Geologic History and Petrology of the Tobago Volcanic Group*

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Abstract

The pre-Cenozoic rocks of Tobago, consists of three East-West trending lithologic belts that cut across the island: the North Coast Schist (NCS), the Plutonic Suite, and the Tobago Volcanic Group (TVG). The geology of the Tobago Volcanic Group has largely been categorized as undifferentiated. In an attempt to understand the geological processes and/or events that culminated in the formation of this volcanic group, the southern part of Tobago was mapped and samples were taken from specific sites which then underwent petrographic analysis. The petrology of the various volcanics show some interesting features, some of which allowed certain conclusions to be drawn about its geologic history, and in doing so, may provide some limitations to various tectonic models of the southern Caribbean. The general petrology of the area gives rise to the conclusion that the area consists of basaltic flows with different eruption times and magmatic compositions. The volcanics were then subjected to very low grade metamorphism and some hydrothermal alteration. Hydrothermal circulation during burial of thick lava successions may have led to the deposition of calcite amygdals in the basalt vesicles. Some of the olivine and or augite and even “skeletons” of the aforementioned minerals were replaced or being replaced by chlorite and then calcite. The numerous mineral replacements indicate that the system is still trying to equilibrate. The quantity of these amygdals and level of hydrothermal alteration can be traced across the volcanic group. This represents a vital clue towards the geologic processes that shaped this part of the Tobago Volcanic Group. This paper will show the petrology of the TVG as a preliminary interpretation of the geology of the area.

GEOLOGIC HISTORY AND PETROLOGY OF THE TOBAGO VOLCANIC GROUP

Aim:

The aim is to map the Tobago Volcanic Group to obtain the Geologic history and to undertake a petrographic analysis of the rock samples to identify variations in their compositions.

Rationale:

- Foundation for more research
- Expand geological information database of the island
- Knowledge of the geological history of Tobago provides some limitations to various tectonic models of the southern Caribbean

Methodology

- The designated area was mapped over the course of 3 weeks
- Samples were taken from specific areas where the composition of the volcanics seemed to change
- These samples' GPS locations were noted and were appropriately labelled
- Some samples were chosen to be made into thin sections and one slab was made from another sample. The thin sections underwent petrographic analysis.
- The Michel Levy extinction test was used during the analysis to determine the approximate composition of the plagioclase feldspars.

Setting

- The island of Tobago is 42km long, 12km wide at its widest point which gives it a pen like shape that is aligned in a northeast to southwest direction. It has an area of 300 square km and lies approximately 31km northeast of Trinidad
- The island consists of Mesozoic igneous and metamorphic rocks that produces a geochemical signature that indicates that these rocks evolved in an oceanic island arc
- Tobago and can be divided into three East-West trending lithologic belts that cut across the island: the North Coast Schist (NCS), the ultramafic to mafic Plutonic Suite, and the Tobago Volcanic Group (TVG)

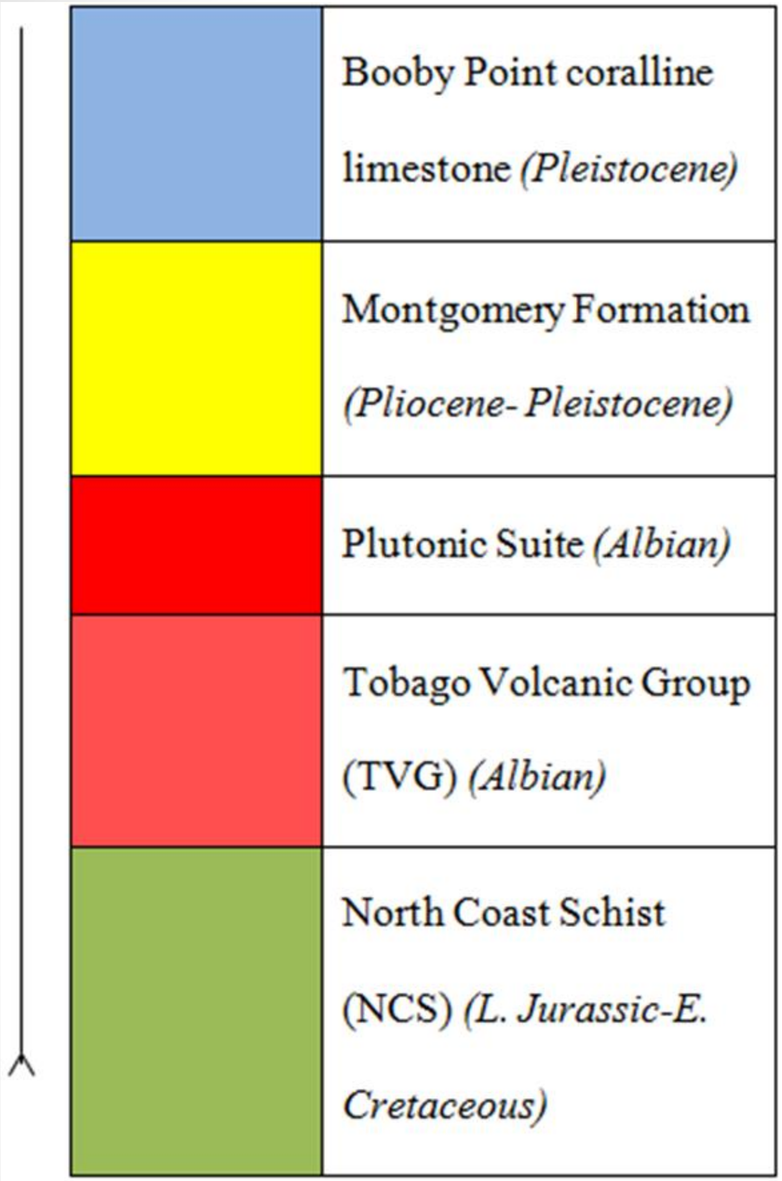


Figure 1.0 showing stratigraphic column of the relative ages of the rocks of Tobago

Northern two thirds of the island are made up of deeply eroded schists and folded igneous rocks. Together they form the oldest part of the island; the Main Ridge, which rises to a height of 580m and forms the backbone of Tobago

The Southern part of the island is dominated by sedimentary rocks (mainly coralline limestone) and parts of the Tobago Volcanic Group.

The mapped area extends from Little Rockly Bay in the South to Mt. Irvine and Blackrock in the West and up to a bit north of Plymouth to Back Bay

Study area

MAP OF TOBAGO SHOWING INSET OF THE GENERAL AREA OF STUDY

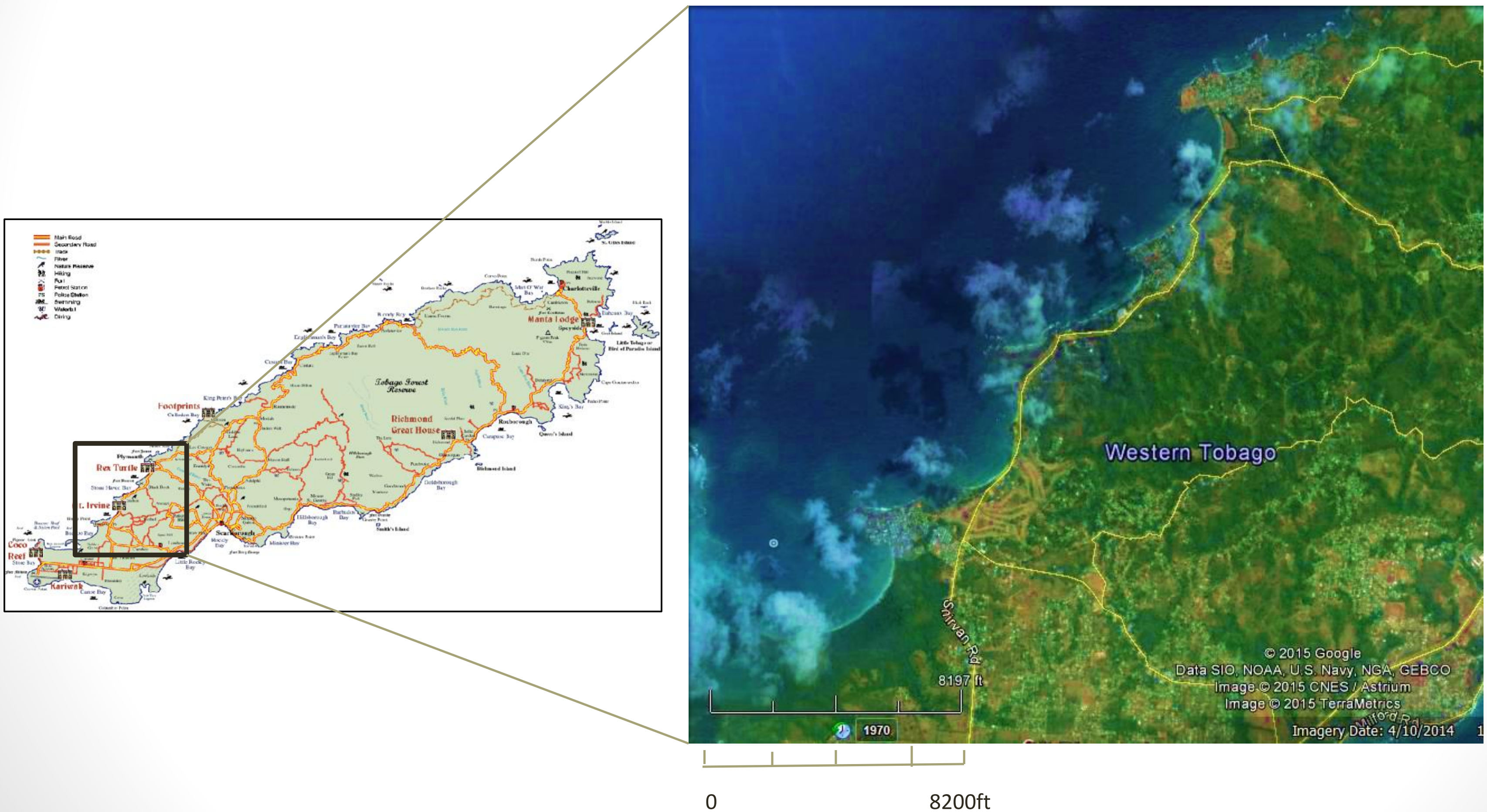
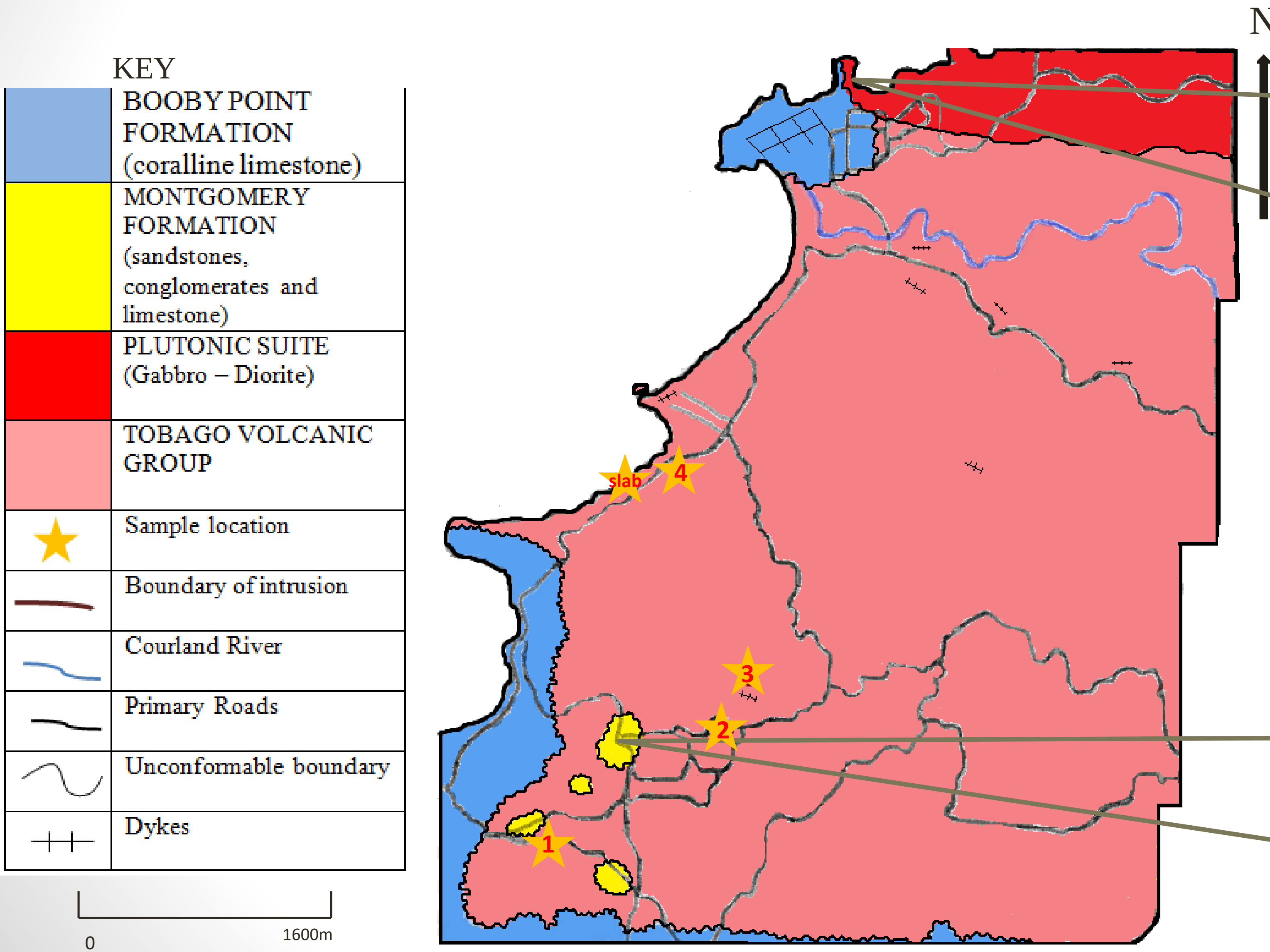


Fig 1.1 showing road map of Tobago with inset of study area. Sources: www.dicover-tt.net and Google Earth , Accessed : January 2015

Geology of the area



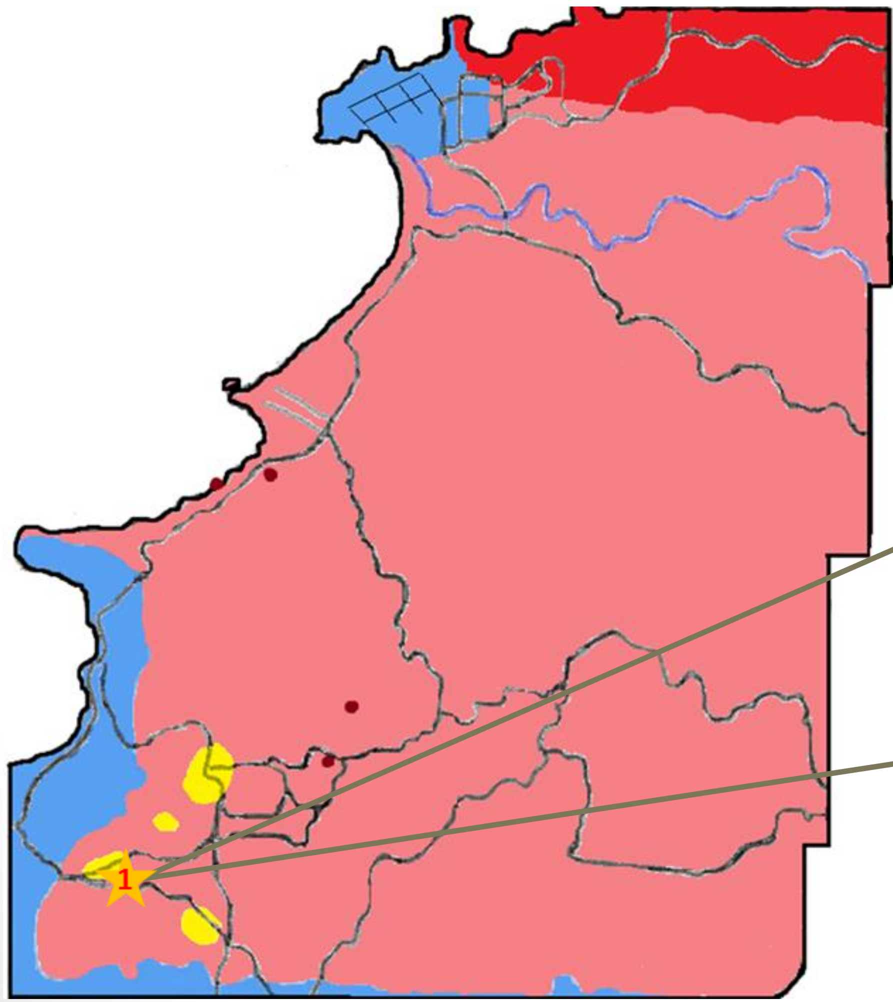
Petrology

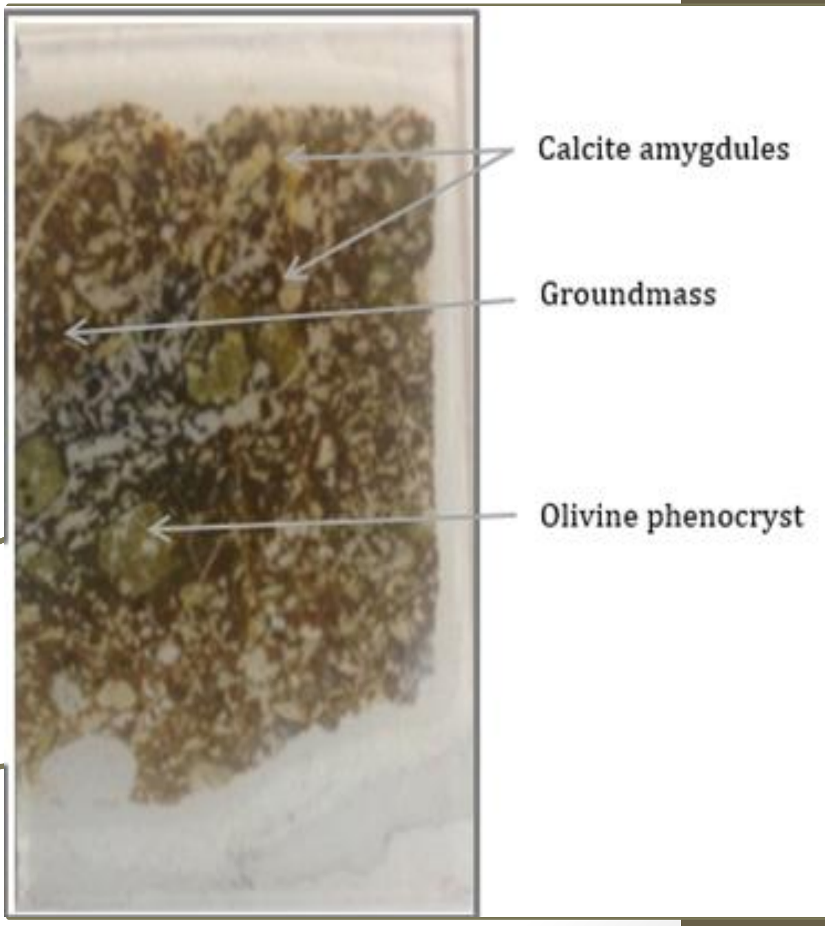
This chapter deals with petrographic observations of thin sections made from various samples collected throughout the TVG. The detailed analysis of minerals by optical mineralogy (microscopy) in thin section and the micro-texture and structure are of great importance in understanding the origin of the rock and processes that may have taken place during and after deposition.

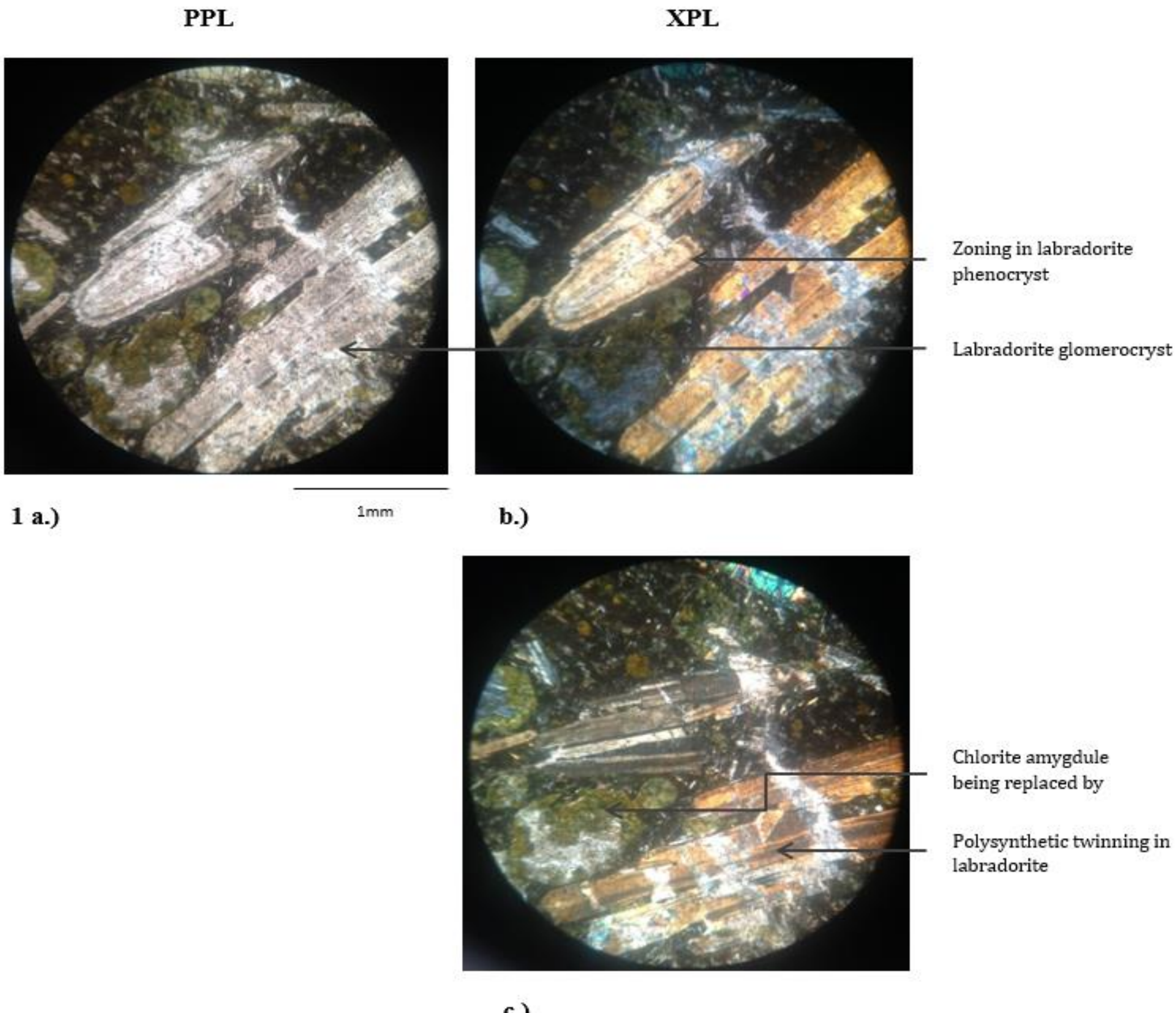
One slab was made and will be described using macroscopic observations to decipher its possible origin, name and method of formation. The types, quantity and physical state of the minerals and groundmass found in the sections were noted and compared.

Thin sections

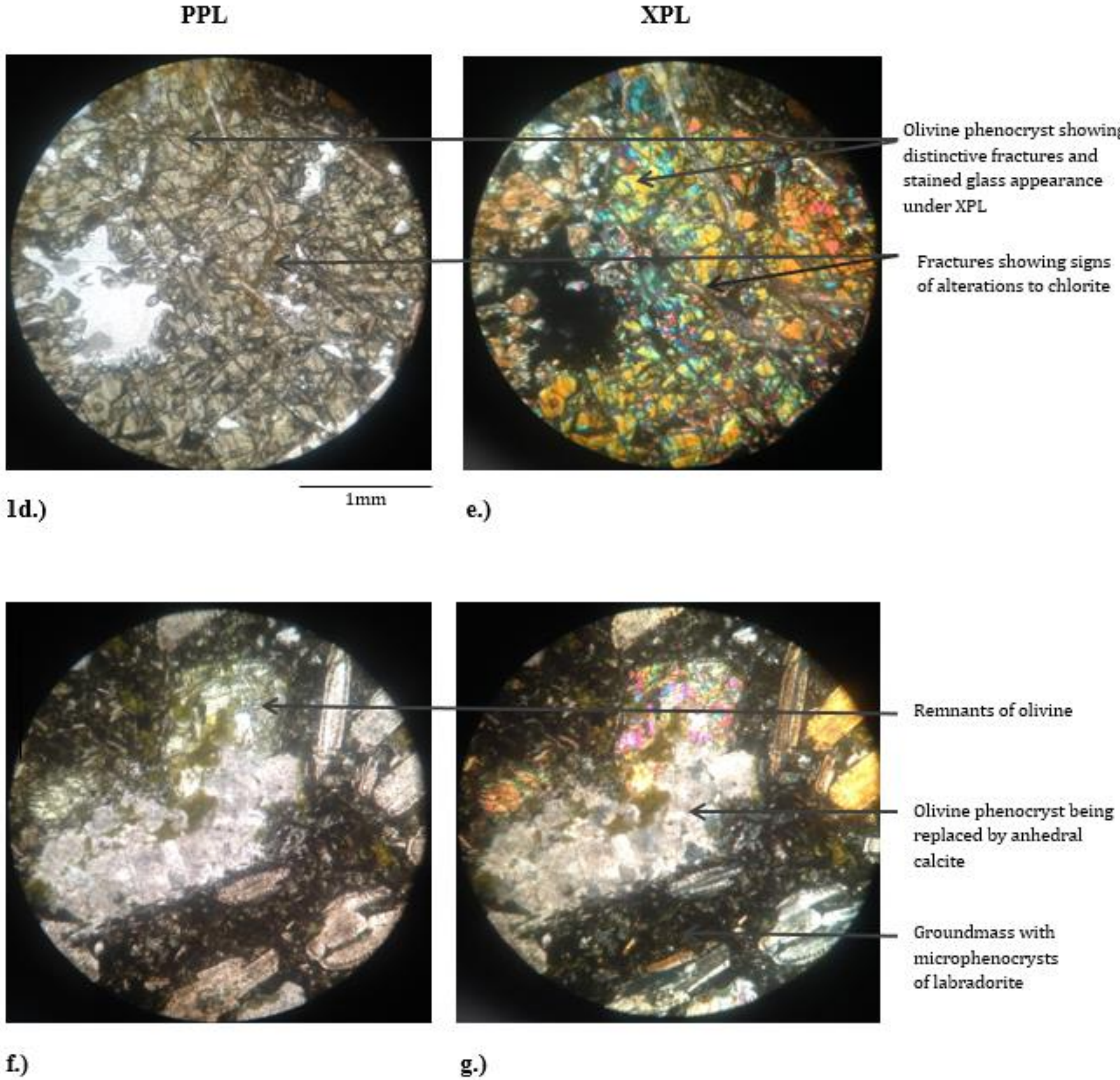
- **Thin section #1:**
- Sample GPS location: 11˚10’45.02”N; W60˚47’43.41”W





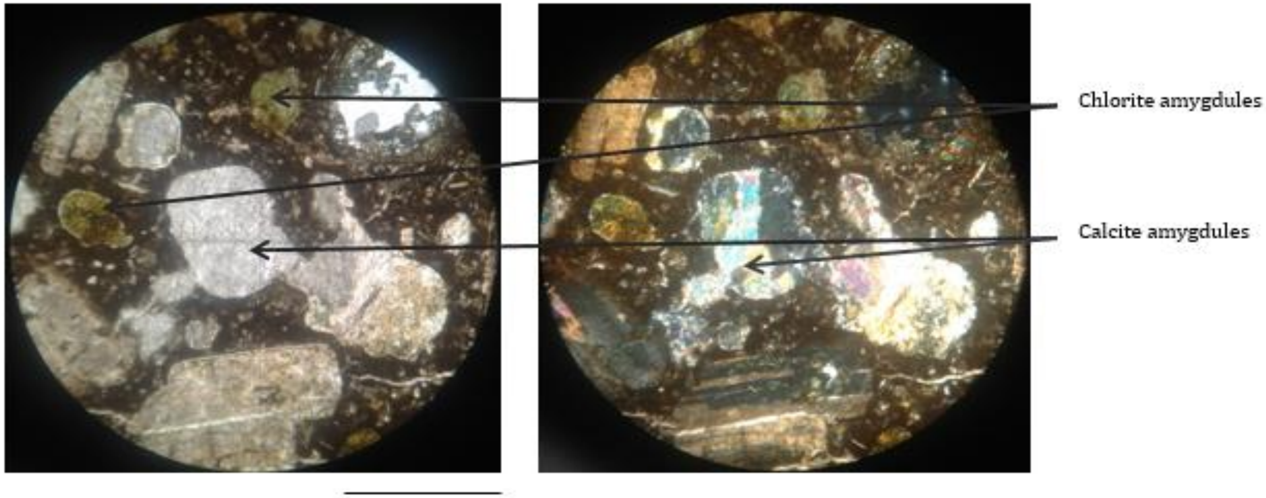


Images 1a, b & c showing labradorite and amygules under the microscope in PPL and XPL

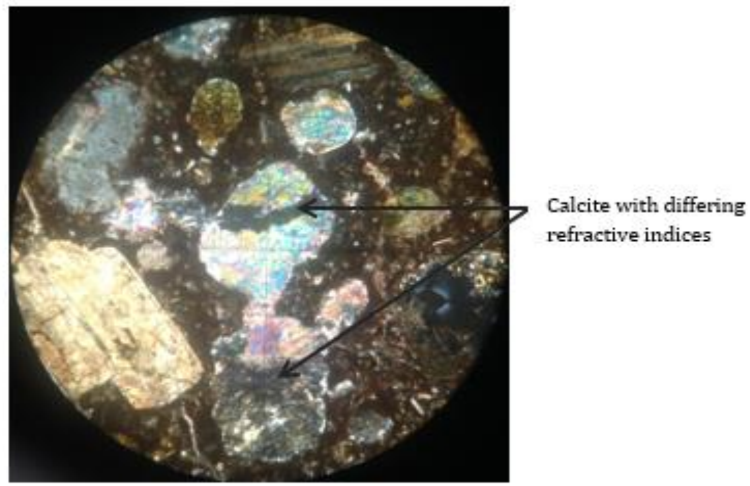


Images 1d,e,f &g showing olivine phenocrysts under the mocroscope in PPL and XPL

PPL **XPL**



1h.) **i.)**

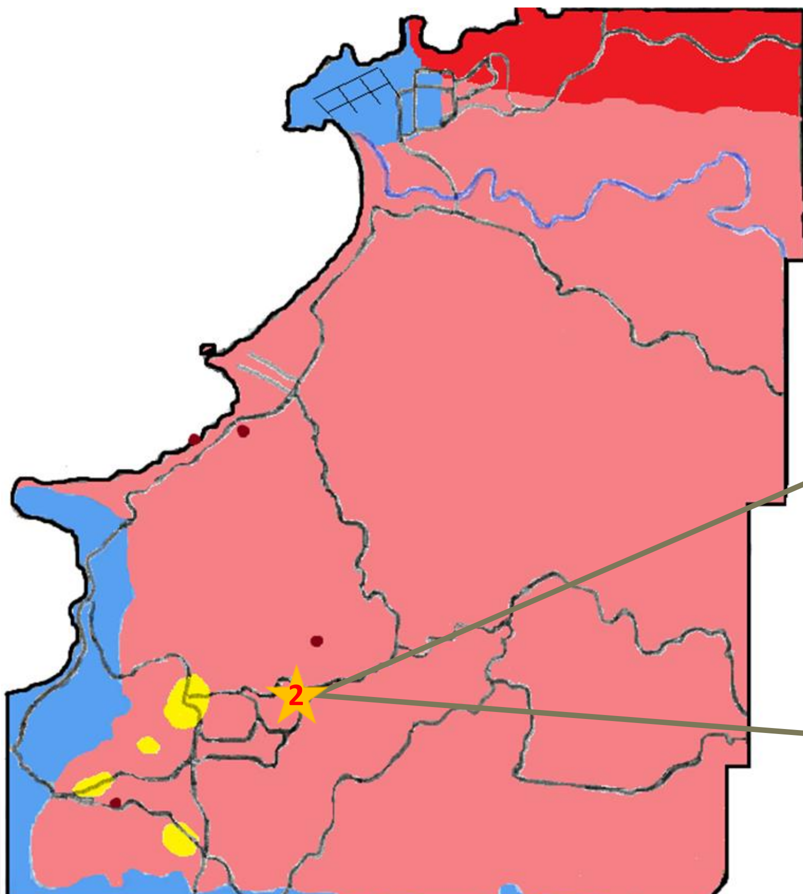


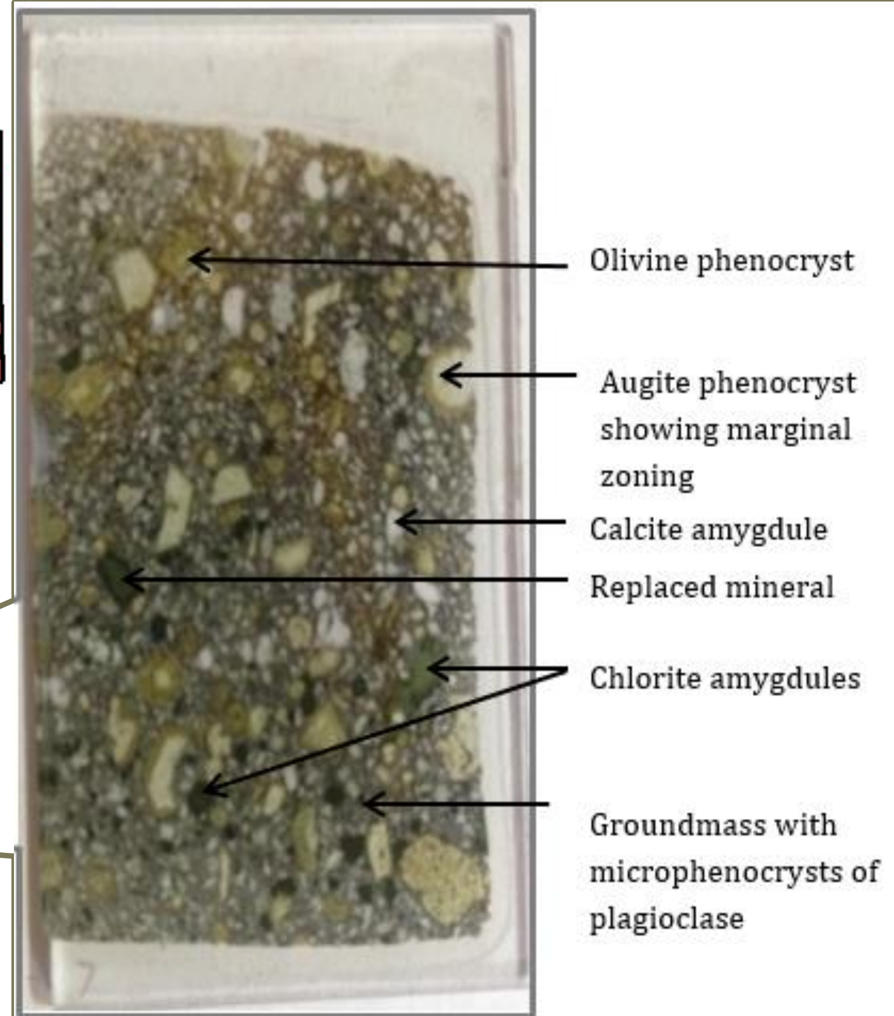
j.)

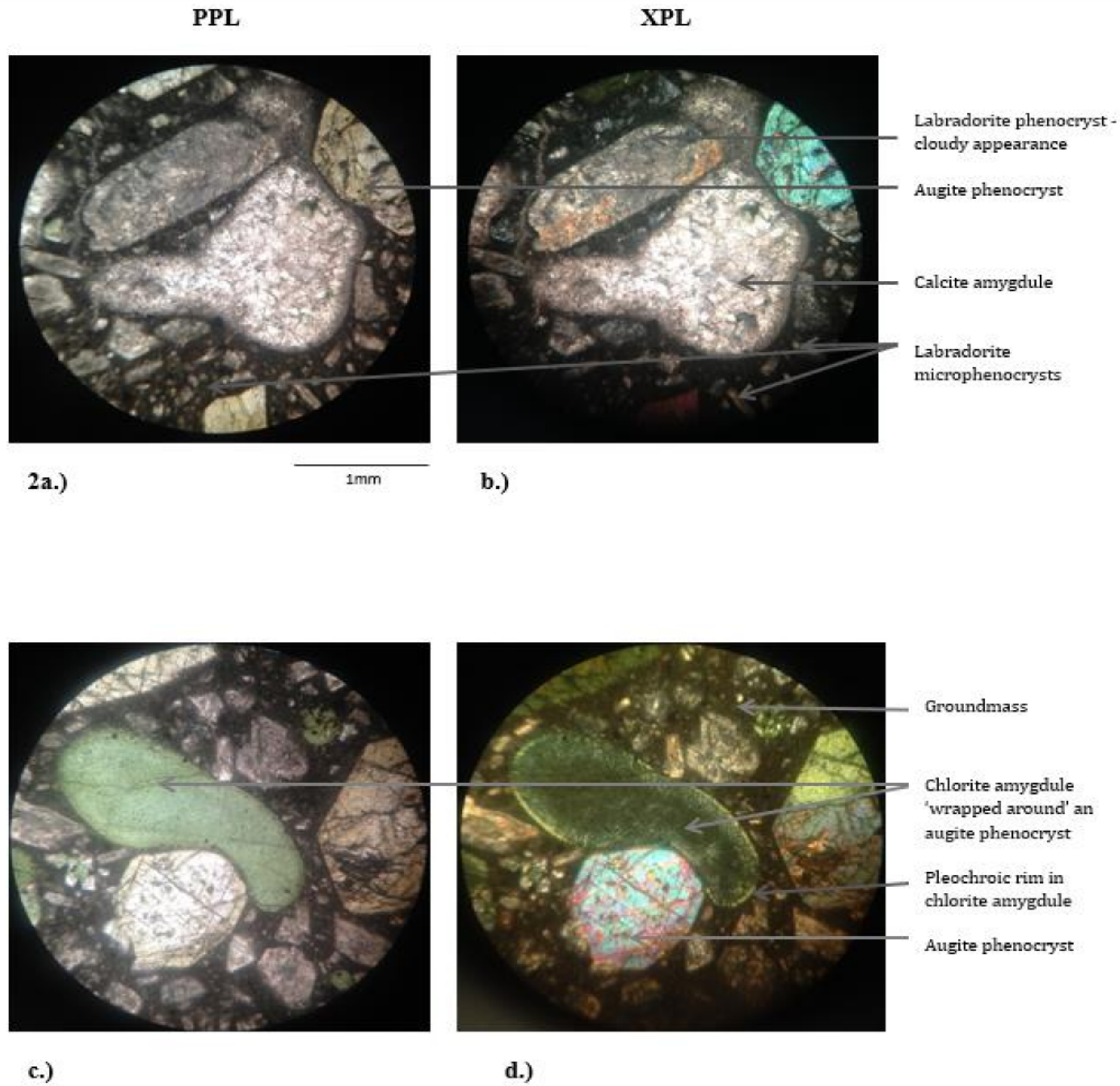
Images 1h, i & j showing calcite and chlorite amygdules in thin section #1 under the microscope in PPL and XPL

Thin sections

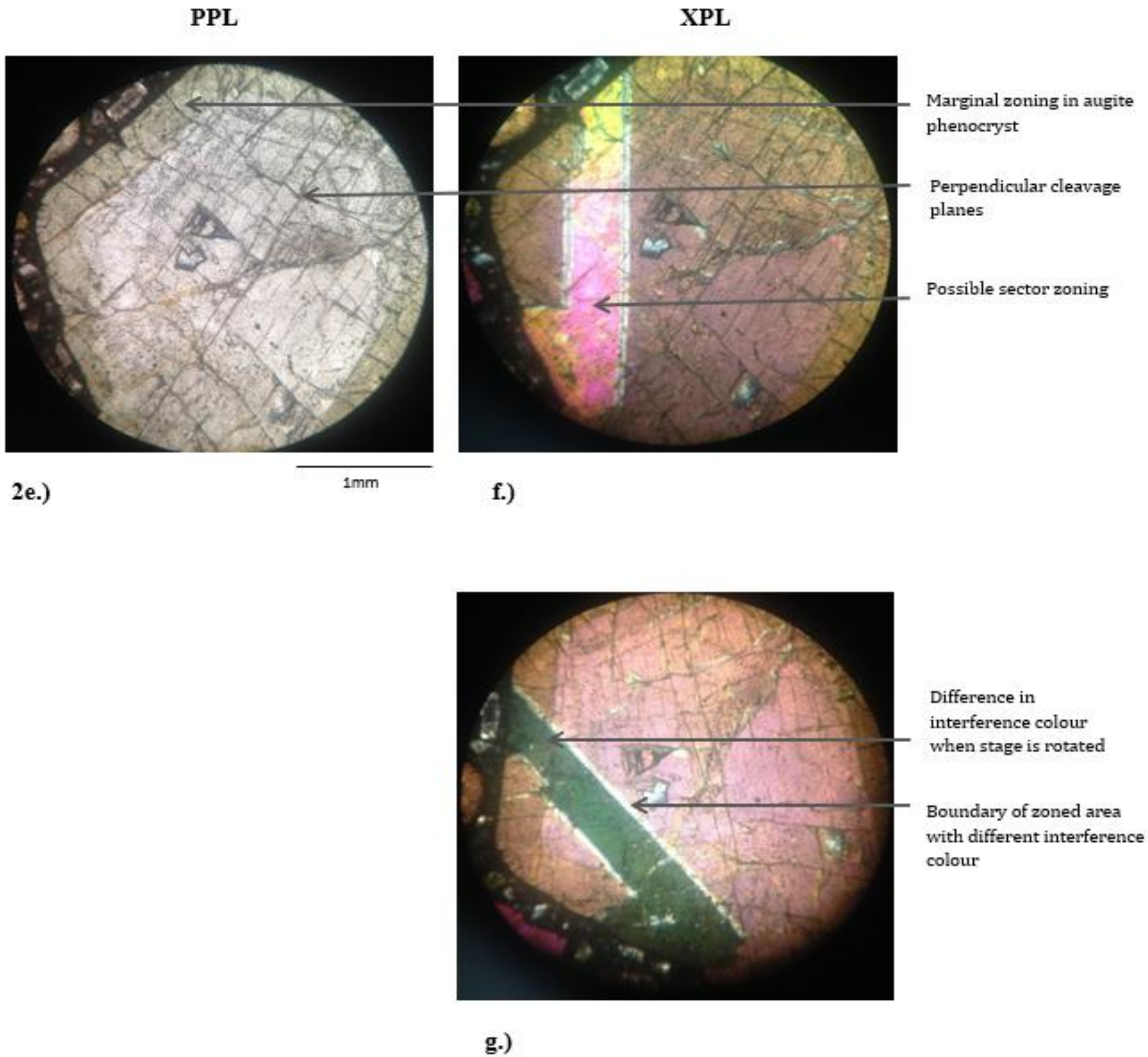
- **<u>Thin section #2:</u>**
- Sample GPS location: 11˚11’15.96”N; 60˚46’41.93”W





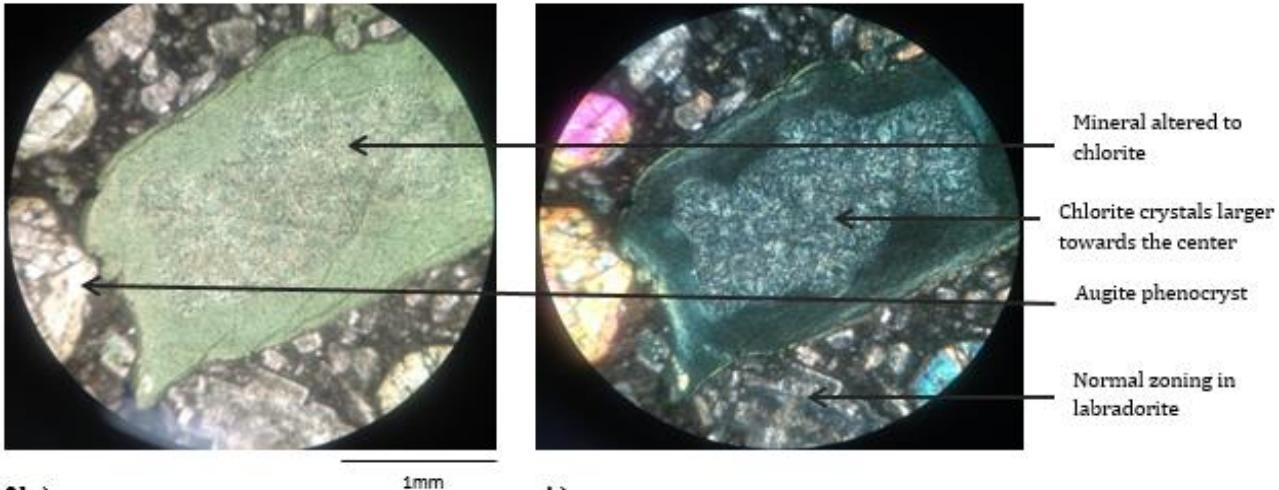


Images 2a,b,c&d showing calcite and chlorite amygdules amongst other minerals in thin section #2 under the microscope in PPL and XPL

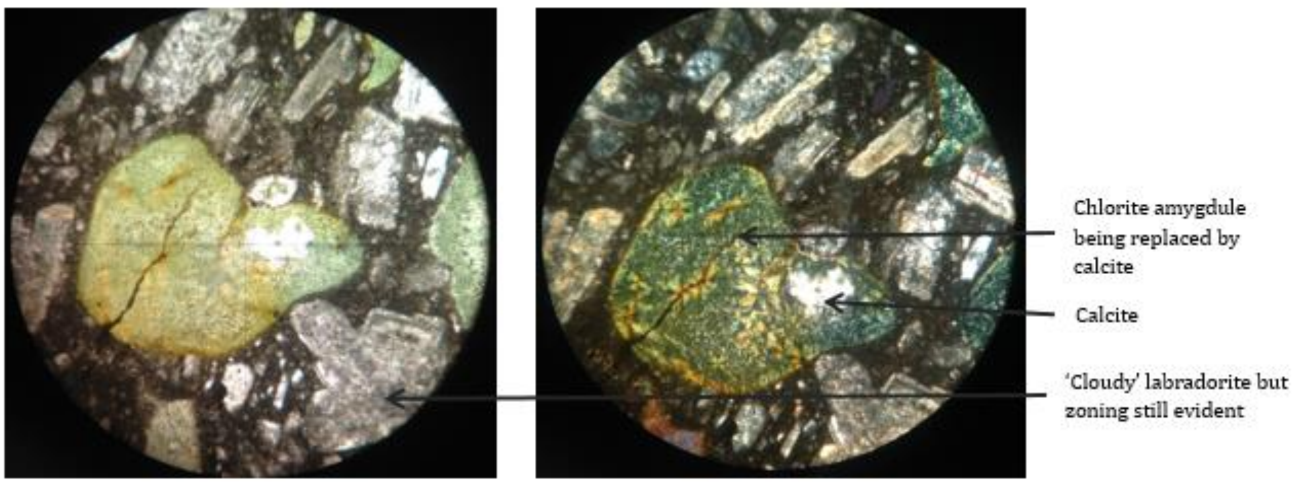


Images 2e, f & g showing zoning in augite phenocryst in this section# 2 in PPL and XPL under the microscope

PPL **XPL**



2h.) **i.)**

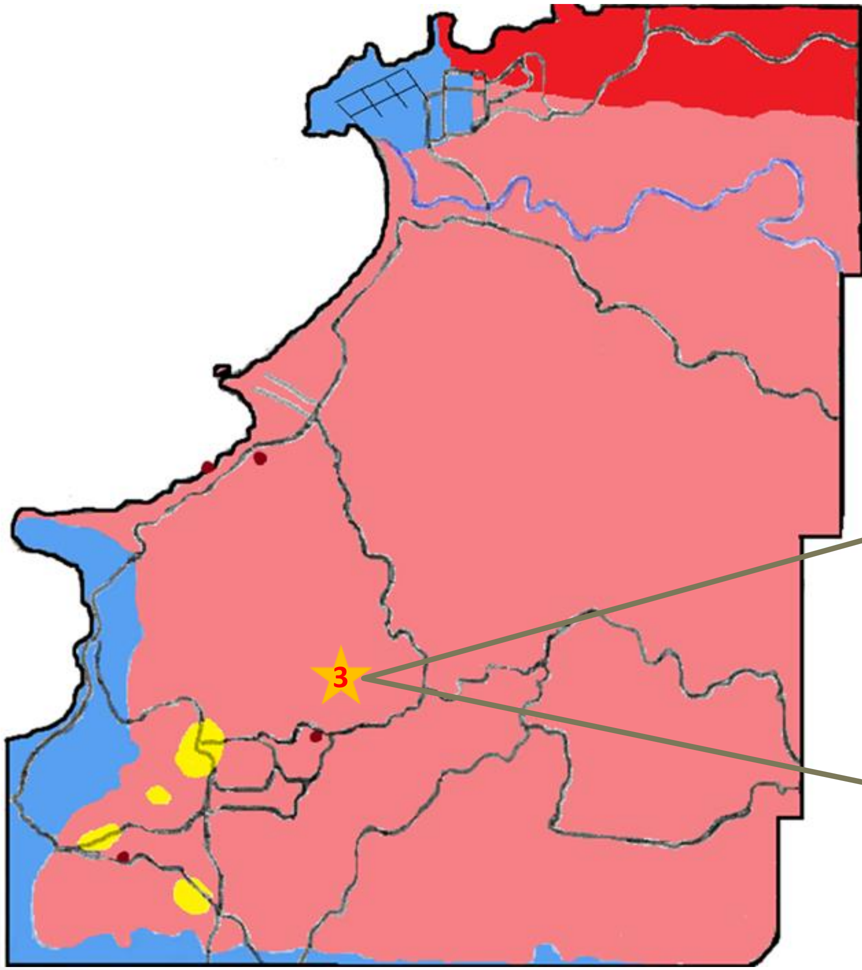


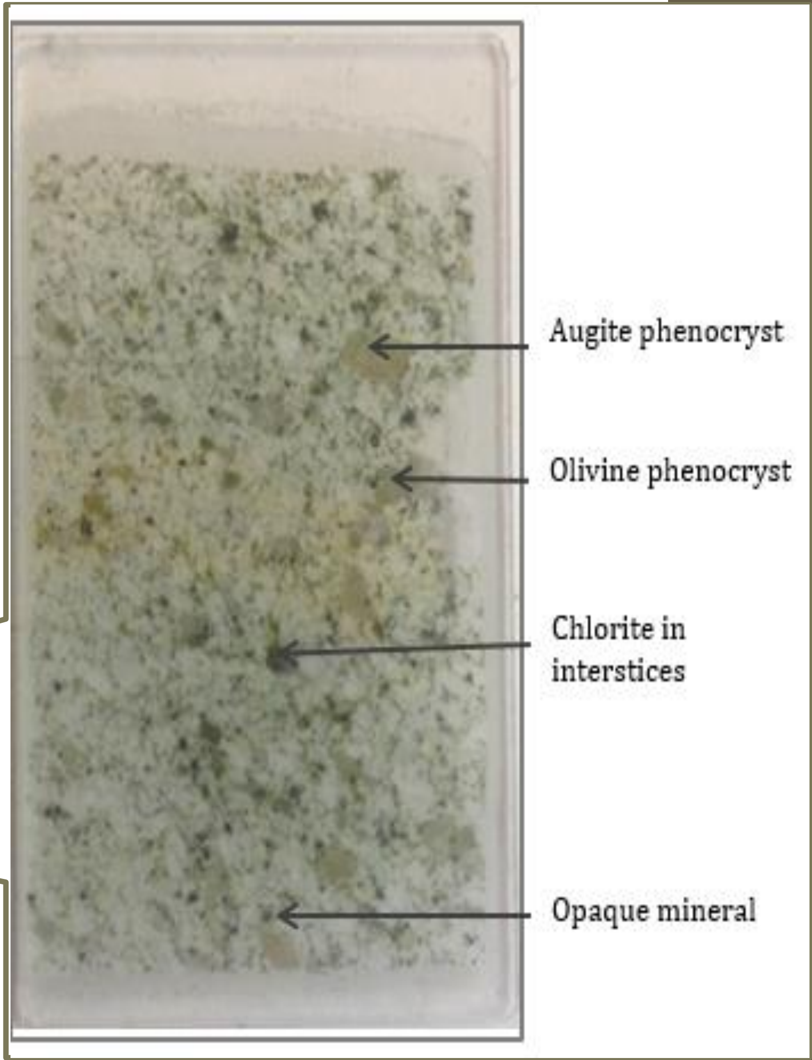
j.) **k.)**

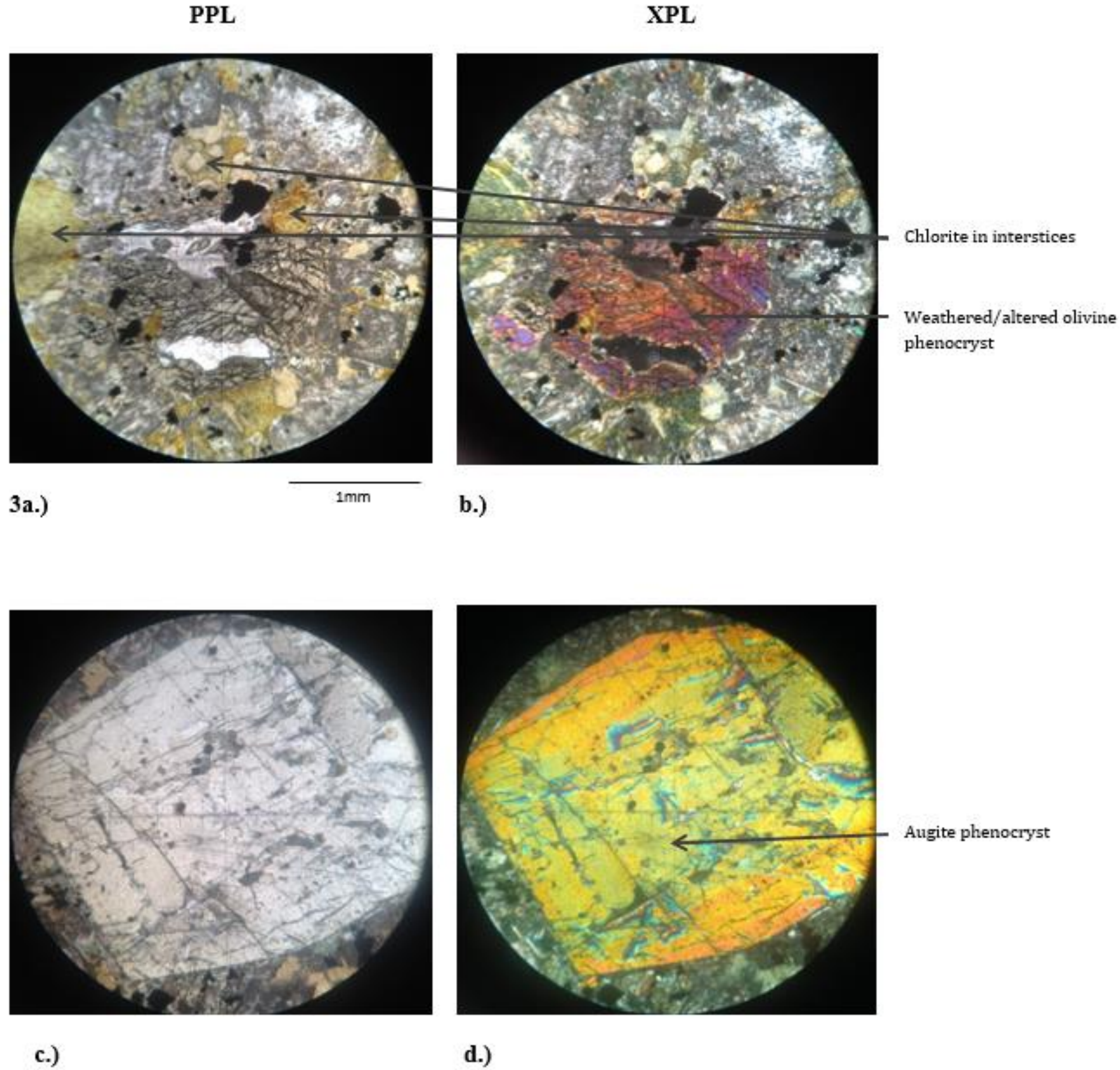
Images 2h, i, j & k showing chlorite infills and replacement, and zoning in labradorite under the microscope in PPL and XPL

Thin sections

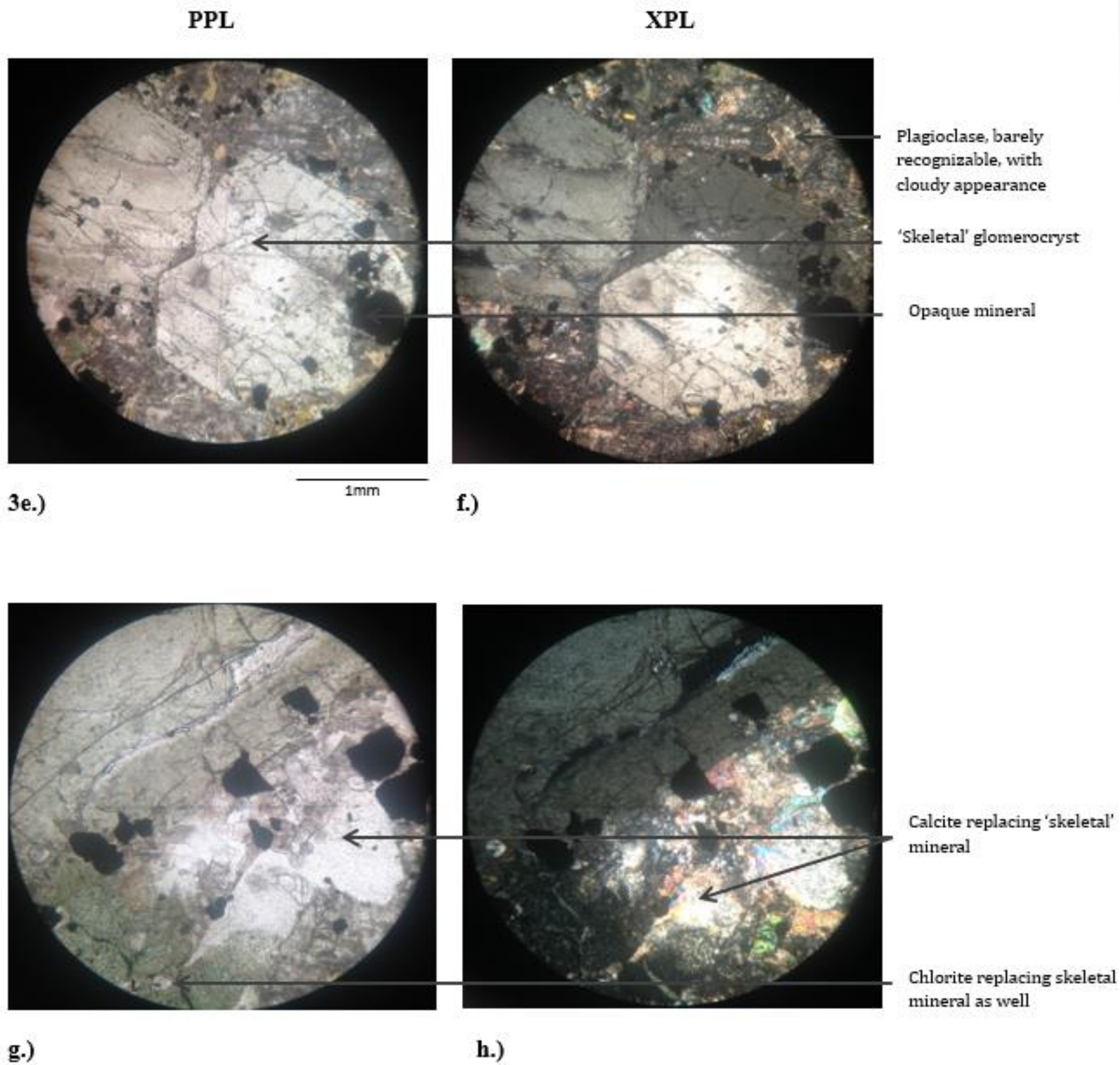
- **<u>Thin section #3:</u>**
- Sample GPS location: 11˚11'26.21"N; 60˚46'34.93"W





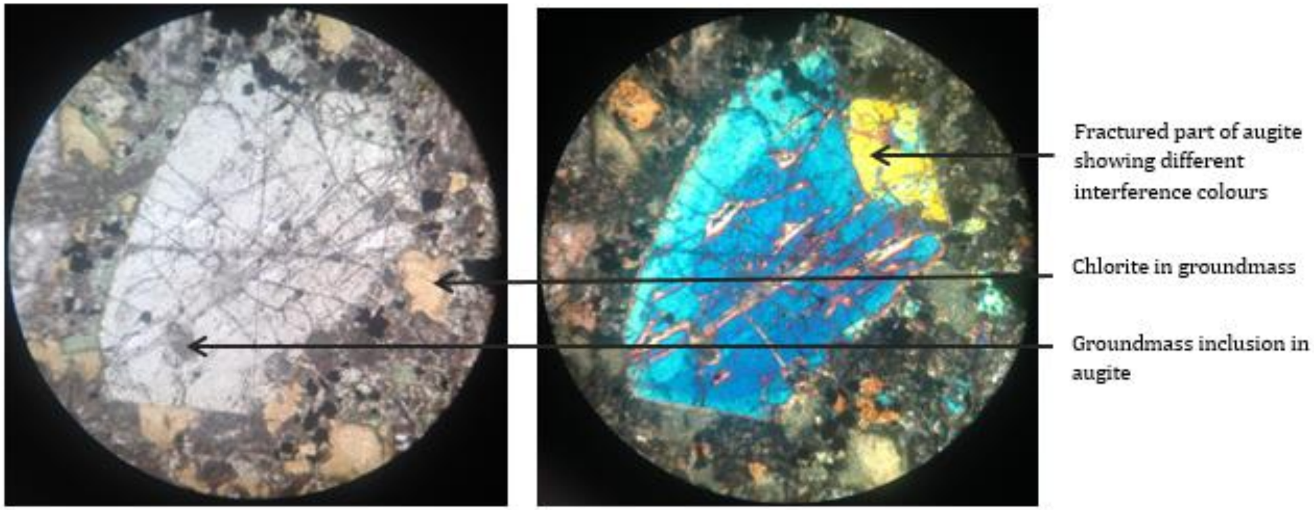


Images 3a, b, c &d showing olivine [a; b] and augite[c; d] phenocrysts in thin section #3 under the microscope in PPL and XPL

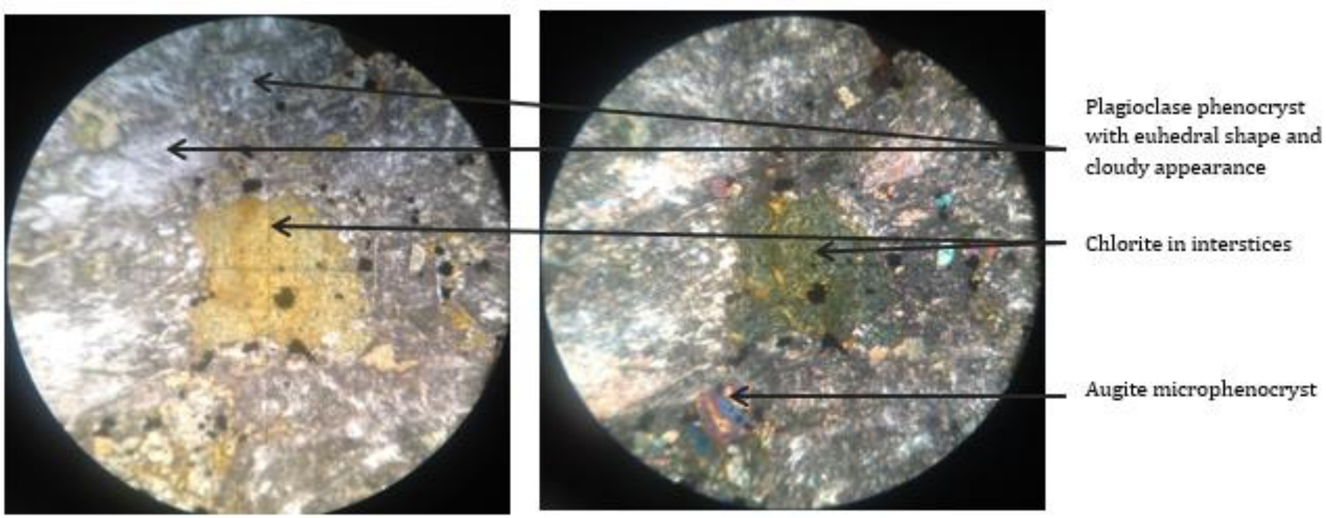


Images 3e, f, g & h showing mineral 'skeleton' and replacement in thin section #3 under the microscope in PPL and XPL

PPL **XPL**



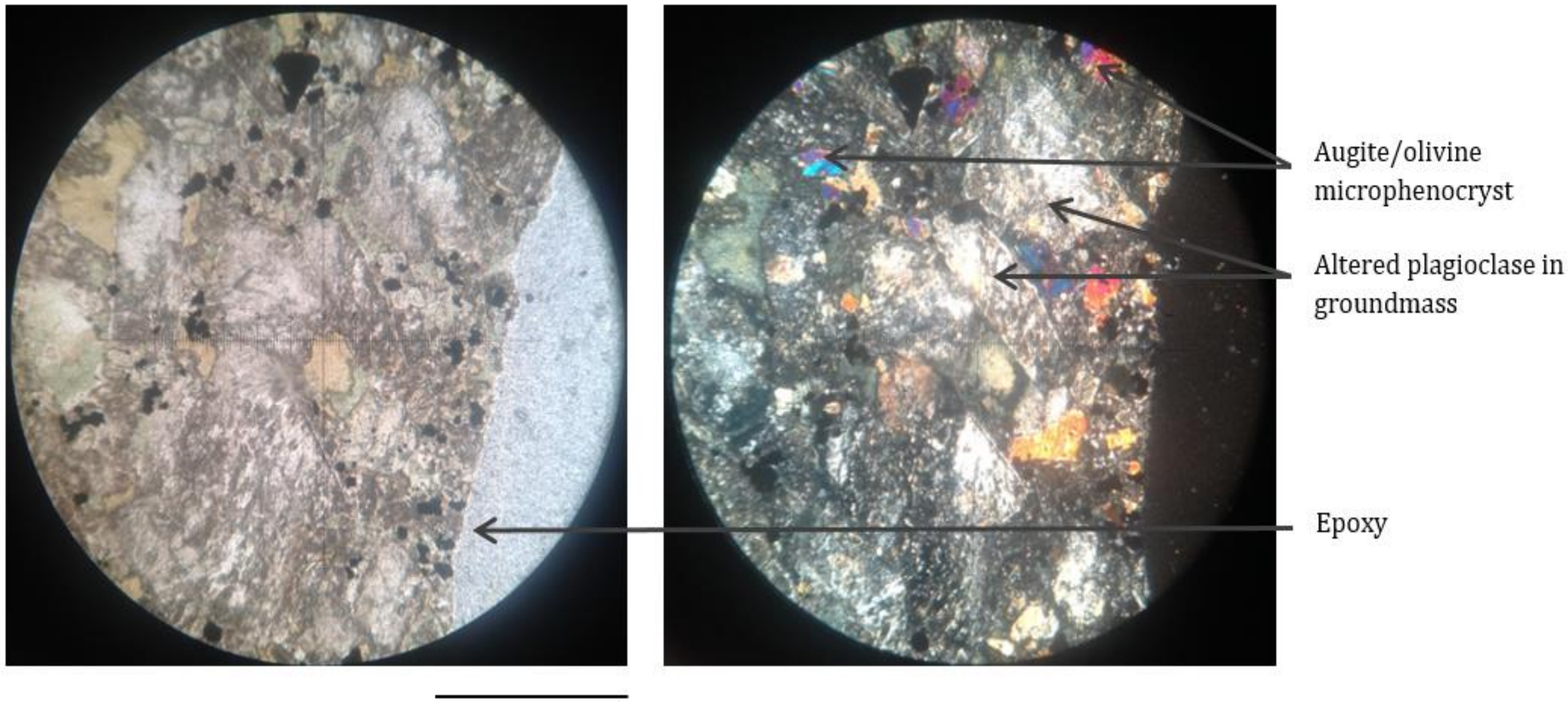
3i.) 1mm **j.)**



k.) **l.)**

Images 3i, j, k & l showing fractured augite phenocryst (i; j) and chlorite in the interstices (k; l) in thin section #3 under the microscope in PPL and XPL

PPL **XPL**

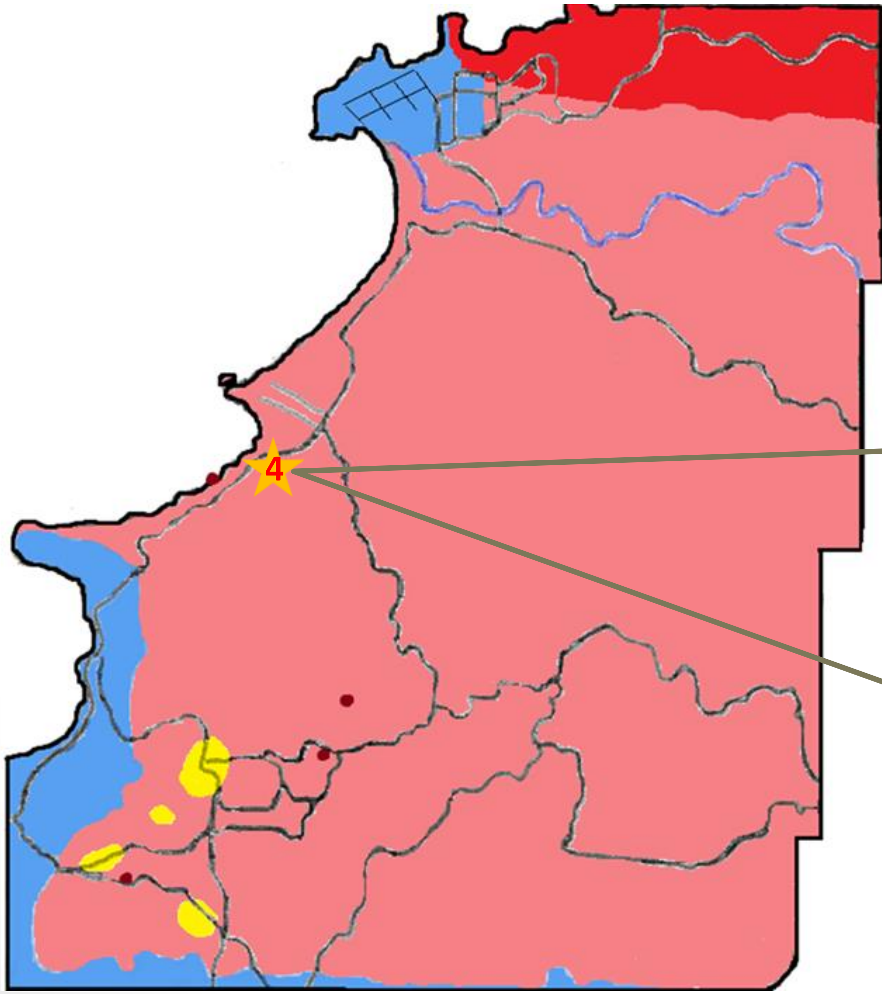


3m.) **n.)**

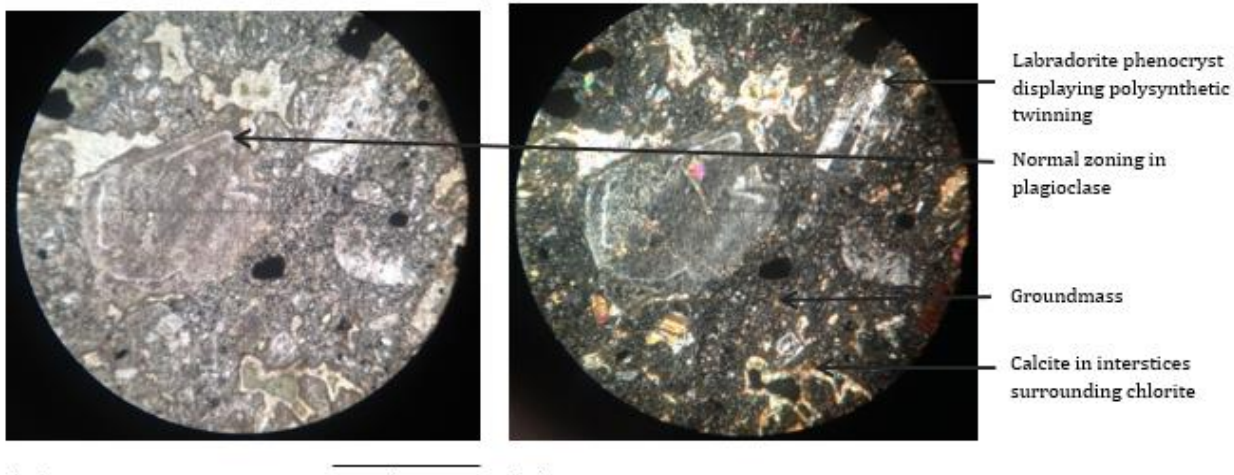
Images 3m& n showing augite/olivine microphenocrysts and altered plagioclase thin section #3 under the microscope in PPL and XPL

Thin sections

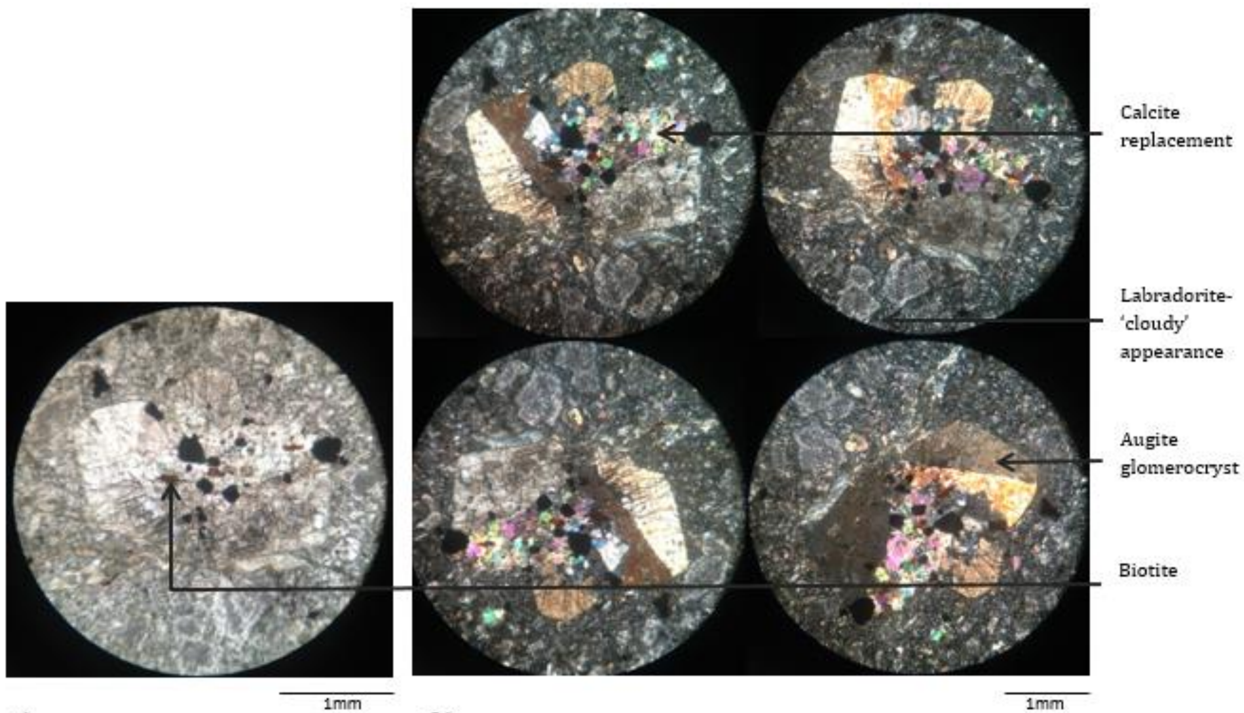
- **Thin section #4:**
- Sample GPS location: 11˚12'4.25"N; 60˚47'8.89"W



PPL XPL

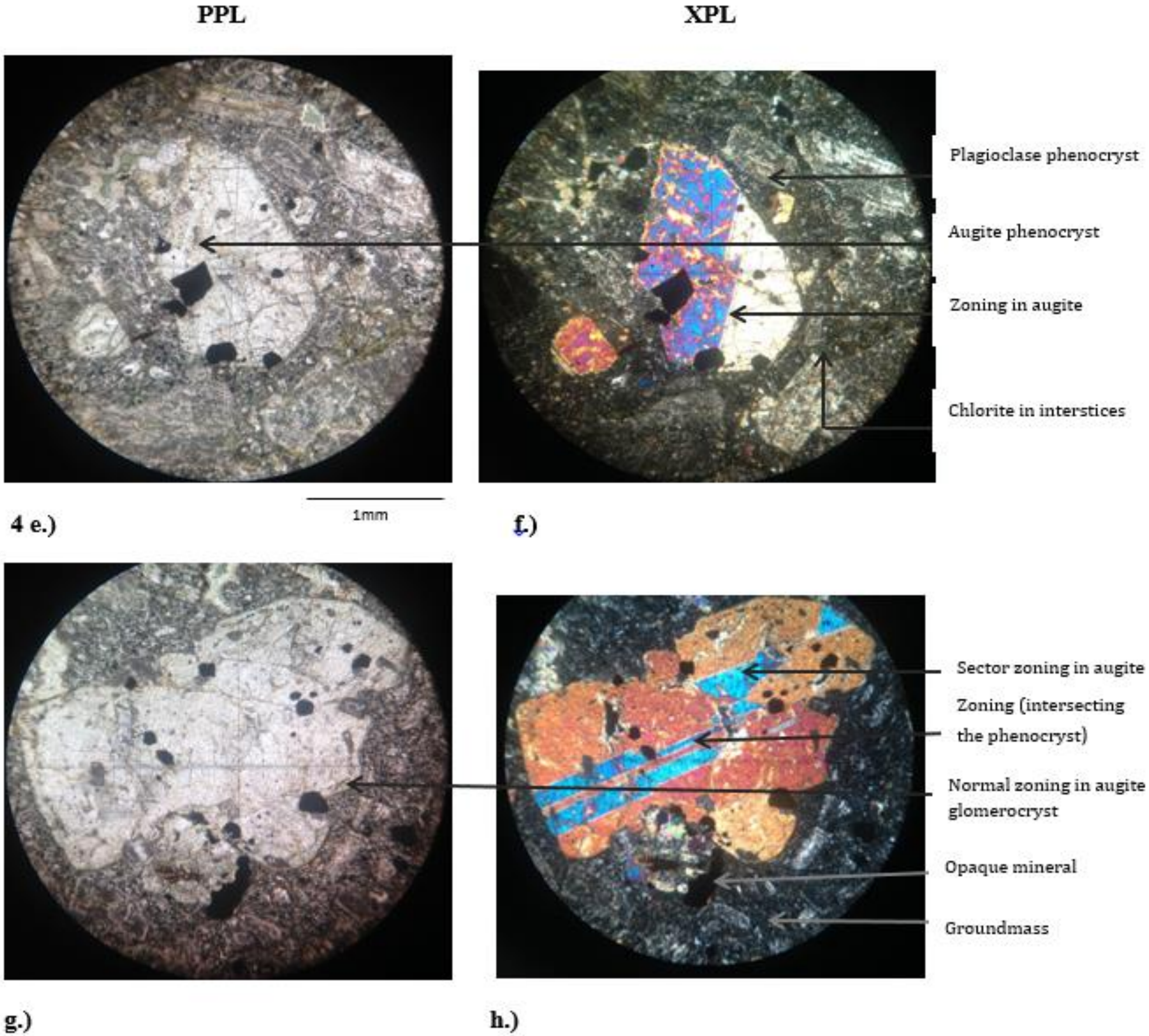


4a.) b.)



c.) d.)

Images 4a, b, c & d showing plagioclase zoning [a; b] and calcite replacement [c; d] in thin section #4 under the microscope in PPL and XPL



Images 4e, f, g & h showing types of zoning in augite phenocryst and glomerocryst in thin section #4 under the microscope in PPL and XPL

Hand samples

Slab #1:

Sample GPS location: 11˚11’11.55”N; 60˚47’54.75”

- The slab was made from a sample that was taken from a volcanic outcrop in the swash zone of Stone Haven Bay

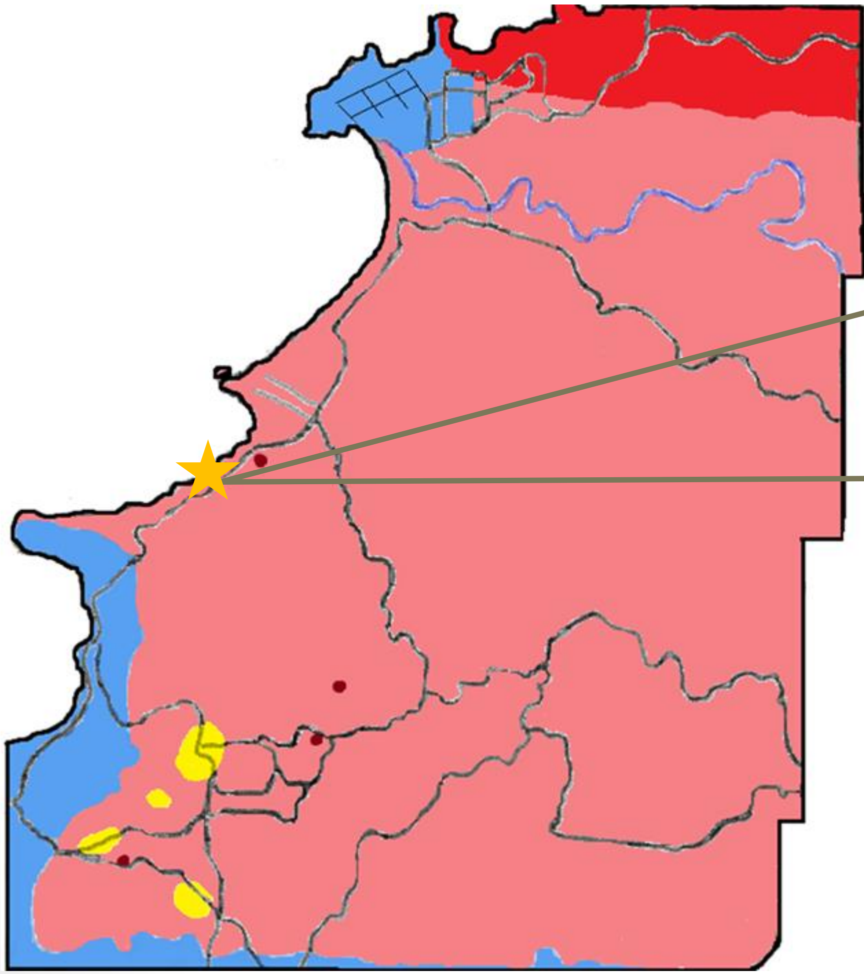


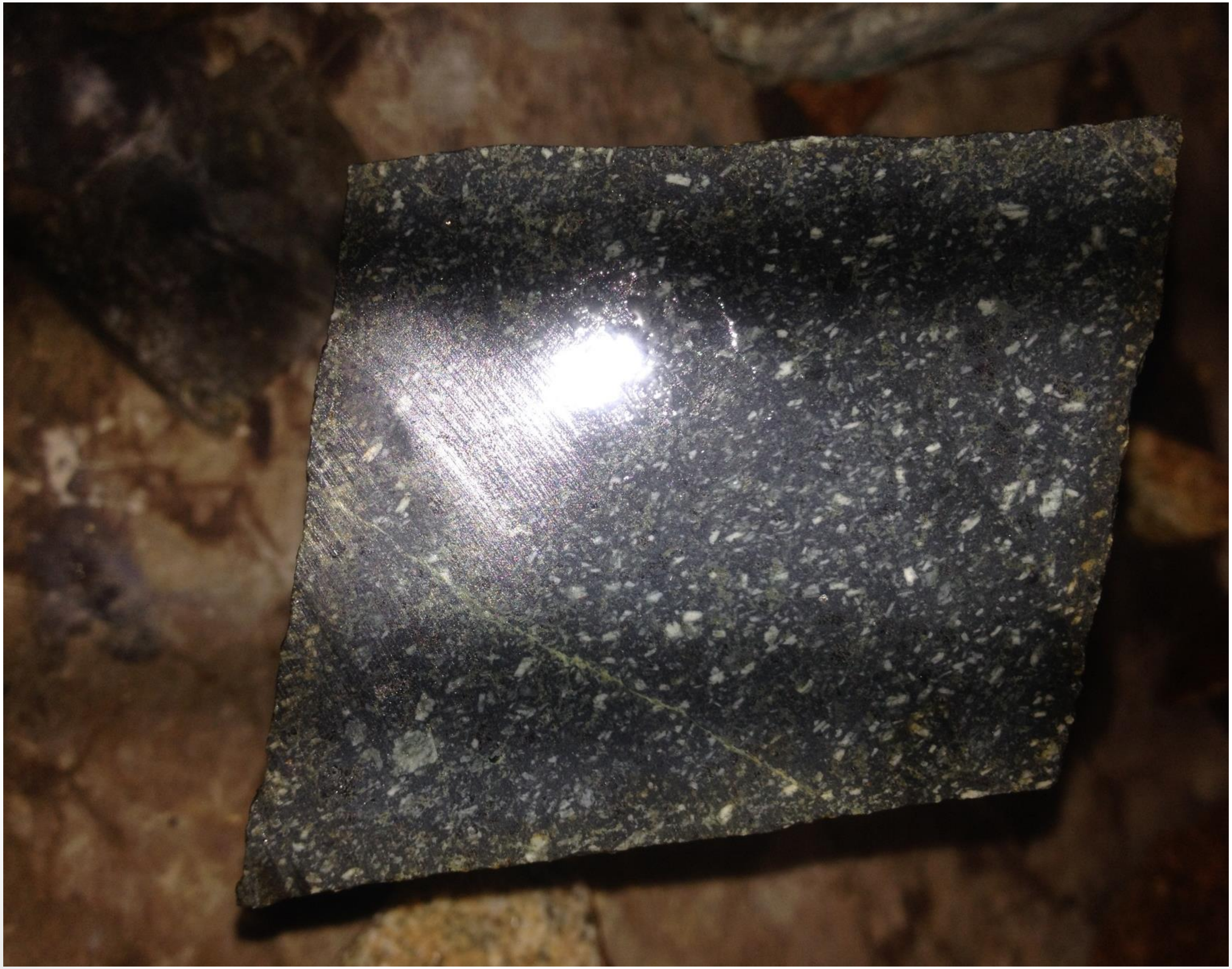
Image 5 showing slab of volcaniclastic agglomerate taken from site #5 (Stonehaven Bay) GPS location: 11°11'11.55"N; 60°47'54.75"W

Hand sample of thin section # 1

1cm

Hand sample of thin section # 4

1cm



Discussion

- A former existing Mesozoic island arc was dispersed following its collision with the northern margin of the South American Plate. One of the fragments formed Tobago and the others were preserved as the Netherlands Antilles; Aruba, curacao and Bonaire and Blanquilla (Faure, 2001). During the Eocene intra arc extension that enabled the growth of the Grenada Basin and inception of the Lesser Antilles Arc, Tobago detached from the fore arc or leading edge of the Mesozoic arc system (Stern *et al*., 2011; Müller *et al*., 1999; Pindell *et al*., 2006 and Neill *et al*., 2013). The rocks give off a geochemical signature which further implies that these rocks were formed in an oceanic arc and thus indicates significant tectonic displacement since its formation or petrogenesis confirming the previous statement (Snoke *et al*., 2001). The characteristics of the rocks, helps to explain the formation of the island, especially those of the Tobago Volcanic Group and the Plutonic Suite. The mineral variances and relative quantities, types of zoning and grade of metamorphism are the characteristics that will be used to help explain this.

- The volcanics of the TVG and the Plutonic Suite were deposited in the Albian (~110 Ma. to ~ 99Ma.) on the North Coast Schist which forms a basement on which they rest. The Plutonic Suite is related to the TVG genetically and may signify the solidified remnants of a magma chamber that intruded the volcanics' exterior (Neill, *et al.* 2013). In the mapped area, the relationship and boundary between the two is one in which the Plutonic Suite intrudes the overlying TVG. One can conclude from the relationship between the igneous rocks that the TVG was deposited first and then was intruded by the Plutonic Suite. The phenocrysts phases and composition indicate clinopyroxene, plagioclase and olivine exerted important controls on the geochemical evolution of the TVG (Frost & Snoke, 1989).

- The TVG was formed by the partial melting of the MORB, fluxed by the fluids derived from the down going slab, subducted recycled volcanogenic material and pelagic sediment (Neill *et al.*, 2013). The thin sections from the various locations in the undifferentiated Tobago Volcanic Group show that all have slightly similar compositions in they contained olivine, augite (clinopyroxenes) and plagioclase in groundmass. There are, however, varying proportions of these minerals and different stages of alterations. Zoning in minerals, amygdules, presence of secondary minerals and plagioclase alterations will be used to interpret the possible geologic history.

- The general petrology of the area gives rise to the conclusion that the area consists of basaltic flows with different eruption times and magmatic compositions (refer to Table 1). The marginal and compositional (sector) zoning in the augite in thin sections #2 and #3 indicates that the mineral was being formed under changing conditions and magmatic compositions probably during magma ascent. This may indicate a compositional change in the mineral from augite to diopside. The normal zoning in the plagioclase in thin sections #1, 2 and 4 confirms that the magma composition was changing as minerals crystalized out of the melt. The glomerocrysts indicate preliminary crystal accumulation of augite, olivine (sinking closer to base) and plagioclase (floating on top).

- During magmatic ascent, vesiculation began, where the dissolved magmatic gases were able to come out of solution, forming gas bubbles in the magma. When the magma was extruded as lava and cools, the lava solidified around the gas bubbles which were preserved as vesicles. Vesicles could have also formed from the burial of thick lava successions as basalt erupted from the MORB- mantle. The in-filled vesicles (amygdules) indicated that hydrothermal circulation with fluids carrying dissolved minerals flowed through the rocks after deposition and deposited the minerals as solids in the vesicles. Seriate texture of thin sections #1 and 2 (the increasing size of minerals like plagioclase, augite and olivine) indicate gradual ascent causing increased cooling rate so the minerals got smaller and smaller.

- Metamorphic alterations due to low grade burial and contact metamorphism (intrusions) and/or hydrothermal circulation lead to the deposition of low temperature secondary minerals; chlorite (extensive) and calcite in patches in the interstices (refer to thin sections 3& 4) and in the amygdules in the olivine augite basalt (refer to thin sections 1 and 2). Striking amygdules with a variety of mineral phases sometimes in one amygdule, and the numerous replacements in other minerals like the augite, olivine, and some amygdules themselves, indicate that the system is still in the process of equilibrating to the new physical and chemical conditions.

- The ‘cloudy’ plagioclase in thin sections 2, 3 and 4 indicate metamorphic alteration more so than actual weathering. Weathering is less likely to cause this because the augite and olivine are strikingly unaltered as compared to the plagioclase phenocrysts. This is not a usual occurrence resulting from weathering alone. This metamorphism was most likely a result of the contact metamorphism caused by the intruding Plutonic Suite. After the intrusion of the TVG by the Plutonic Suite, a dyke swarm intruded the igneous rocks. The dykes could have contributed to the metamorphic alteration of the rocks, which potentially caused the ‘cloudy’ looking plagioclase phenocrysts in the northern section of the mapped TVG as seen in Images 3f, k and n.

- Delineation of metamorphic zones (degree of metamorphism) and relative ages of the basaltic flows can be inferred due to the different characteristics of the thin sections and location of the dyke swarm. The outcrops of the southern section of the TVG, closer to the Quaternary sediments, show less or no intrusion by the dyke swarm that are very frequent further north. This indicates that the southern area or section of the TVG erupted last or is youngest. There are also more vesicles (amygdules) present here, which as stated previously could be formed from the degassing of the basaltic succession beneath. In addition, the plagioclase in this area was not significantly altered.

- In contrast, further north, closer to the Plutonic Suite intrusion, the rocks do not have amygdules or vesicles. They contain chlorite as patches in the interstices instead of amygdules (as in the southern section) and the plagioclase is significantly altered. These areas are also notably more frequently intruded by the dyke swarm of unknown composition. This all indicates that the northern section has undergone a higher grade of metamorphism than those in the southern section and thus is older (erupted before) or is closer to the source of metamorphism which is the intruding Plutonic Suite. The rocks also are more andesitic in nature indicating a different eruption time and magmatic composition. In summary, the age and grade of metamorphism of the rocks increase northwards in this section of the TVG.

- The volcaniclastic agglomerate slab taken from the coast at Stone Haven Bay contains clasts of differing compositions that resemble the variety of rocks found in the TVG. This indicates that it was located near the volcanic vent or conduits during the time of eruption. Its suggested origin would also explain the possible ash deposits as shown in Image 5. The agglomerates were also intruded by the dykes and show no significant signs of weathering or alteration therefore they most likely were deposited around the same general time as the rest of the TVG (Albian).

- The Pliocene- Pleistocene sediments of the Montgomery Formation (sandstones, conglomerates and limestone) denote shallow marine accumulations that have been uplifted. The coralline limestone was deposited on the TVG in the late Pleistocene and they were subsequently exposed after tectonic uplift or sea level change probably from the last interglacial highstand in the Quaternary. The Quaternary sediments were likely deposited after Tobago was situated close to its current location.

Thin section #	Mineral quantity and characteristics				
	plagioclase	**augite**	**olivine**	**amygdules**	**Other notes**
1 	25%; labradorite; unaltered; euhedral shape polysynthetic twinning seen clearly; normal zoning; glomerocrysts present.	No augite noted in thin section	5%; Heavily fractured; emphasized by incipient alteration to chlorite	20%; mainly calcite amygdules and some smaller chlorite amygdules.	Brown groundmass (50%); plagioclase microphenocrysts make up some of the groundmass
2 	30%;labradorite; some alteration; euhedral and subhedral shape; some polysynthetic twinning noted; normal zoning; few glomerocrysts	15%; euhedral and subhedral shape, marginal zoning and possible sector zoning; broken/ fractured minerals	5%; heavily fractured; alteration to chlorite	10%; calcite amygdules and chlorite amygdules; some amygdules contain both	Some mineral replacement or alteration to chlorite; groundmass (40%) made up of microphenocrysts of plagioclase (seriate texture)
3 	25%; weathered or altered; cloudy appearance; euhedral shape; relatively large number of glomerocrysts	10%; micro- & macrophenocrysts; Euhedral and subhedral shape; some zoning seen (not marginal)	5%,fractures, mostly subhedral; significan signs of weathering or alteration	No amygdules present; Chlorite and calcite contained in interstices of thin section	Opaque minerals seen (3%); mineral skeletons and skeletal glomerocrysts noted with chlorite and calcite replacement
4 	10%; labradorite; mostly subhedral; some polysynthetic twinning; normal zoning	7%; euhedral and subhedral; possible sector zoning frequent; calcite replacement and alteration to chlorite	No olivine found in thin section	No amygdules found; calcite and chlorite found in interstices	Groundmass (70%) fine grained, cloudy appearance, no notable mineral crystals can be identified.

Table 1. showing summarized petrology of the thin sections.

Conclusion

- The thin sections show similar composition in that almost all contained olivine, augite and plagioclase in groundmass.
- The general petrology of the area gives rise to the conclusion that the area consists of basaltic flows with different eruption times and magmatic compositions.
- The volcanics were then subject to very low grade metamorphism most likely from the intruding plutonic and some hydrothermal alteration. The degree of metamorphism increased from south to north
- Hydrothermal circulation during burial of thick lava successions may have lead to the formation of amygdules in the basalt vesicles which were then in-filled and some underwent some replacement. Some of the olivine and or augite were replaced by chlorite and then calcite due to system equilibration.

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