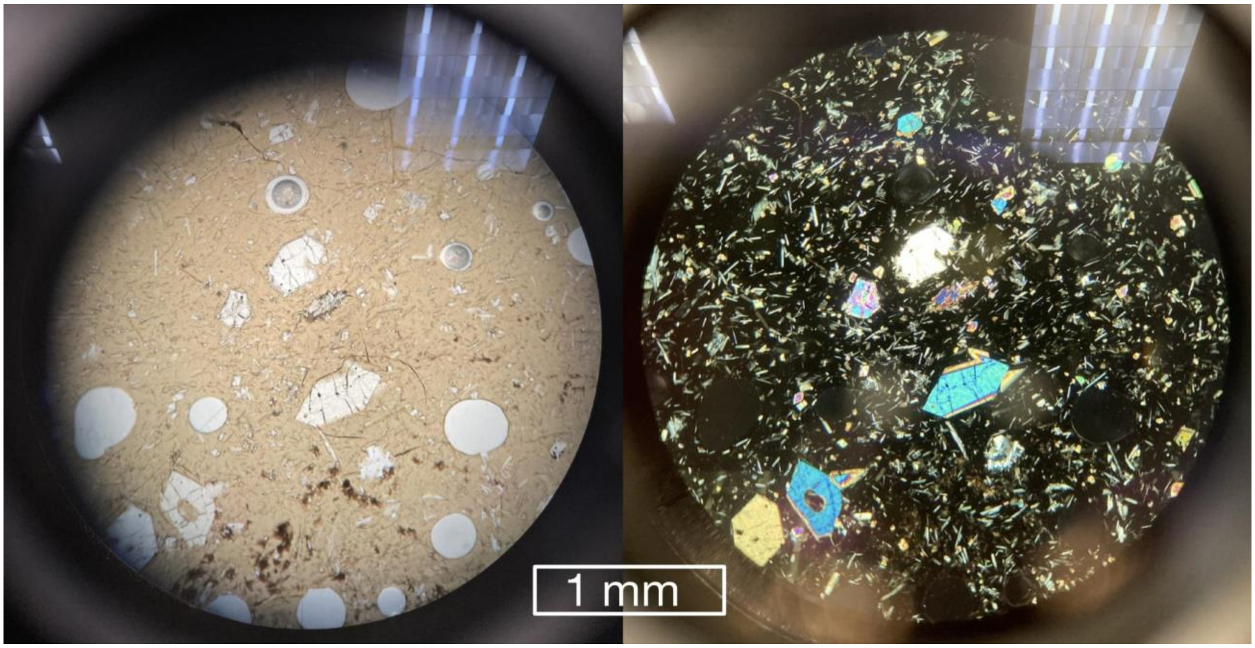

Figure 21 - Glomeroporph present in the middle. It is composed primarily of clinopyroxene and plagioclase.

Lastly, the sample from the Southwest Reykjanes Peninsula contains a slightly different composition. Its matrix is still glassy, but contains many microphenocrysts of olivine, which are less than 0.01 mm in size. These olivine microphenocrysts are euhedral and are stubby in shape. Plagioclase phenocrysts also exist as part of the matrix and occur between the sizes of 0.1 - 0.5 mm in length. They appear long and very thin and are euhedral.

The Southwest Reykjanes sample does contain standalone plagioclase phenocrysts as well. These phenocrysts range in size from 0.5 - 2 mm. They display characteristic polysynthetic twins and are euhedral in nature. They also are part of the composition of the few glomeroporphs present in this sample. Olivine phenocrysts are not very present in this sample, but a few have been observed between the sizes of 0.1 - 0.8 mm. They are euhedral to subhedral. Clinopyroxene phenocrysts are present in this sample as well, but they only exist in a glomeroporph. The phenocrysts that are present show various zoning, including hourglass zoning. They are subhedral and range in size from 0.1 - 0.7 mm in size. Within the glomeroporphs, the clinopyroxenes contain plagioclase crystals within them.

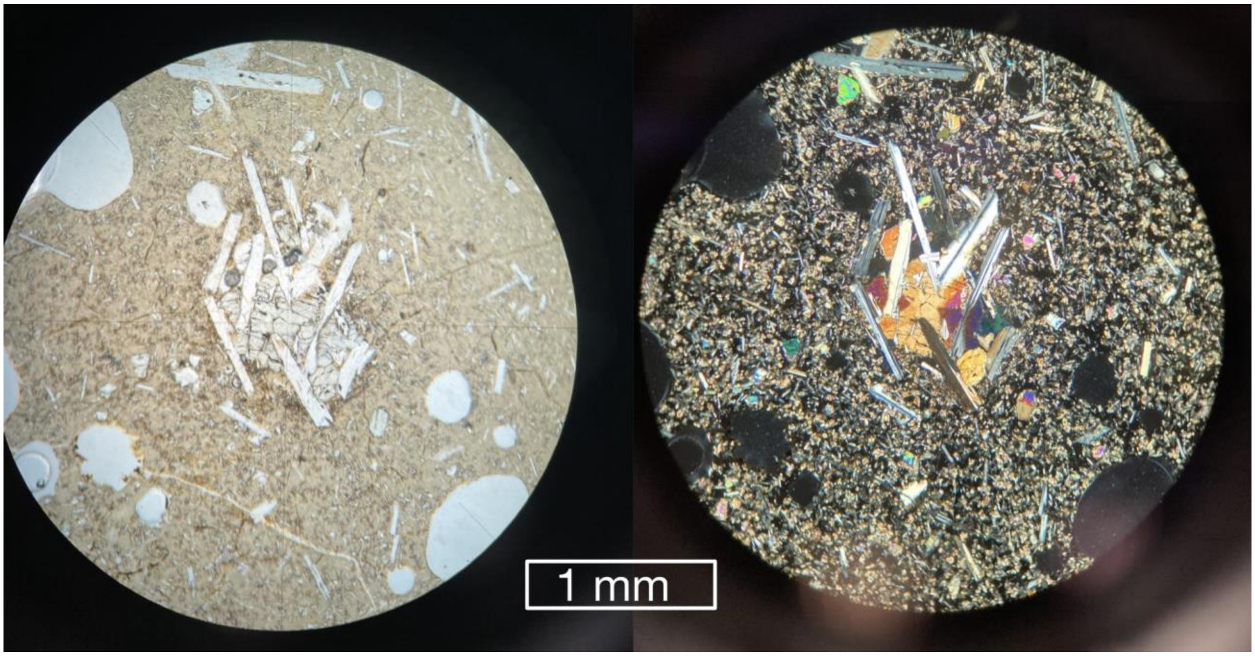

Figure 22 - Glomeroporph consisting of plagioclase phenocrysts surrounding a few clinopyroxene phenocrysts.

DISCUSSION

Midfell and Sandfell

Overall, the texture of the clinopyroxenes in the Midfell samples appear to be evidence of magma mixing. Unless part of a xenolith, the phenocrysts are quite broken up and are unusually rounded (See **Figures 6-8**). While some do contain what appear to be melt inclusions, it is more likely that the glass intruded due to a fracture that connects externally to the crystal. A paper done by Tronnes in 1990 studies the petrography of Midfell samples. He identified the clinopyroxenes as displaying evidence of resorption (Tronnes 1990).

This is further supported by the fact that clinopyroxenes in the Midfell samples contain inclusions of euhedral minerals like olivine or opaque minerals. The simultaneous presence of euhedral and subhedral minerals indicates that two different kinds of source materials must be present. However, since the fractured clinopyroxenes are individual phenocrysts and not always part of xenoliths or other structures, this points to fluid magma mixing. Old magmatic material left over in a magma chamber that cannot get enough pressure to make it to the surface starts to cool and form clinopyroxenes. When a new batch of magma comes into the magma chamber, it mixes with the old magma, resorbing any sort of crystals formed in the previous batch. This new mixed magma gains enough pressure to erupt into the pillow basalts present in the Midfell location. These basalts contain newly formed minerals such as plagioclase and olivine, while still containing traces of the primitive magma that contained clinopyroxenes.

Sandfell, on the other hand, appears quite different from the petrography witnessed in the Midfell samples. Many of the clinopyroxenes are quite euhedral and display noticeable zoning. Sector zoning, such as hourglass zoning, results from the clinopyroxenes being out of equilibrium while they are being formed. In other words, clinopyroxene zoning is characteristic of a magma composition change. This indicates that these phenocrysts are forming via undercooling before they reach the surface (Ubide et. al., 2019). However, the Sandfell samples are surface level pillow basalts that have erupted. This means that it is possible a new batch of magma mixed with the original batch that formed the clinopyroxene, pushing the magma to the surface and ending up with zoned clinopyroxene phenocrysts in erupted basalts.

Other Locations

All these locations share the similar feature that clinopyroxenes do not occur as isolated phenocrysts in the matrix. In both the Geitafell and Southwest Reykjanes Peninsula, the clinopyroxene phenocrysts existed solely as part of glomeroporphs, intertwined with plagioclase phenocrysts (**Figure 21-22**). The Fagradalsfjall clinopyroxenes existed as part of a resorbed xenolith present within the sample (**Figures 18-20**). The reason that only one sample of each of these locations was analyzed was because these were the only samples that contained clinopyroxenes. Throughout all these three locations, clinopyroxenes are not a common mineral occurrence.

Fagradalsfjall does not contain sufficient evidence to prove magma mixing occurred. There are glomeroporphs present, but they contain material that is seen in the matrix, as well as other individual phenocrysts. The presence of xenoliths also does not mean that magma mixing has occurred, it just proves that the magma from Fagradalsfjall is interacting with the host rock surrounding it. Further research is required to prove that magma mixing is occurring at this location.

At the Geitafell and Southwest Reykjanes locations, the presence of glomeroporphs implies some level of magma mixing. Glomeroporphyritic clots are formed through the process of synneusis. This process involves a crystal-poor melt encountering magma that contains phenocrysts of plagioclase that pick up more minerals as the form in the magma (Gogoi & Saikia, 2018). This explains why the Geitafell and Southwest Reykjanes do not have an abundance of large crystals like Midfell. They have undergone a magma mixing process that was able to produce glomeroporphs that contained clinopyroxenes. However, the crystal-poor melt that the magma was exposed to did not contain clinopyroxene, hence why they are only present in glomeroporphs.

CONCLUSIONS

To understand magmatic processes, it is crucial to understand the petrography of an igneous rock. Textures within minerals that occur in these rocks can point towards the magmatic history of the rock. Basalt samples from Iceland were visually analyzed under petrographic microscopes. These samples were taken from various locations around the Southwest Reykjanes Peninsula, including Midfell, Sandfell, Geitafell, Southwest Reykjanes, and Fagradalsfjall. To get an understanding of the processes that formed these basalts, clinopyroxene phenocrysts were analyzed in these samples. Clinopyroxenes contain useful features like zoning and are abundant in many kinds of igneous rocks.

Despite the many various compositions and textures of all these localities, all of them except for Fagradalsfjall have one thing in common. Clinopyroxene states and interactions with other minerals in these samples strongly point towards magma mixing being a driver for volcanic eruptions on the Reykjanes Peninsula. Magma mixing is known to be a trigger for volcanic eruptions. Possible evidence for magma mixing can be seen from Midfell, Sandfell, Geitafell, and Southwest Reykjanes. This would explain why volcanic activity is happening so often. With the location along the rift zone, new batches of magma can easily make their way to the surface, replenishing magma chambers that lack the pressure to erupt.

While petrographic analyses are a good starting point, they lack quantitative data about composition. To make this thesis stronger, element compositional data of clinopyroxenes or other minerals would be needed. Petrographic analyses are limited to interpretation and comparison of other known data. However, unseen anomalies such as unusual amounts of certain rare earth metals cannot be seen with the human eye, even under a petrographic microscope. Having electron microprobe data would have been much stronger evidence to support the ideas in the discussion section of this thesis.

RECOMMENDATIONS FOR FUTURE WORK

Most of this thesis revolved around the clinopyroxene analysis in these various samples. It did not consider much of the other minerals present. Future research could be done by looking more in-depth into other types of minerals, such as plagioclase or olivines. This could lead to further understanding of the relationships between these minerals in the lavas.

This thesis also only focused on the physical appearance of the thin sections. It was planned to have an analysis of specific clinopyroxenes via electron microprobe data, but due to time constraints it was unsuccessful. However, this project set up the data collection on clinopyroxenes for future endeavors. Understanding the chemical composition of these phenocrysts and their surroundings can provide deeper understanding to the various lavas present in Iceland. Of course, this extends to other minerals present. Analysis of olivines and plagioclase phenocrysts present would also benefit this understanding.

Lastly, expanding the locations observed could provide even more insight. Only a select few locations were chosen for this project, and of those only two were looked at in-depth. Other volcanic localities are plentiful, and samples have been collected from areas such as Undirhlidar and Haleyjarbunga. Samples from deep sea locations off the shore of Iceland have also been procured and would be a valuable project to investigate.

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