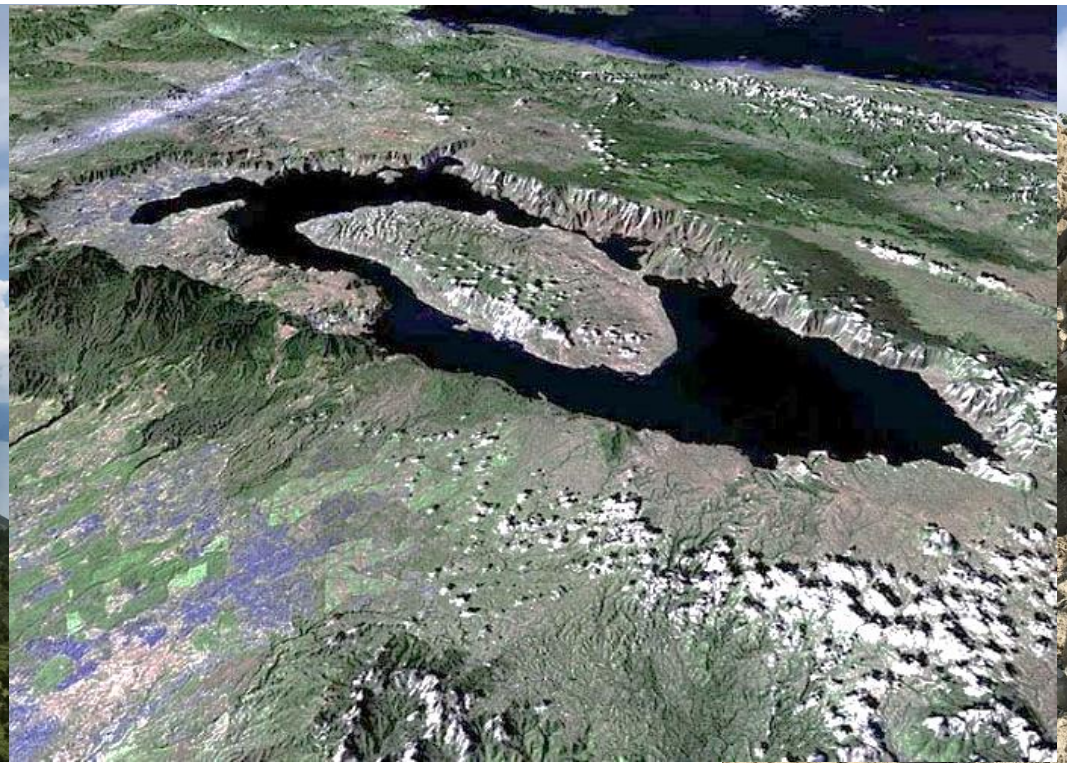
The Youngest Toba Tuff Crystals Characterization

GMPV9.6 "Magma ascent, degassing and eruptive dynamics: linking experiments, models and observations"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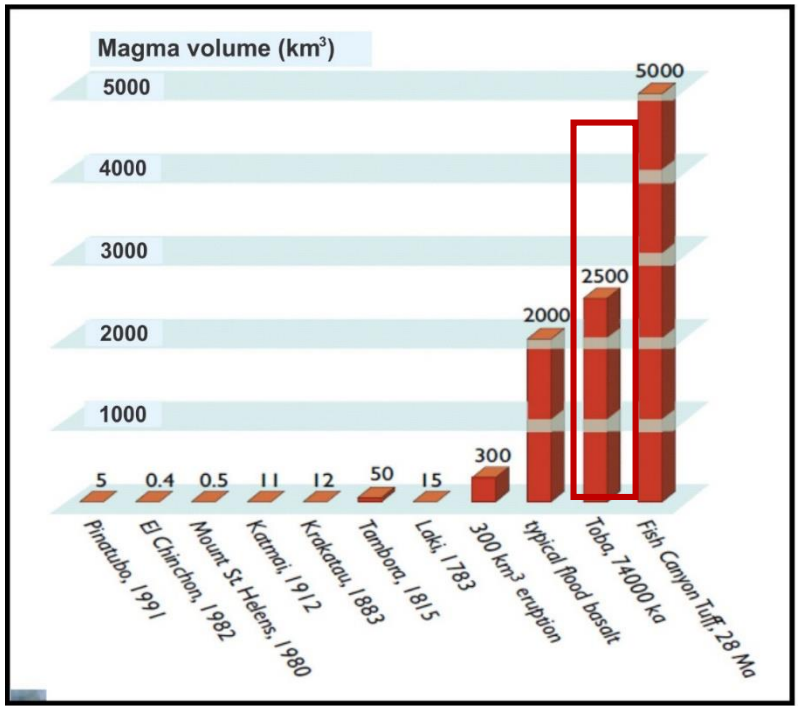
European Geoscience Union, May 2020

Toba Caldera Complex

a,b) Toba Caldera located at North Sumatera Indonesia c) Toba Caldera Complex (Chesner, 2011) ; HDT: Harranggaol Dacite Tuff, OTT: Oldest Toba Tuff, MTT: Middle Toba Tuff, YTT: The Youngest Toba Tuff

- Toba Caldera Complex, North Sumatra, Indonesia is known as the largest Quaternary Caldera that formed by super volcano eruption (8 VEI).
- The long axis of the depression is parallel to the Sumatra Fault (SF)
- Toba Caldera was formed by four major eruptions while the biggest one is the eruption of the Youngest Toba Tuff (74 ka).



Total Estimated Magma Volume of Several Eruption
Source: Report of Geological Society of London Working Group

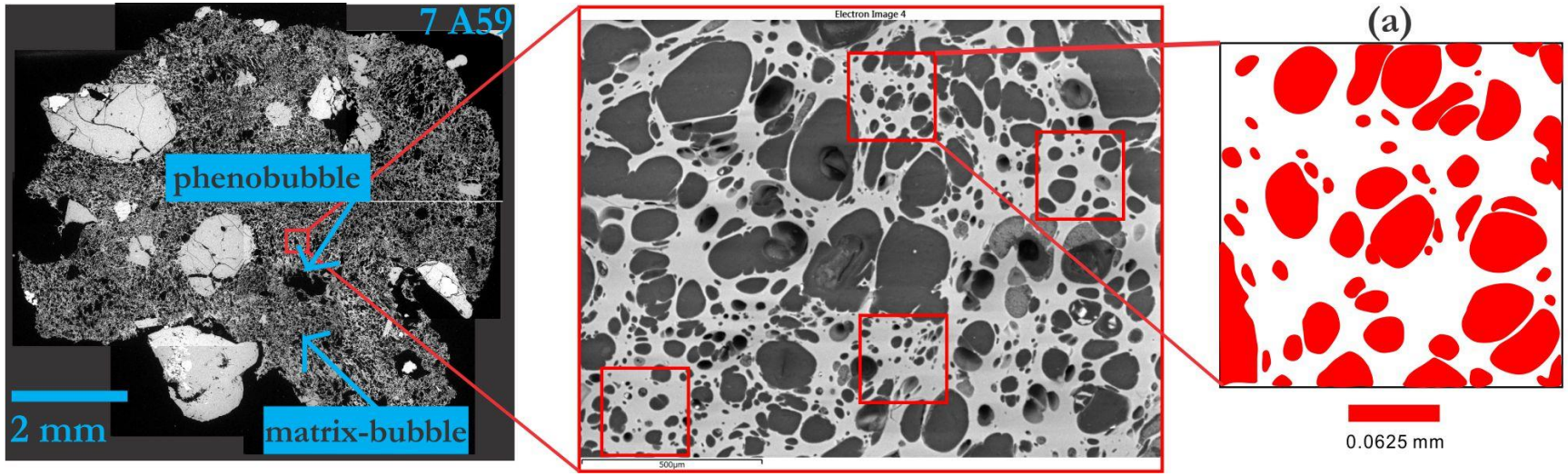
Previous Study (EGU 2019) & Aim of this Study

1. Previous Works (EGU 2019)

- Focused on **textural study of the pumice clast** from the youngest Toba tuff eruption to **estimate the decompression rate** of the **biggest event of Toba caldera forming** eruption by using **bubble number density (BND) data**.
- The result showed that Toba caldera forming eruption generates a remarkable caldera forming eruption **represented by the BND (10^4–10^6 mm^{-3}) value**. It shows that this eruption **has high decompression rate and varies in two order magnitude** ranging from **10^6 – 10^8 Pa/s.**
- Southern pumices show **the lower value** than pumices from northern caldera. Data about **lithic distributions** and **mineral components of YTT** from the northern and southern caldera showed **several different characteristics**.
- This fact suggests **possibility of different processes which cause differences of southern and northern deposits**. Therefore, **understanding both conduit and chamber processes is needed to reveal the origin of differences in deposits**.

2. Aim of this Study

- This study aims to **elucidate magma chamber** condition by **characterizing the deposit especially crystals from YTT eruption.**

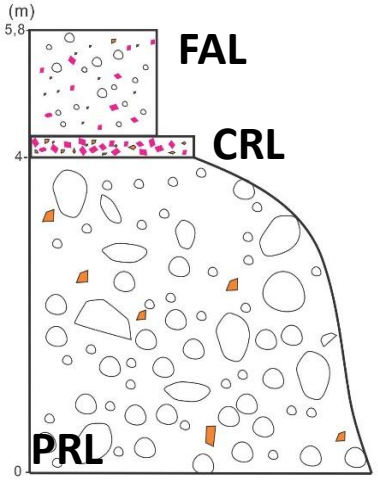


Bubble Terminology & BND Methods (Previous works)

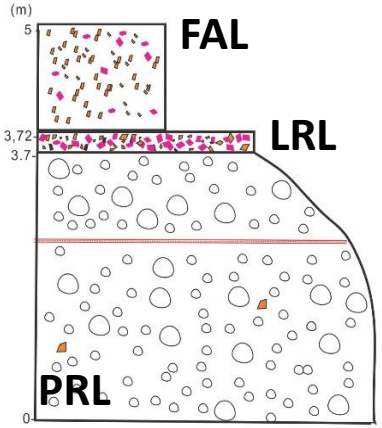
Previous Study
Stratigraphy of YTT (Selected Location)

NORTH CALDERA

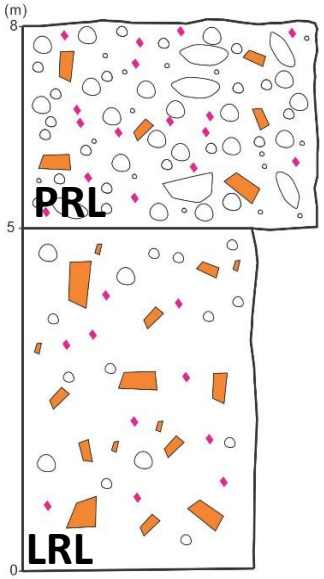
NW (Sumbul) STA 2



N (Merek) STA 5

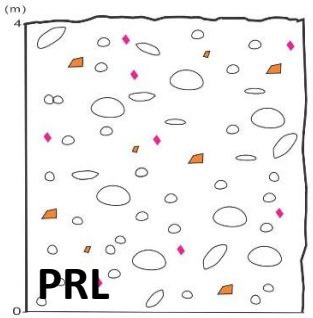


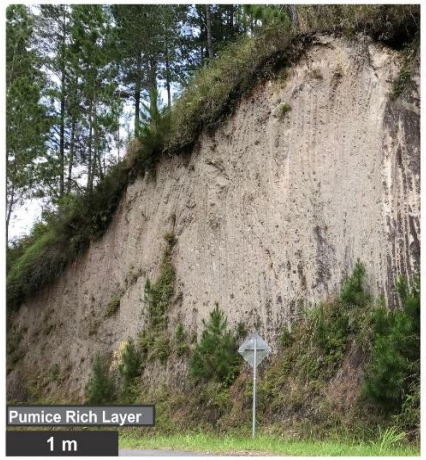
NE (Haranggaol) STA 7

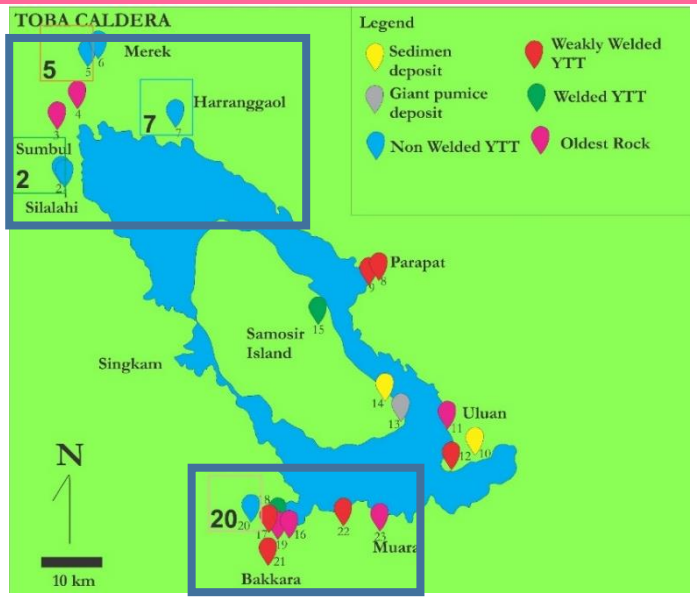


SOUTH CALDERA

S (Bakkara) STA 20







- In the **northern** part **associated with several thin layers**, such as crystal rich layer **(CRL)**, fine ash layer **(FAL)**, and lithic rich layer **(LRL)**. While in the **southern** part **generally massive pumice rich layer (PRL)**.
- **Lithic** type and abundance is different
- **Crystal** type and abundance is different

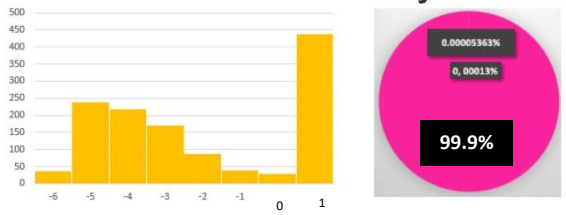
Previous Study

Grain Size Distribution & Component Analysis (larger than 2 mm)

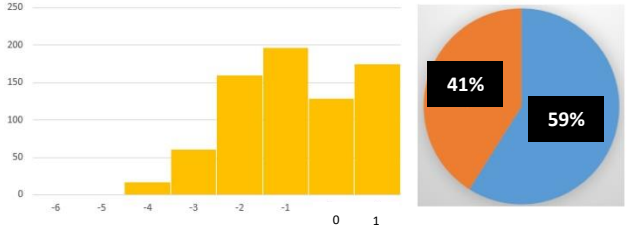
- GSDs show **typical pyroclastic flow deposits**
- Lithic content **is decreasing to Southern area**

N_STA 5_MEREK

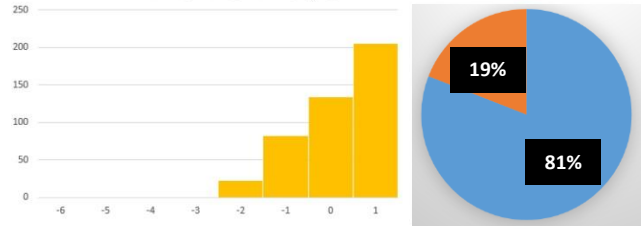
Pumice Rich Layer



Lithic Rich Layer

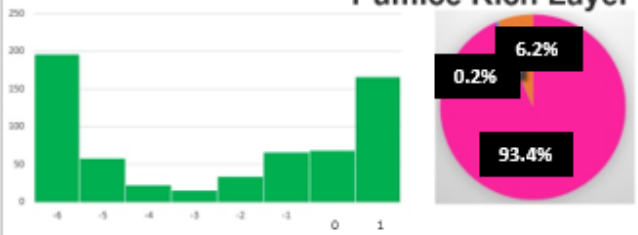


Fine Ash Layer

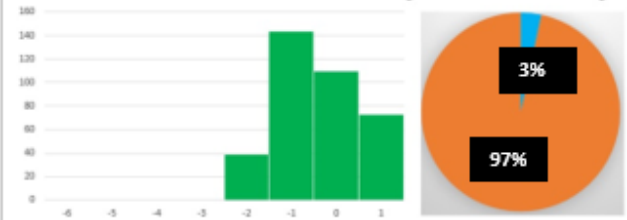


NW_STA 2_SUMBUL

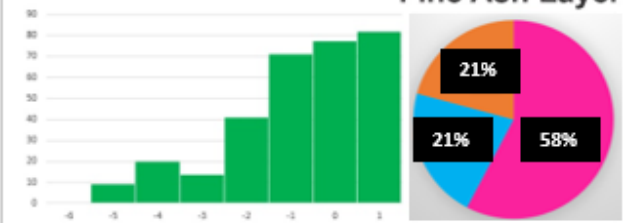
Pumice Rich Layer

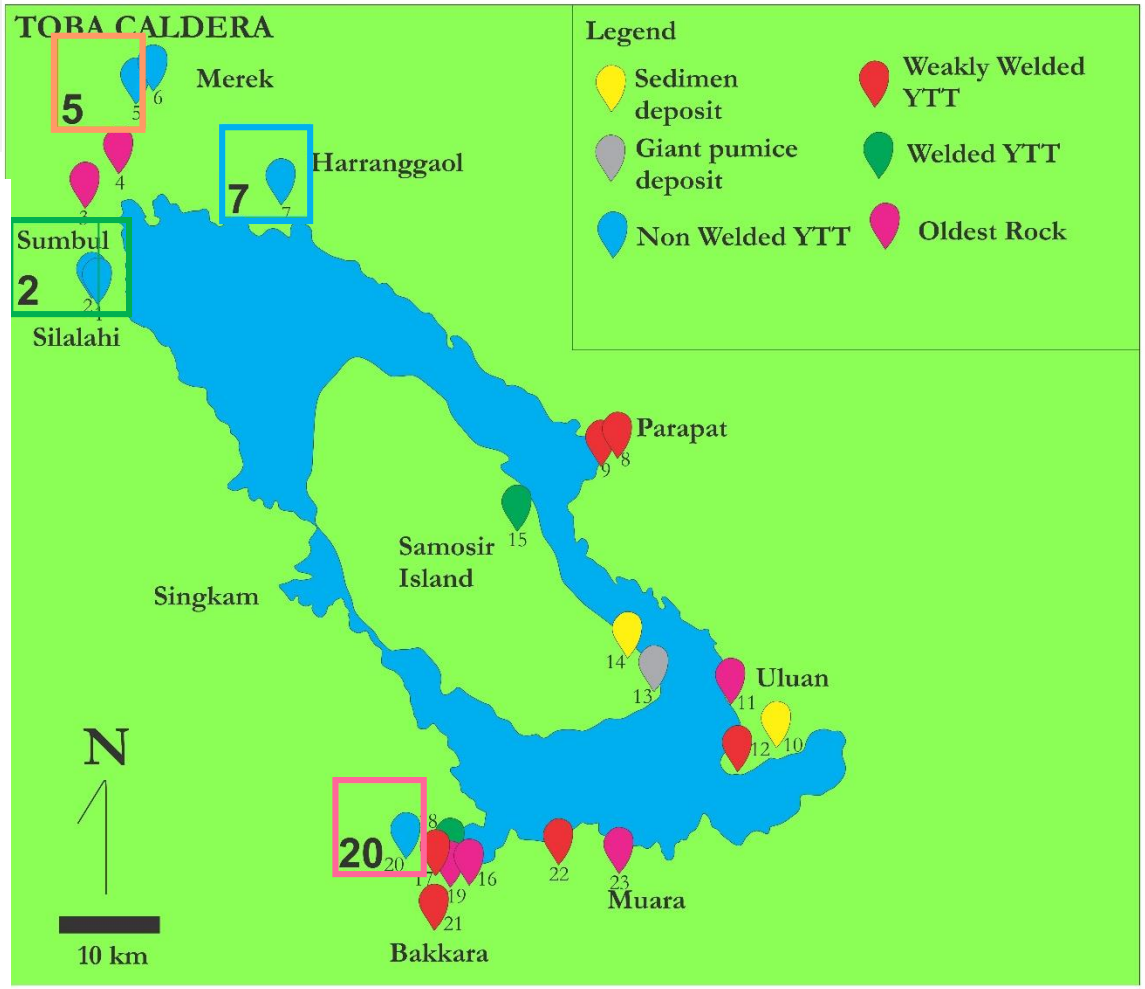


Crystal Rich Layer



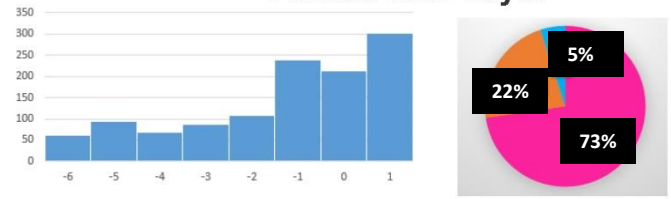
Fine Ash Layer



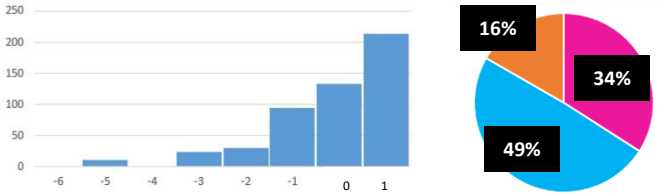


NE_STA 7_HARRANGGAOL

Pumice Rich Layer

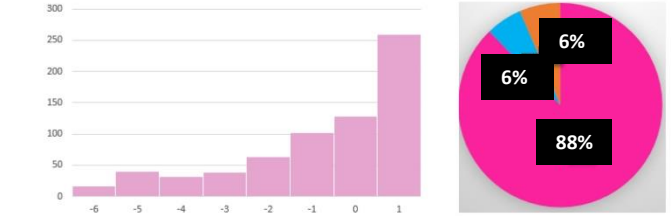


Lithic Rich Layer



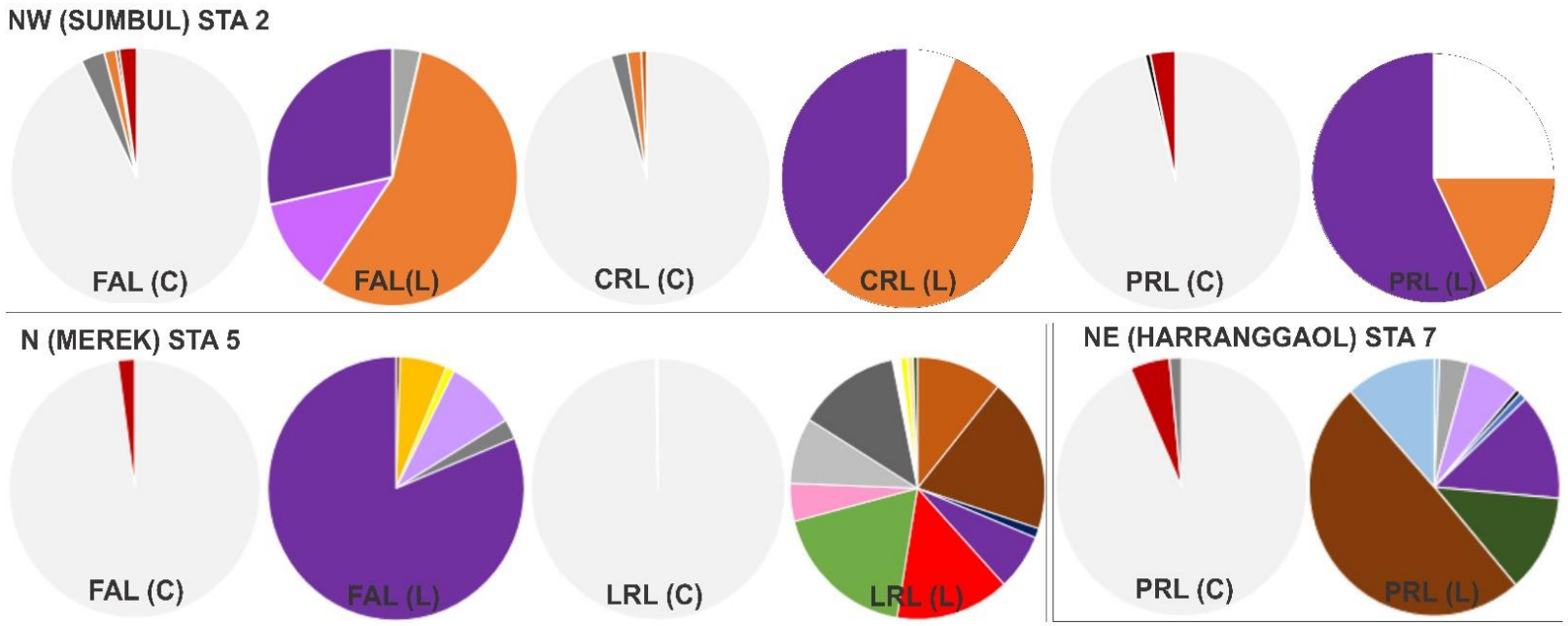
S_STA 20_BAKKARA

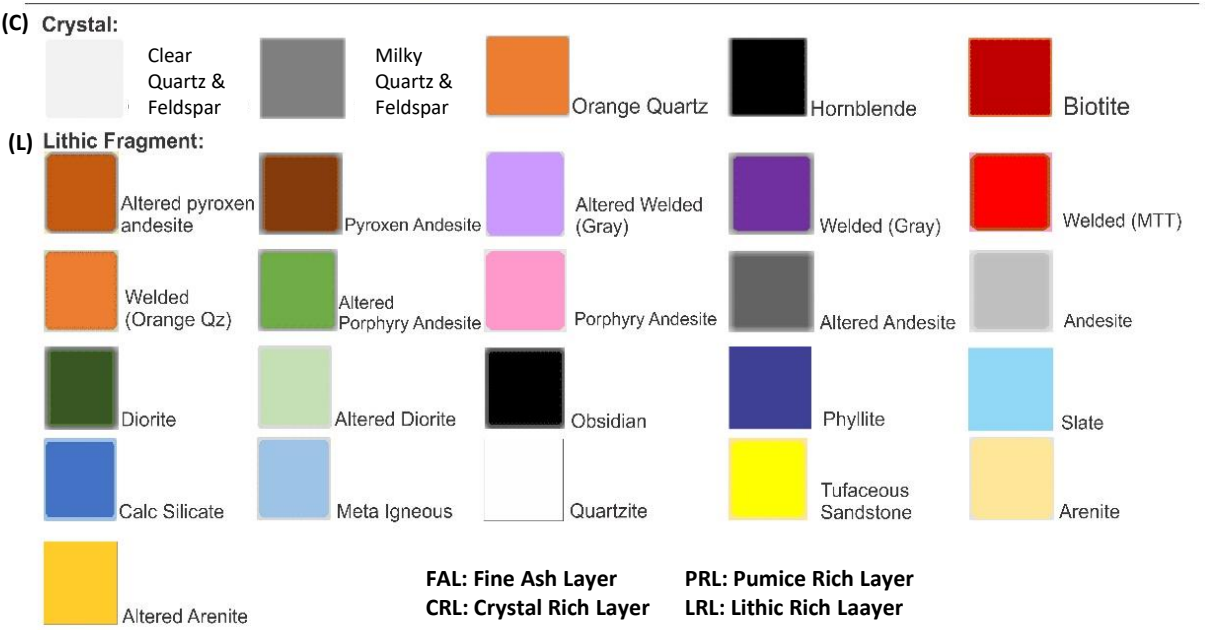
Pumice Rich Layer



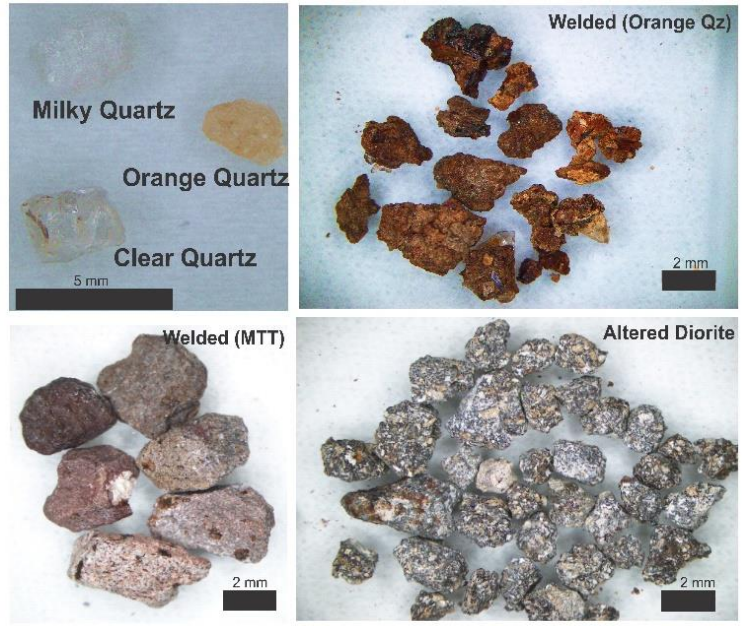
Previous Study

Component Analysis of Crystals and Lithics Fragment





FAL: Fine Ash Layer **PRL: Pumice Rich Layer**
CRL: Crystal Rich Layer **LRL: Lithic Rich Laayer**



Similarity

Mostly consists of **altered welded and welded gray fragmen; clear quartz and feldspar**.

Difference

- Different **variation of lithic type** in the northern and southern deposit.
- **Orange Quartz** is only found in northern deposit
- **Milky Quartz & Feldspar** abundance is getting increase in the Southern part of caldera.

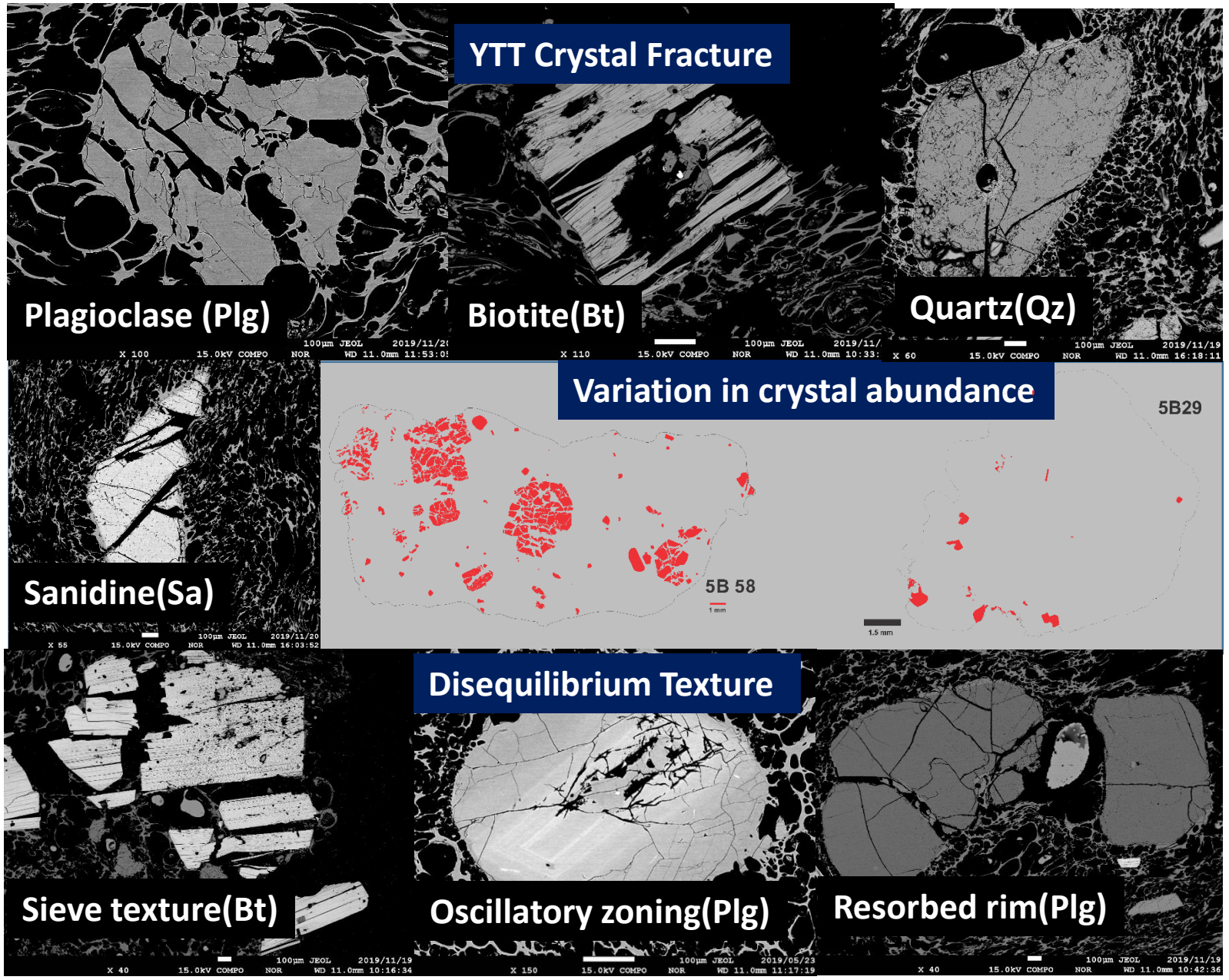
This Study
YTT CRYSTAL - Phenocryst

Major Mineral
Plagioclase, Biotite, Sanidine, Quartz

Minor Mineral
Amphibole, Zircon, Fe-Ti Oxide, Allanite, Apatite, Monazite, Sulfide (Pyrite), Copper

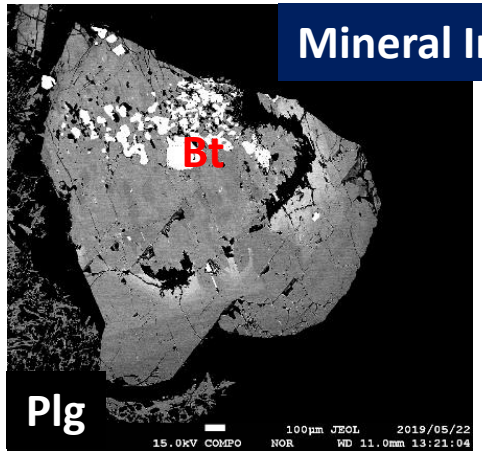
General Characteristics of YTT Phenocryst

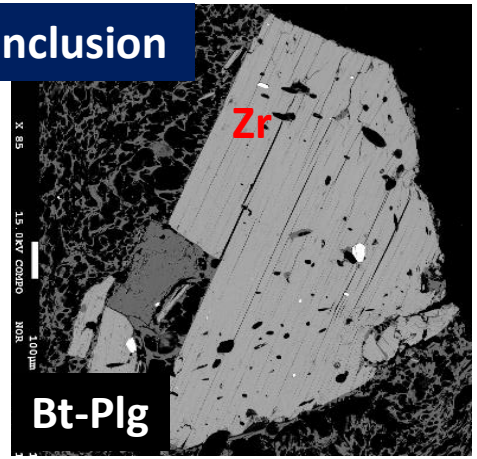
- Most crystals have fractures and are anhedral in shape
- Plagioclase and biotite as main minerals
- Plagioclase has a wide range of An numbers
- Dominated by Fe rich Biotite
- Phenocryst shows variations in shape, size, and abundance (poor - rich)
- Presence of crystal clots and aggregate
- There are several disequilibrium textures: oscillatory zoning, reverse zoning, resorbed rim, and sieve texture.

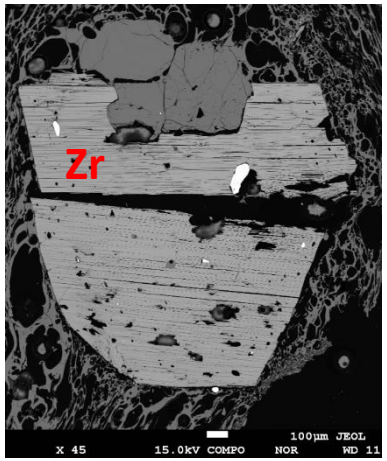


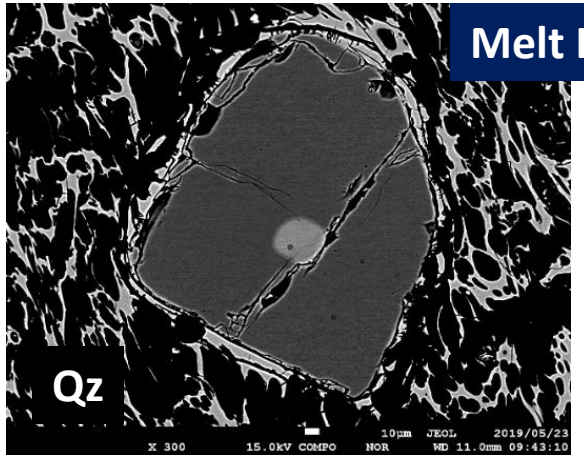
This Study

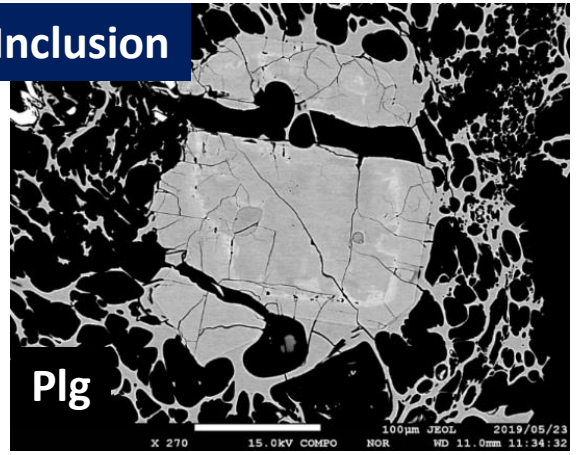
YTT CRYSTAL - Phenocryst

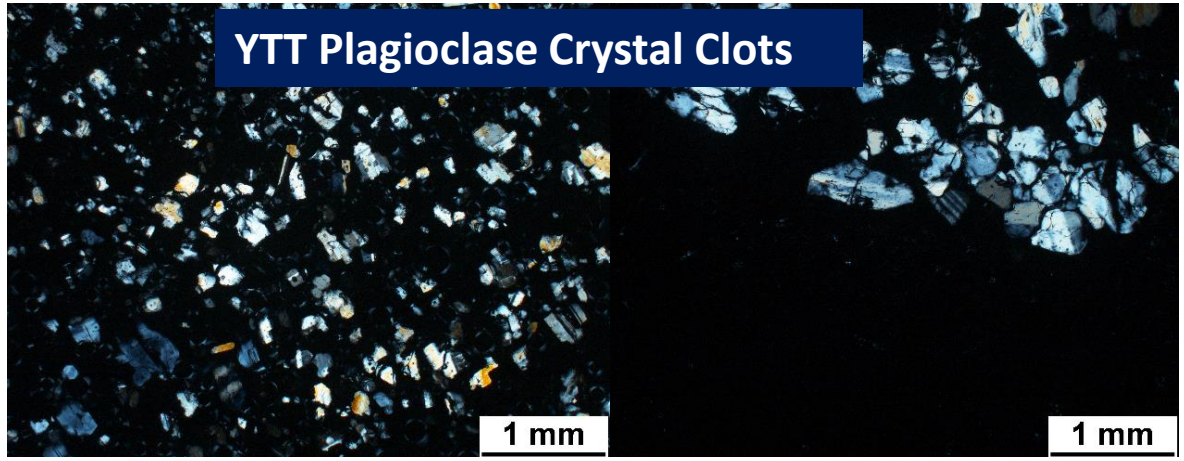


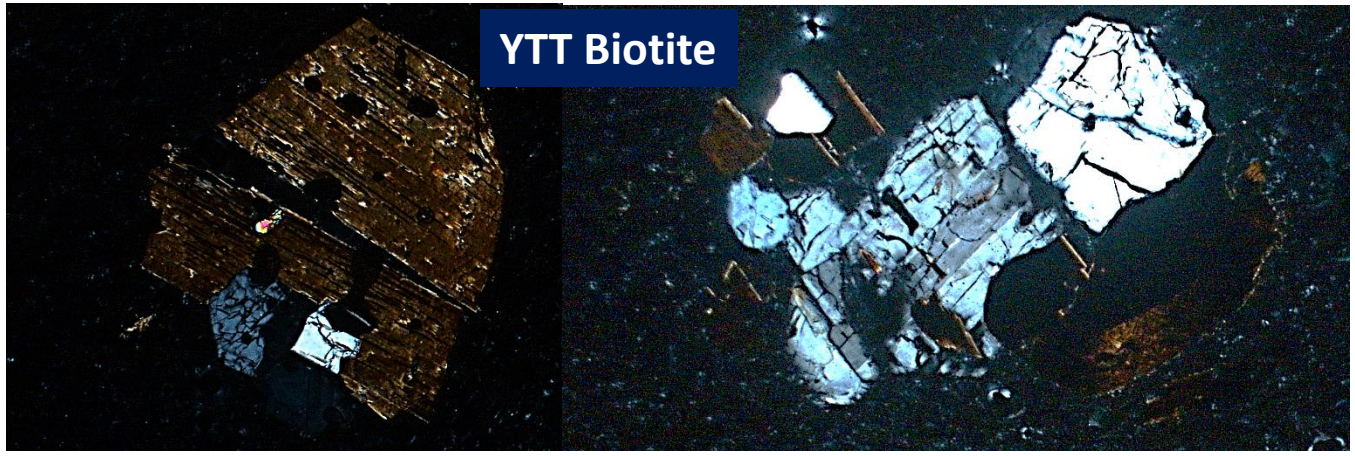












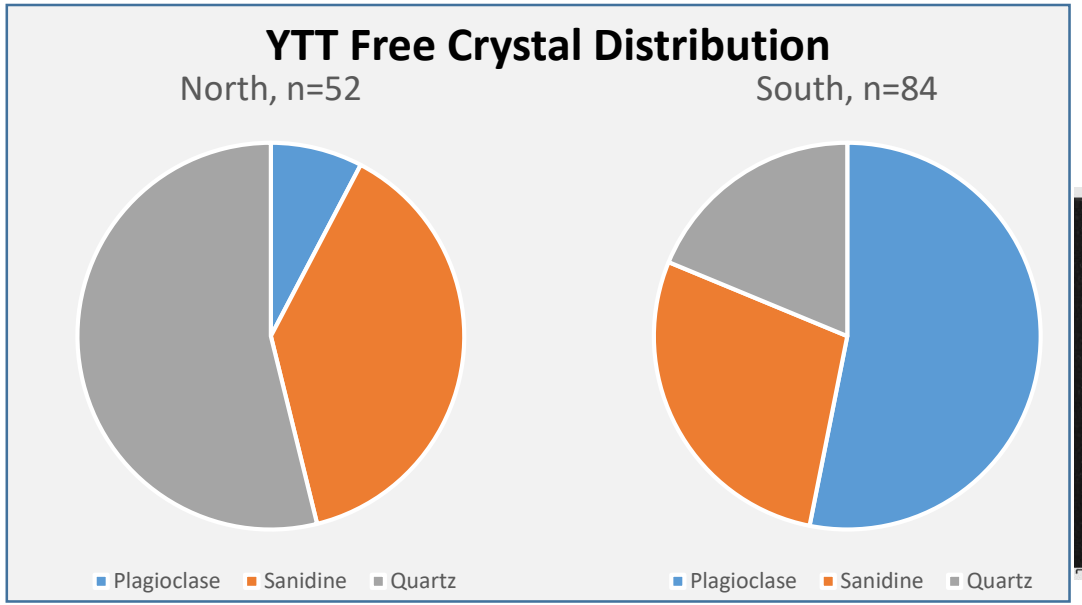
General Characteristics of YTT Phenocryst

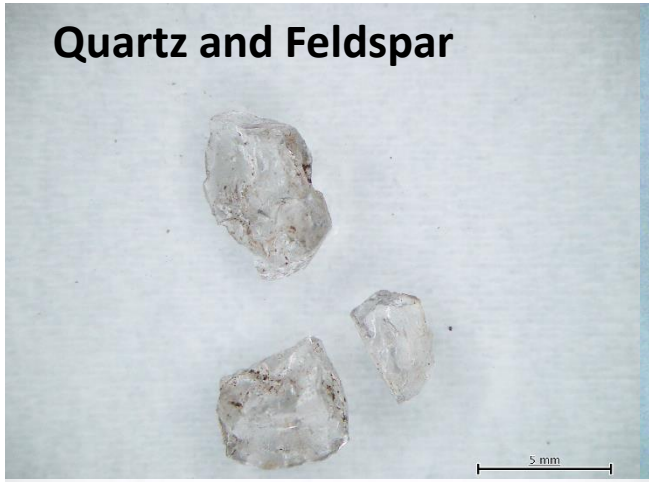
- Have variations in mineral inclusions
- Melt inclusions occur in quartz, plagioclase, and biotite minerals
- Quartz crystal aggregates are common
- Crystal aggregate bt-plg, plg-sa, plg-sa-bt

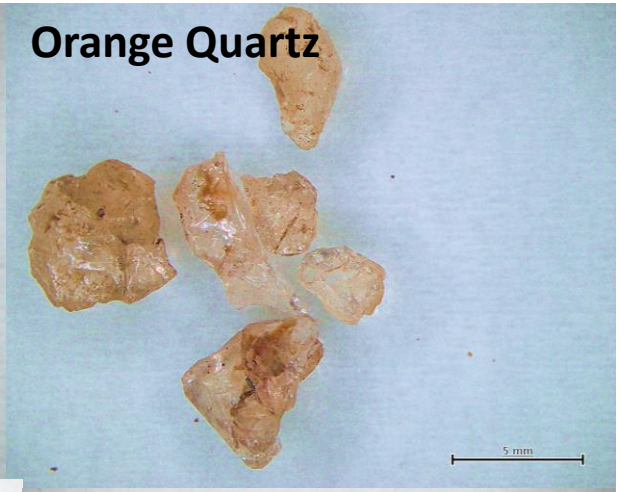
This Study
YTT CRYSTAL – Free Crystal

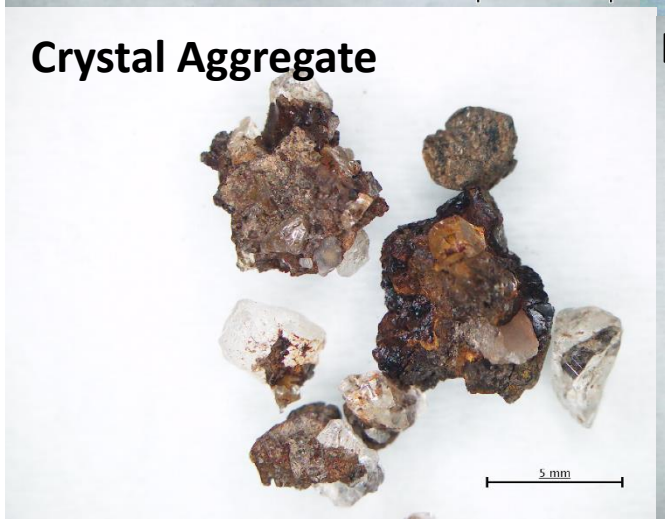
Major Mineral
Plagioclase, Biotite, Sanidine, Quartz, and Amphibole

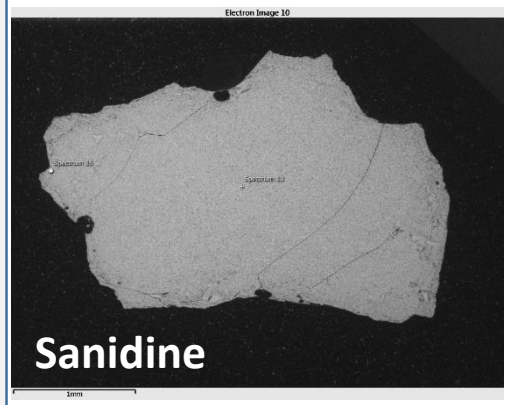
General Characteristics of YTT Free Crystal
- Generally crystals have anhedral shape
- Commonly found abundantly in thin layers above or below the PRL (Pumice Rich Layer)
- Crystal abundance differs between the northern and southern deposits, the north is dominated by quartz, while the southern deposits are dominated by plagioclase.
- The size of the crystals of southern deposits is relatively smaller than in the northern deposits

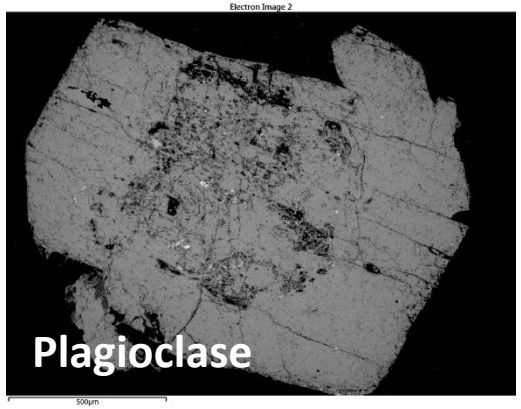


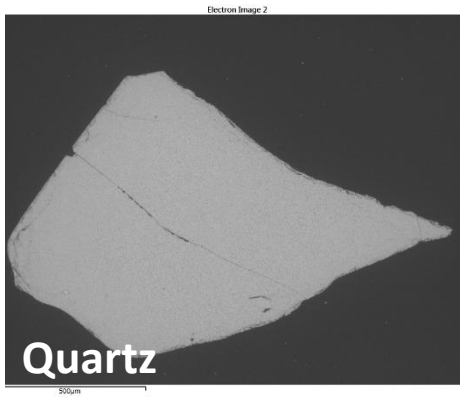






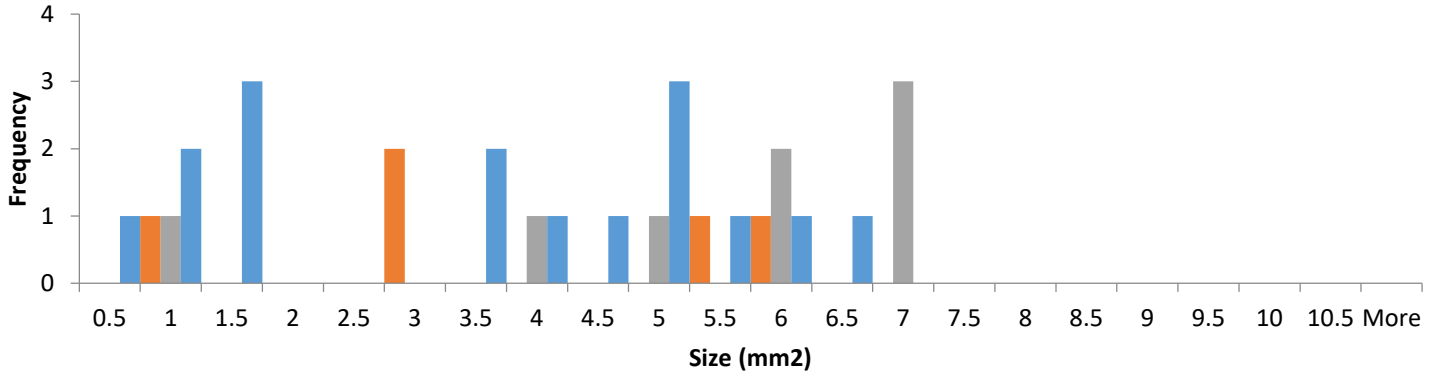




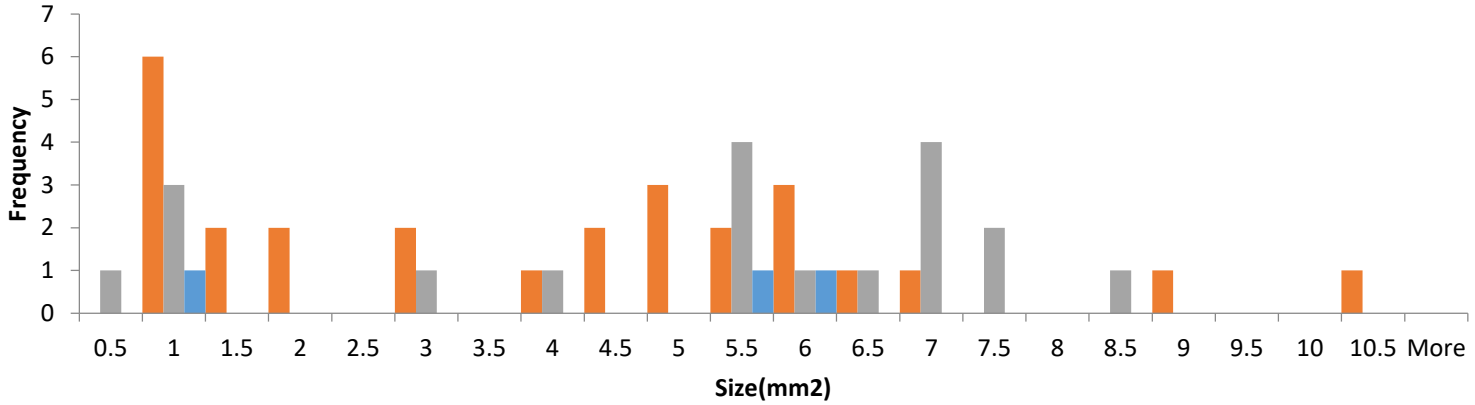


This Study
YTT CRYSTAL – Free Crystal – Crystal Size

Crystal (South), n:32

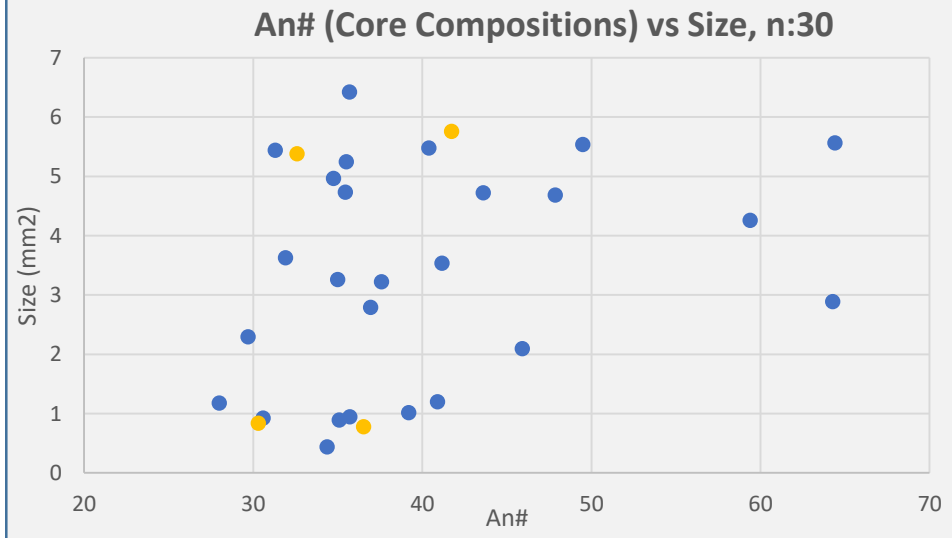


Crystal (North), n:52



Blue: Plagioclase, orange: Quartz, Gray: Sanidine

Plagioclase free crystal



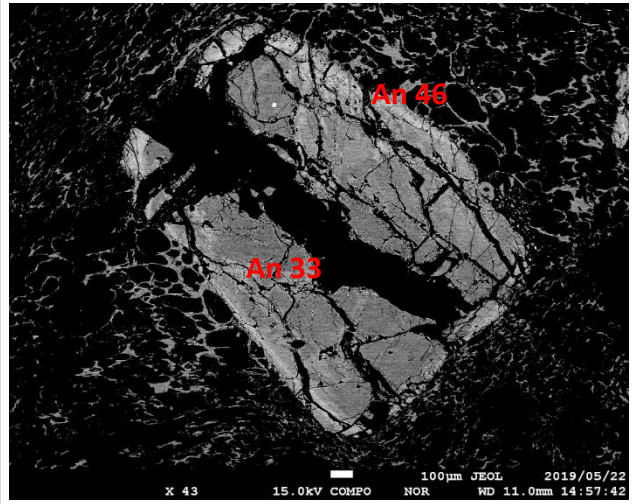
Blue: South Samples, Yellow: North Samples

- Small crystals generally have a low An#, whereas large crystals have varying An# values from low to high.

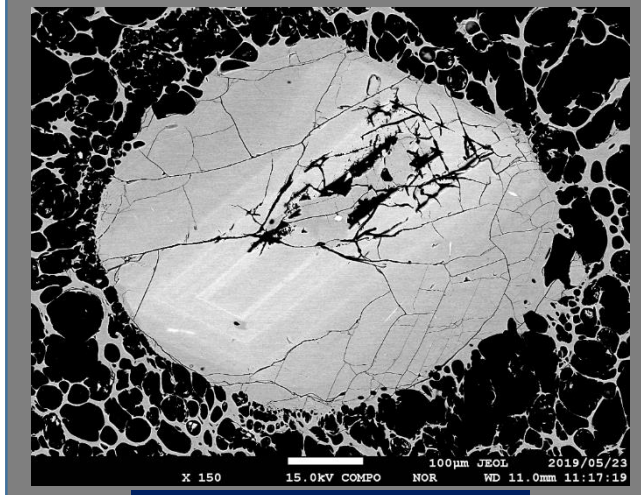
- YTT crystals (Qz, Plg, Sa) have varying sizes
- High range of crystal size was found on northern deposits
- Quartz has the widest range of size

This Study
Plagioclase

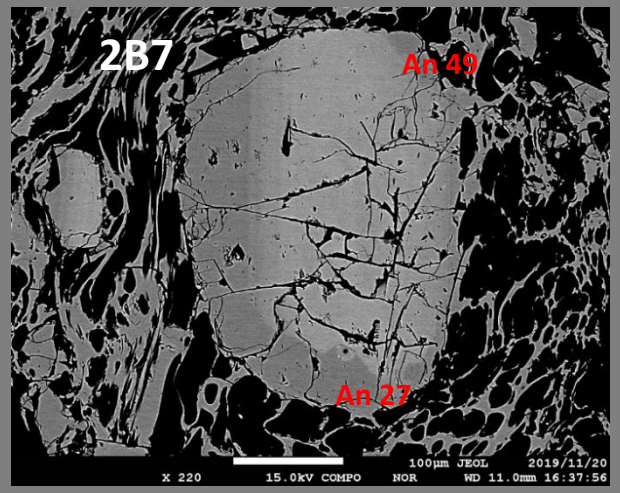
- Plagioclase shapes: euhedral & anhedral, dominated by: anhedral shape
- Types of zoning: Oscillatory zoning, reverse zoning, patchy zoning, normal zoning
- Mineral inclusions are common, consisting of: Zircon, Biotite, Iron Oxide, Ilmenite, Apatite, Amphibole, Allanite, Pyrite
- Sizes range from: 0.005 mm^2 - 13.113 mm^2
- Anortithe composition ranges from: An 21 - An 87
- Number (An #): Ca / (Ca + Na + K) * 100%
- Plagioclase from northern deposition shows a wider range of An# than Southern plagioclase
- Crystal clots are only found on the NW deposit
- There are two types of melt inclusion, without and with cracks.



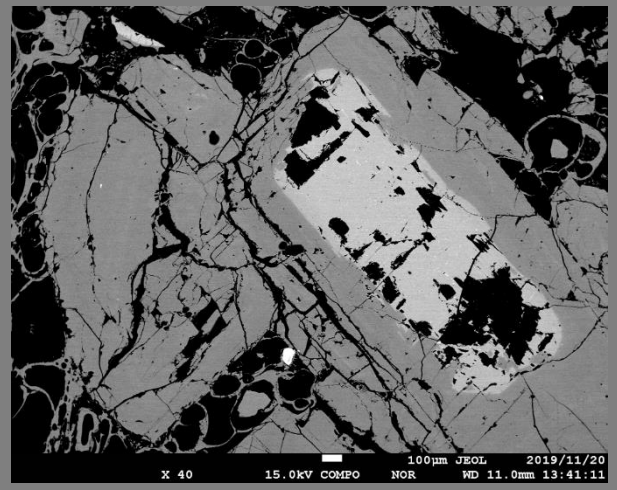
Reverse Zoning

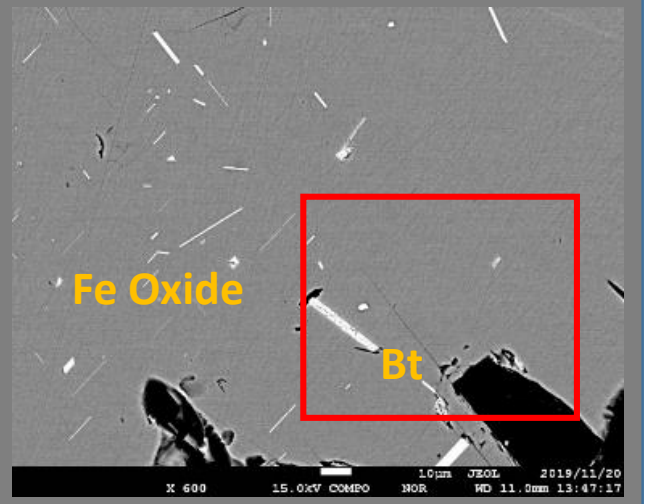


Oscillatory Zoning



Normal Zoning



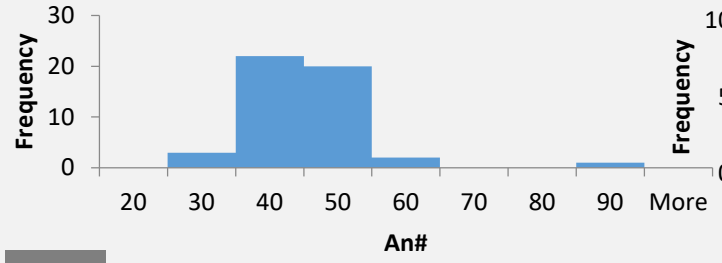


Mineral Inclusion

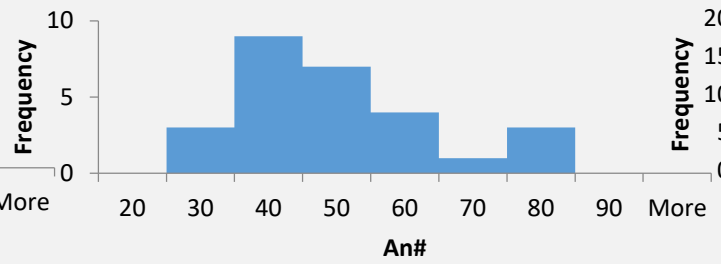
This Study
Plagioclase: Mineral Chemistry

Core

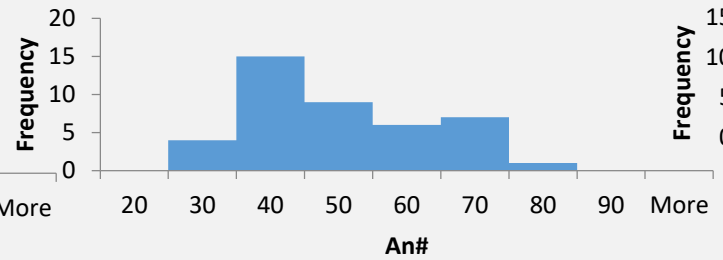
North West



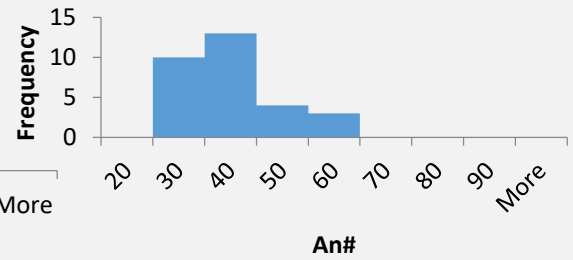
North East



North

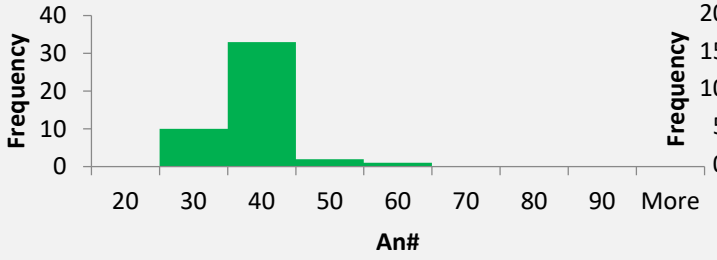


South



Rim

North West



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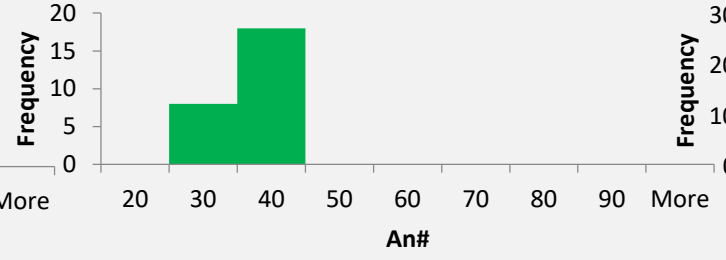

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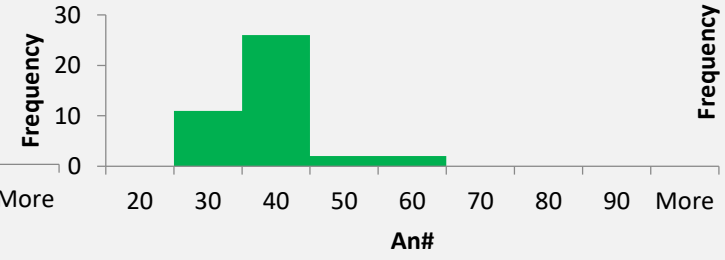

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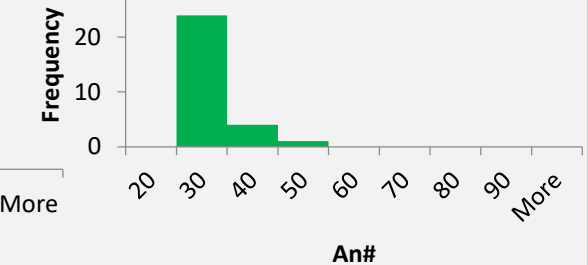
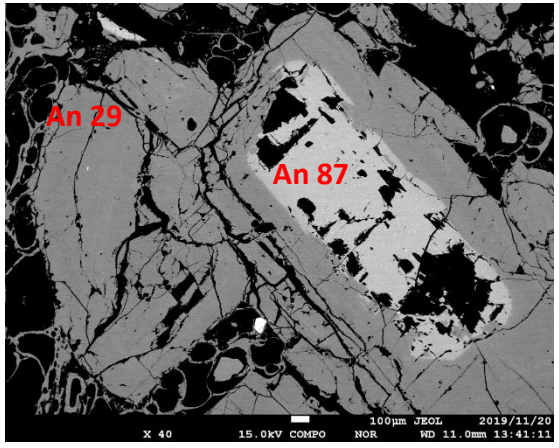
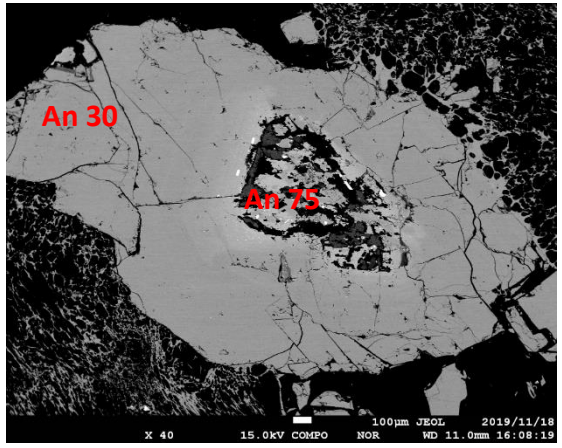




2B1 – North West



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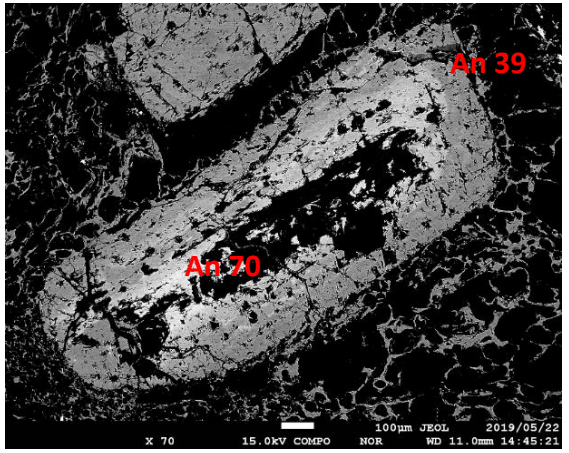
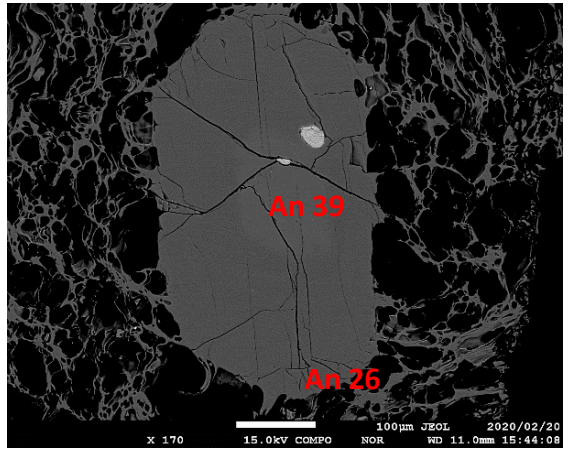
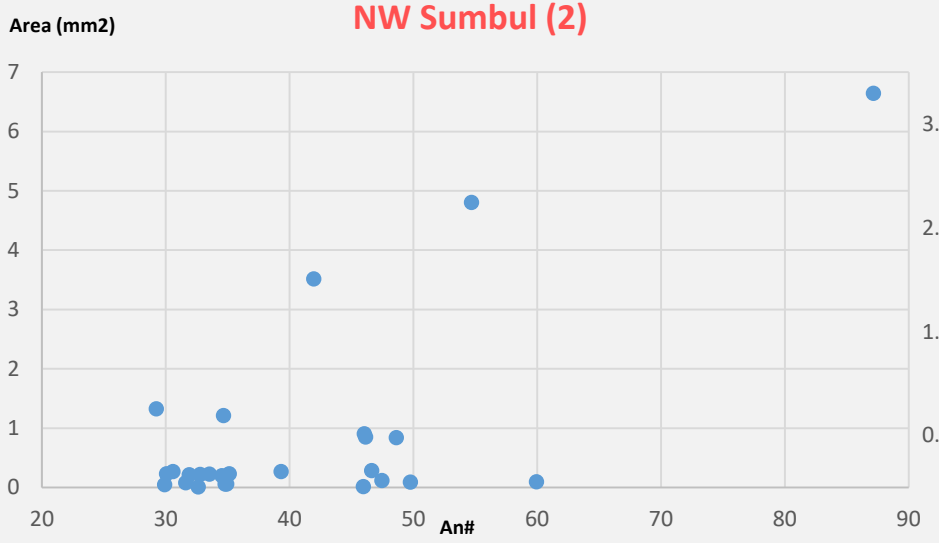


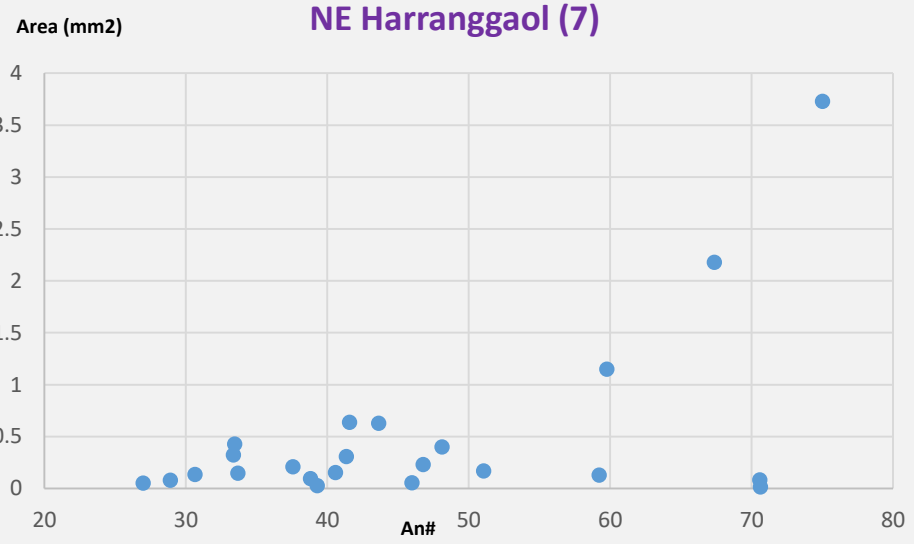
5B33 - North

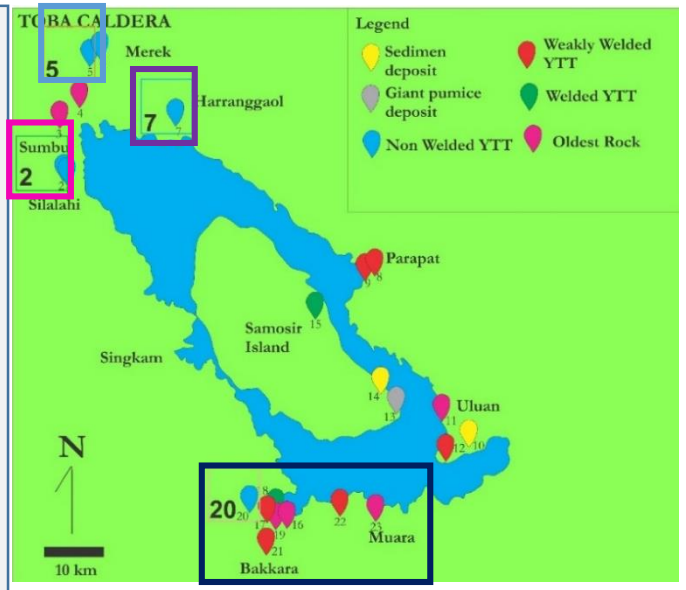


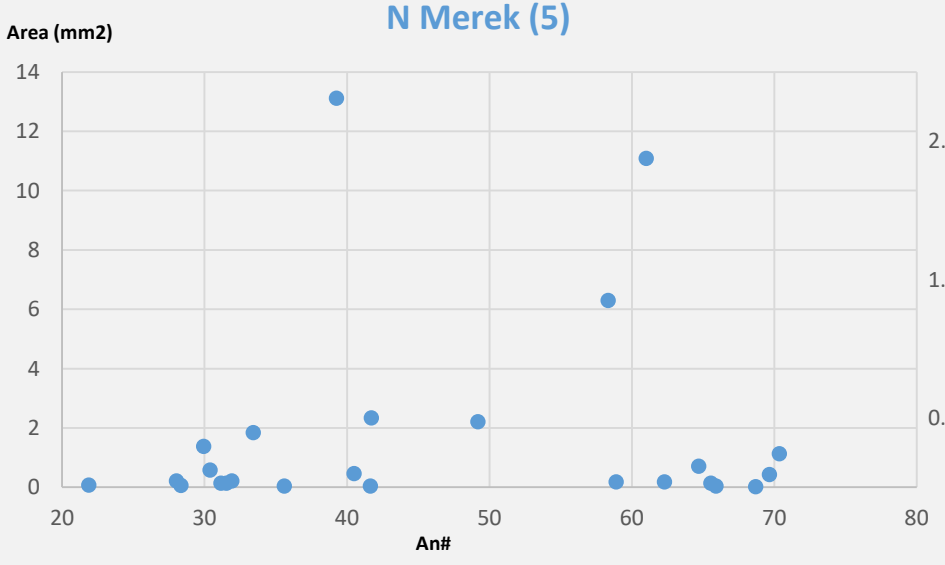
21B5 - South

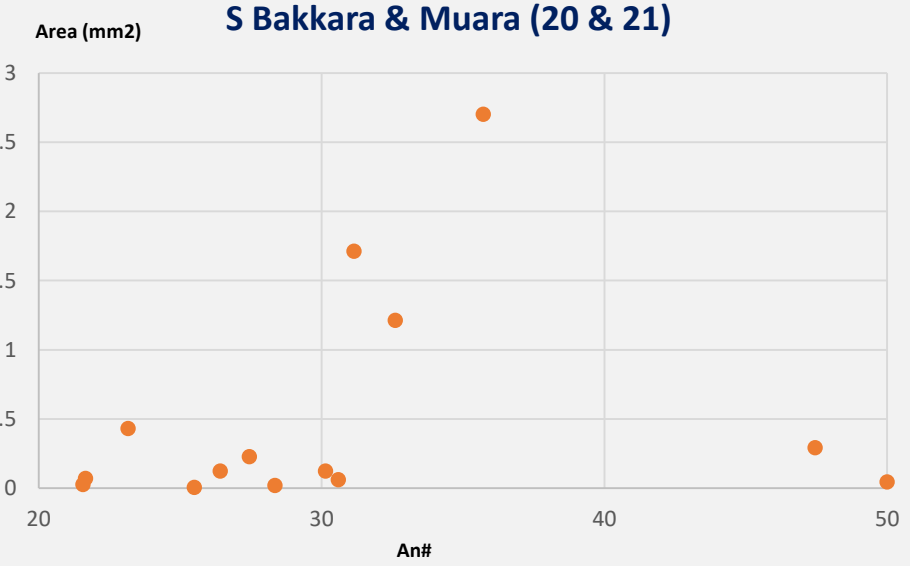
This Study
Plagioclase: Anorthite Content vs Size

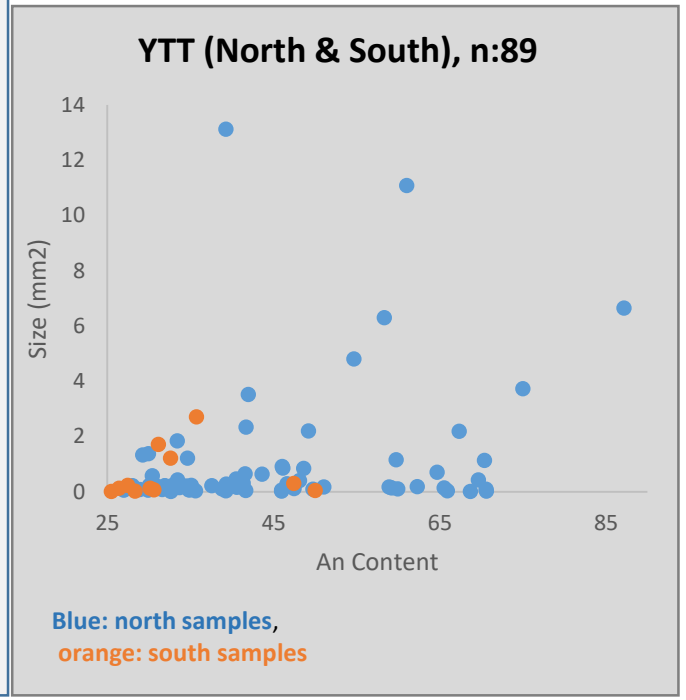










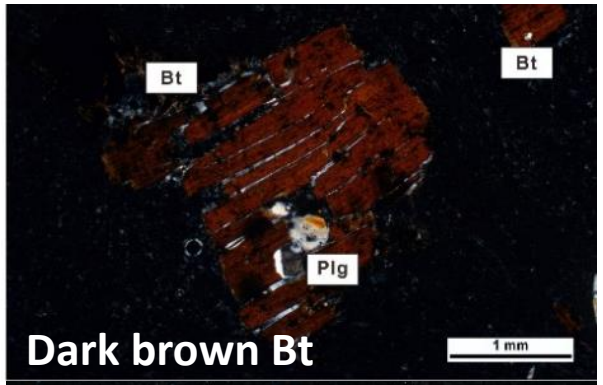


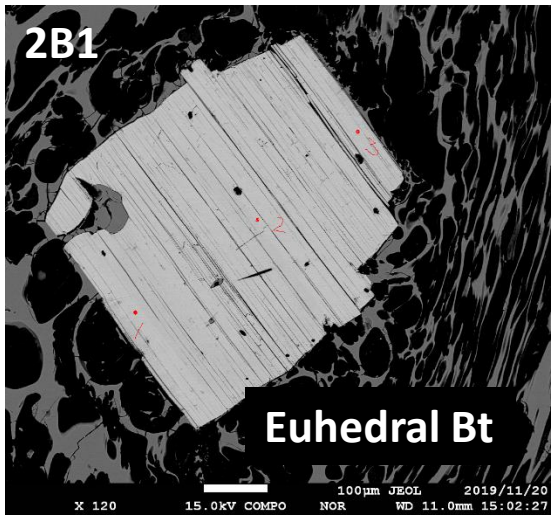
This Study
Biotite

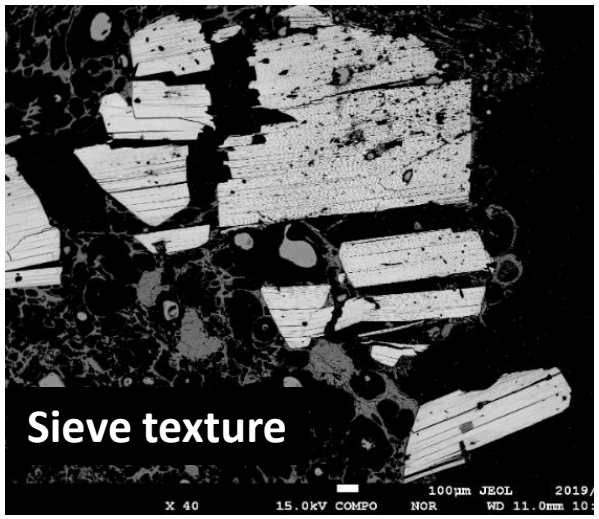
- Biotite shapes: euhedral & anhedral, dominated by: anhedral
- Biotite colour: green brown - dark brown
- Mineral inclusions are common, consisting of: small plagioclase, zircon, copper, monazite, ilmenite, allanite, and olivine
- Biotite texture: Sieve, Kink
- Mg content composition ranges from Mg 35 - Mg 48
- Biotite in the northern deposits has a wider range than biotite in the southern deposits
- Mg#: Mg / (Mg + Fe) * 100%

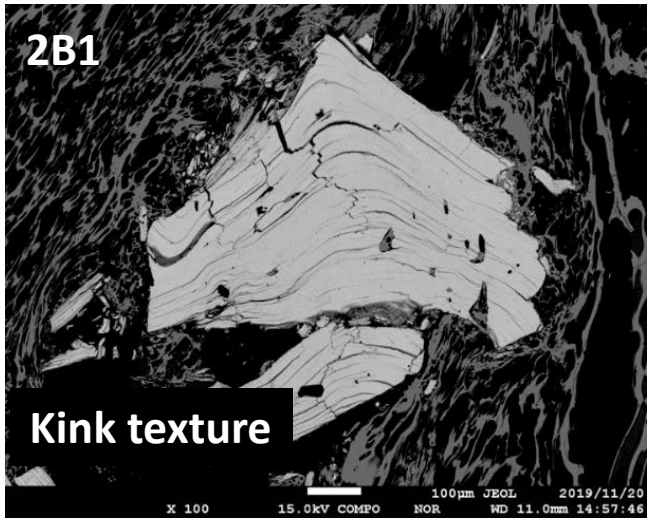
(Fe rich in Biotite in the north and south deposits)

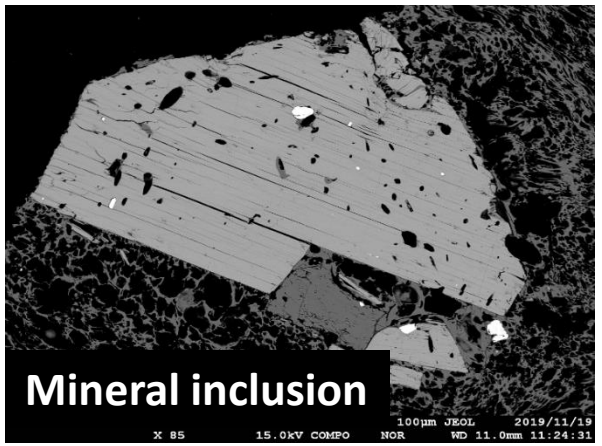
- Common both in the northern and southern deposits



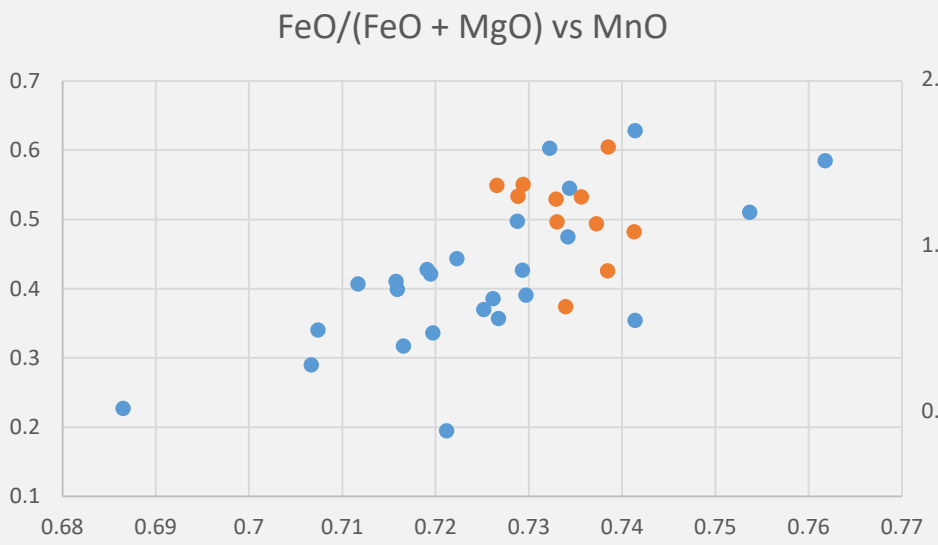


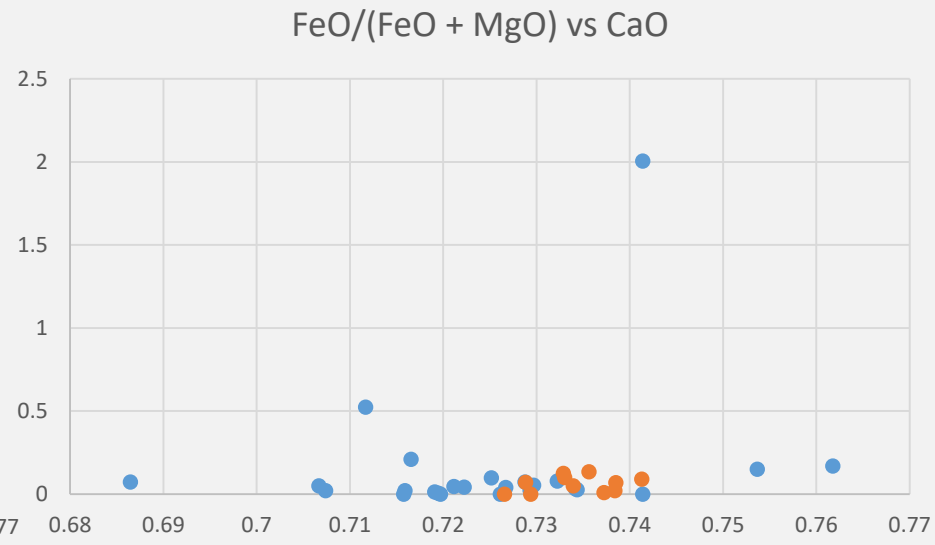


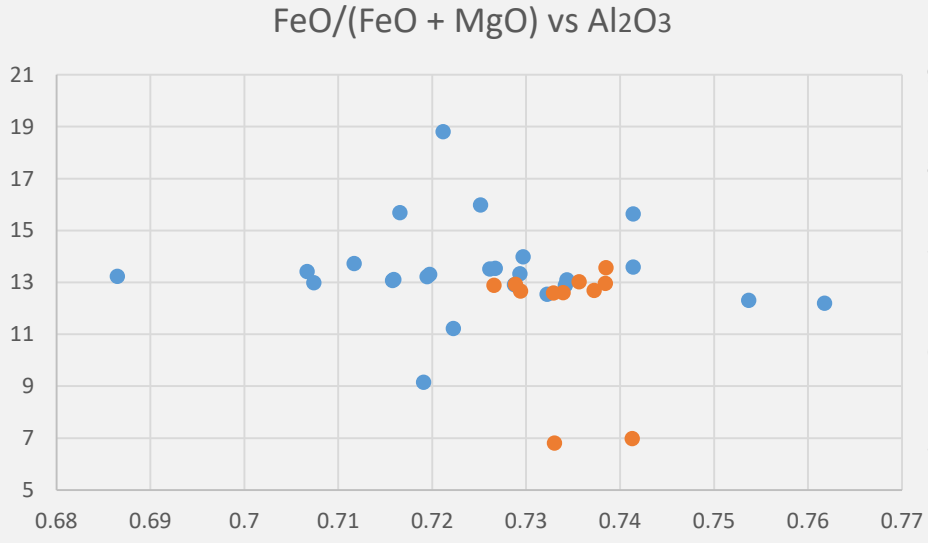


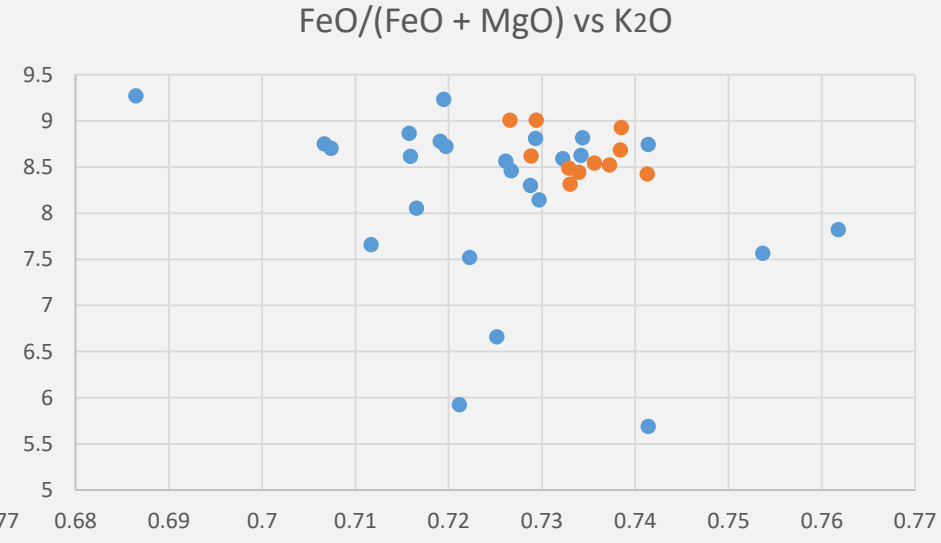


This Study
Biotite: Mineral Chemistry







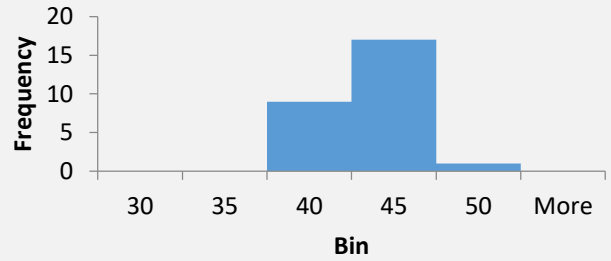


Blue: north samples, orange: south samples

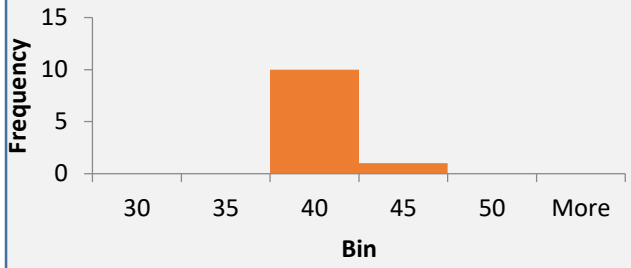
Biotite from northern deposits wider range of biotite compositions than biotite from southern deposits

Mg Number

North



South



- Biotite in the northern deposits show a wider range of Mg# than biotite in the southern deposits

This Study
Felsic Mineral

Sanidine

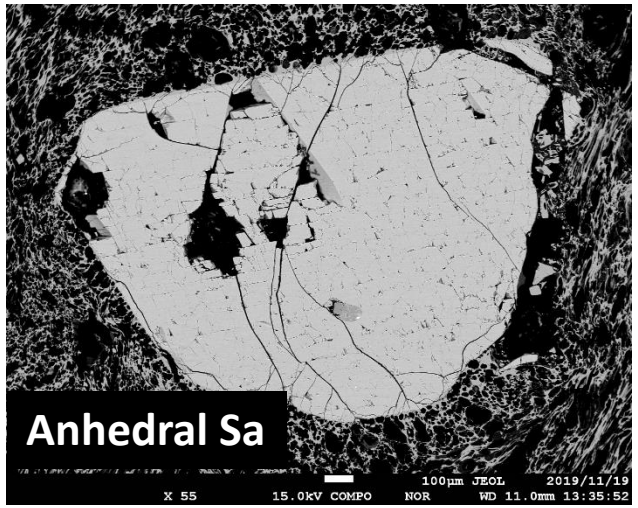
- Sanidine shape: euhedral & anhedral, dominated by: anhedral shape
- Mineral inclusion is common, consist of : Zircon, Ilmenite, Apatite, Iron Oxide
- Or content composition range from: **Or 54 – Or 85**

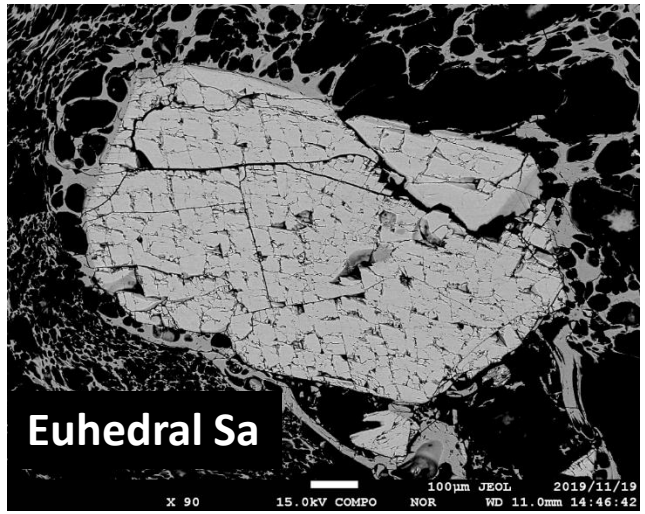
Or#: K/ (Ca+ Na + K) * 100 %

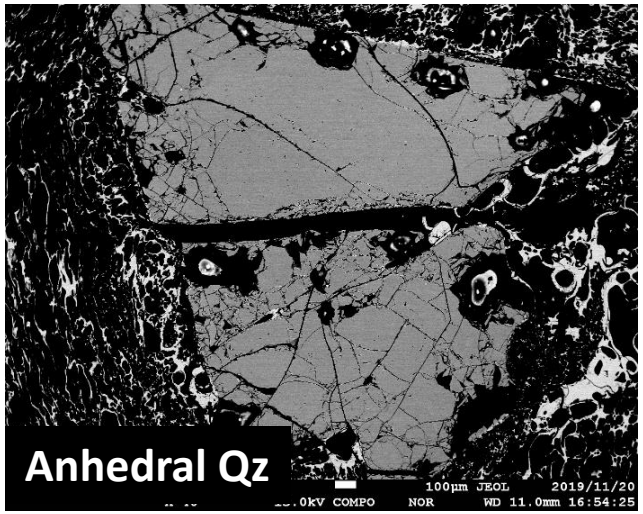
- Sanidine in the southern deposits has a wider range (Or 54 – 85) than Sanidine in the northern deposits (Or 71 -73)

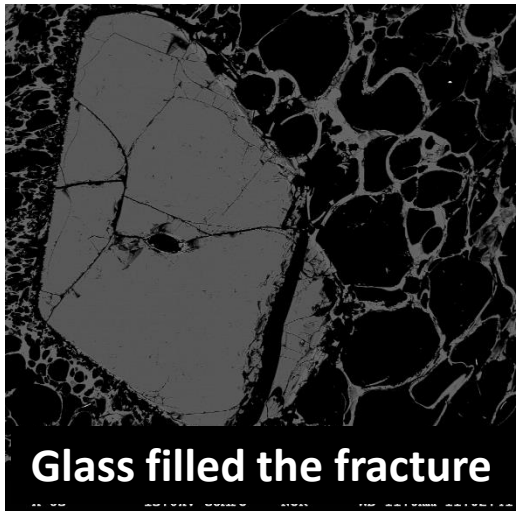
Quartz

- Quartz shape: anhedral
- Commonly form as aggregate
- Commonly experience with resorbed texture
- Generally has a fracture, glass fills the fracture
- Melt inclusion in quartz commonly with cracks



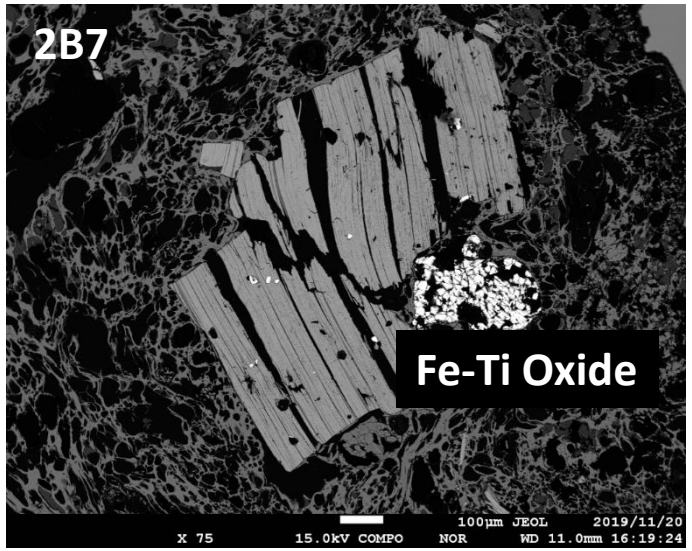


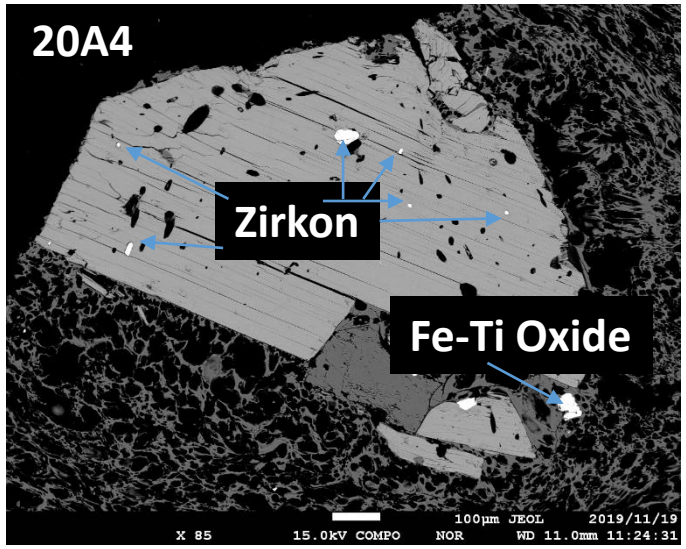


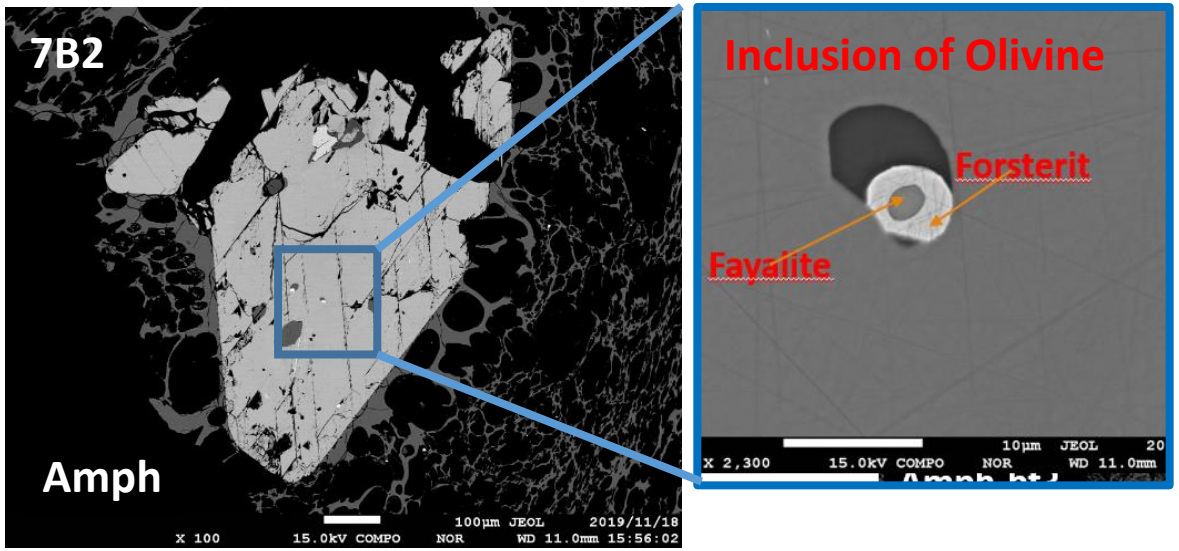


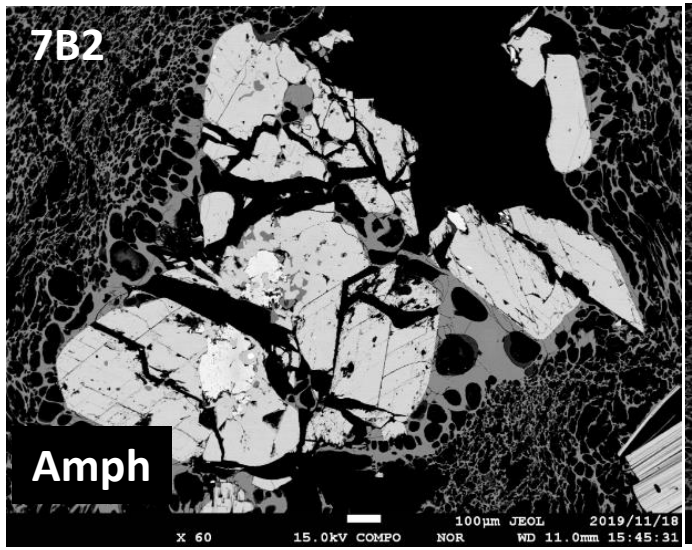
This Study
Minor phase

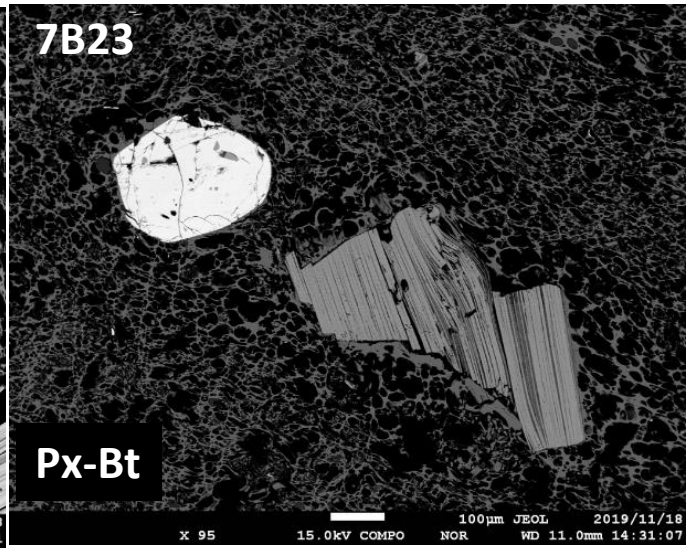
- Consist of: Amphibole, Pyroxene, Zircon, Fe-Ti Oxide, Allanite, Apatite, Monazite, Sulfide (Pyrite), Copper, and Olivine
- Amphibole phenocryst only found in northern deposit.
- The other minor phase are found both in northern and southern deposit.
- Chesner (1998) interpreted that some amphibole in YTT deposit as xenocryst origin (by experimental petrology).



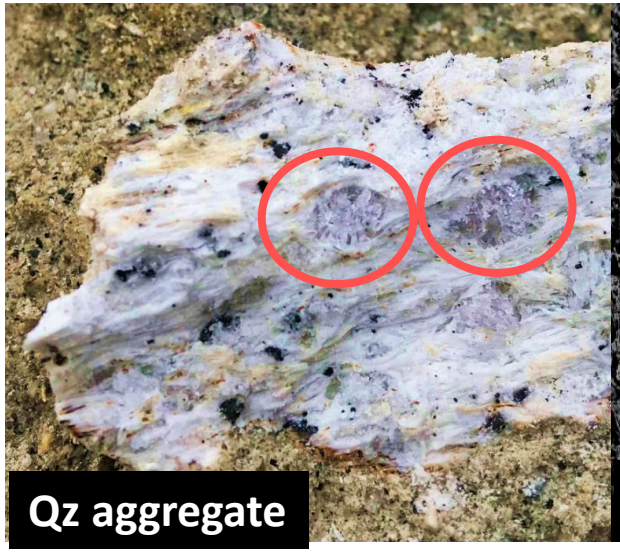


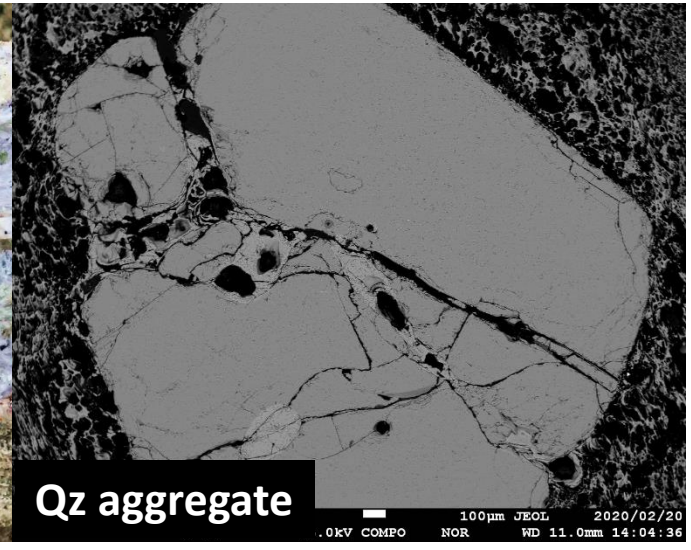






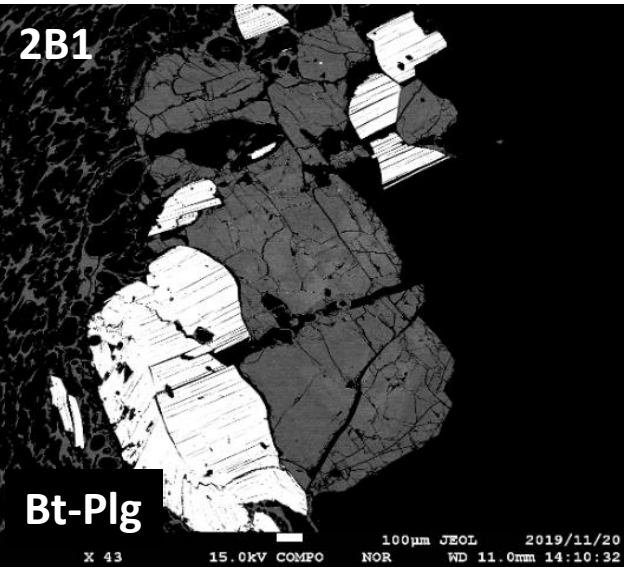
This Study
Crystal Aggregate

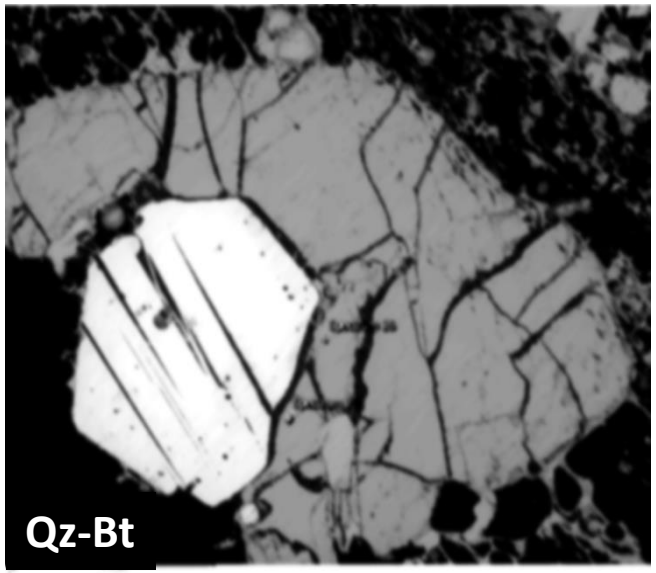


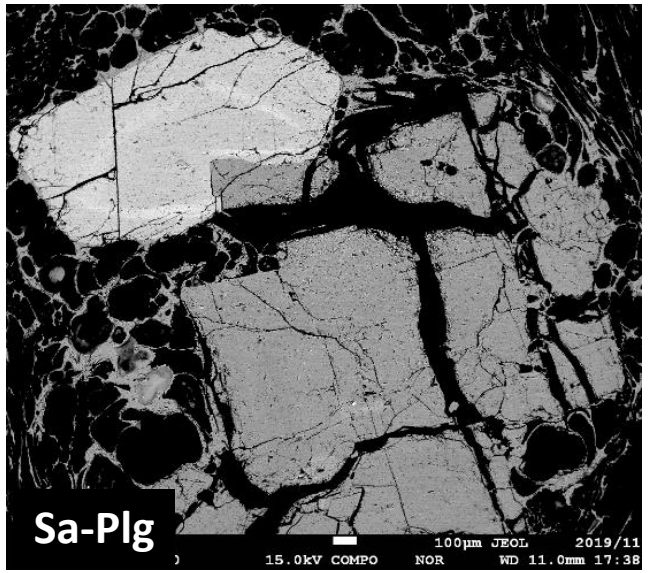


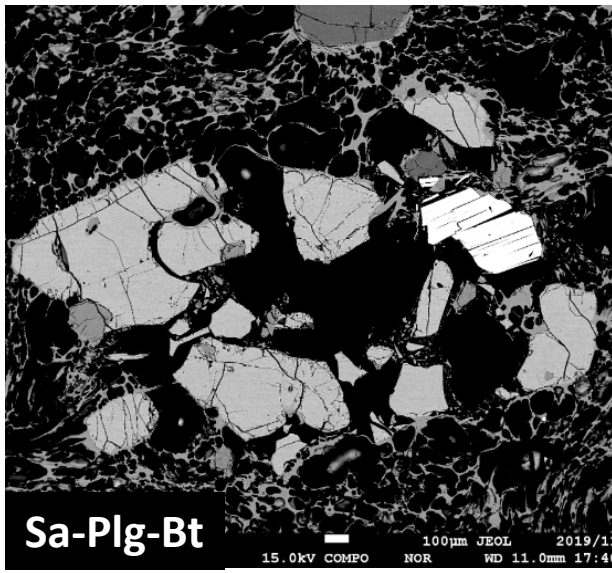
YTT Crystal Aggregate

- YTT deposit has a variety of aggregate crystals
- Both pumice from northern and southern deposit experience with crystal aggregate.
- Qz aggregate, Aggregate of Bt-Plg is found both in northern and southern deposit
- Aggregate of Qz-Bt is only found in northern deposit
- Aggregates are found in small to large sizes
- Quartz aggregates are generally found to fill bubbles in pumice







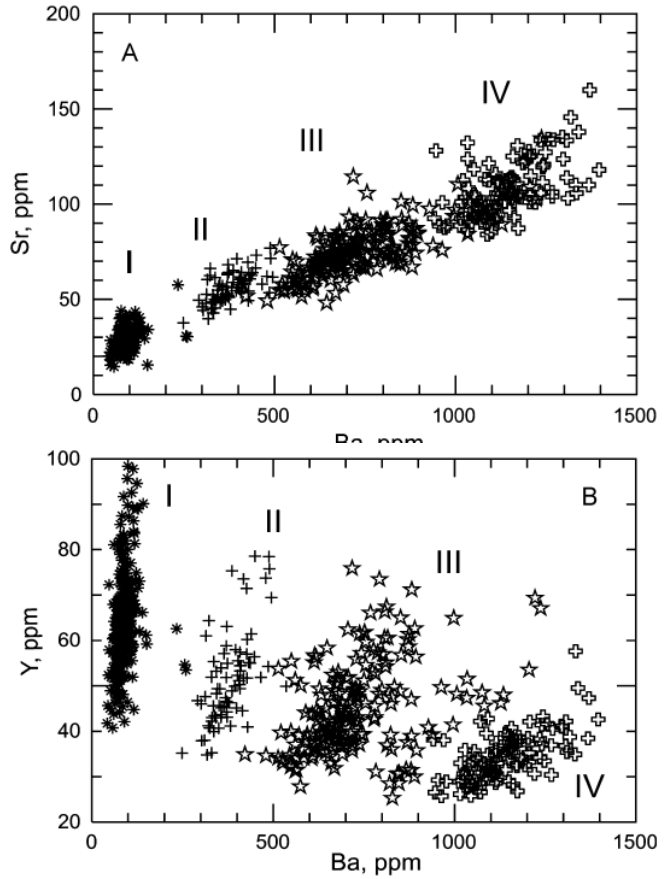


Characterization of YTT Phenocryst

Parameter	Northern	Southern
Presence of amphibole	Presence	Absence
Crystal aggregate type	Sa-Plg-Bt, Plg-Bt, Qz	Sa-Plg, Bt-Qz
Presence of crystal clots	Presence	Absence
Variation of disequilibrium texture	Oscillatory, reverse, and patchy zoning, resorbed rim	sieve texture
Anorthite number	Wider range: An21-87	Restricted range: An21-57
Magnesium number	Wider range : An21-87	Restricted range: Mg36-41
Orthoclase number	Restricted range: Mg35-48	Wider range : Or54 to 85
Presence of antecryst (Orange Quartz)	Presence	Absence
Domination of free crystal	Quartz	Plagioclase
Plagioclase shape	Dominated by anhedral shape	Dominated by euhedral shape
Crystal Size	Larger than southern crystal, show wider range	Smaller that northern crystal

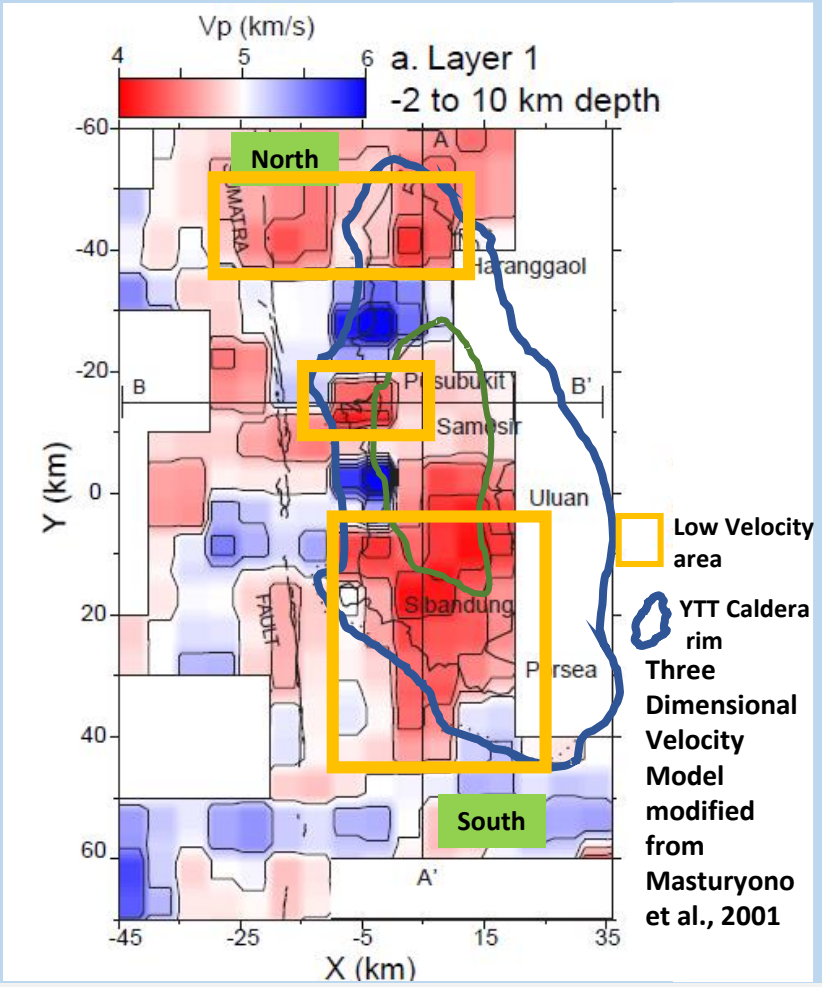
YTT Crystal from North and South Part deposit shows different characteristic

- YTT mineral especially plagioclase **show complex crystallization history which cannot explain only with fractional crystallization (there is another process that gives effect to magma reservoir dynamics)**.
- Plots of anorthite number versus size show **random distribution**, suggesting the **complex crystallization** of plagioclase: other processes than fractional crystallization in magma chamber.
- Presence of antecryst and disequilibrium textures in northern deposit indicates **intervention from older rocks or even other systems**
- Different characteristics between northern and southern deposits suggest that YTT deposits are generated by multiple eruptions from independent, **at least two magma chambers**.



Sr – Ba and Y – Ba plots showing four distinct populations of glass shards in YTT (Westgate et al., 2013)

Four primary glass populations, well defined by their Sr, Ba and Y concentrations, occur in the Youngest Toba Tuff (YTT), which was deposited during a super eruption of the Toba caldera complex in northern Sumatra 75 ka. **No clear pattern in the areal distribution** of these four glass groups can be discerned (**Wesgate et al., 2013**). However, this information is very important as one of the earliest indications of **different magma chambers** that produces YTT eruptions.



This shallowest section shows that In the southern part there are **largest low velocity area (15 x 40 km), while in the northern a smaller area of low velocities** is observed in the upper crust under the north end of the depression (Masturyono et al., 2001). Separating the two regions is a zone of **locally high velocities** indicating that **the caldera magma system is composed of three separate reservoirs**.

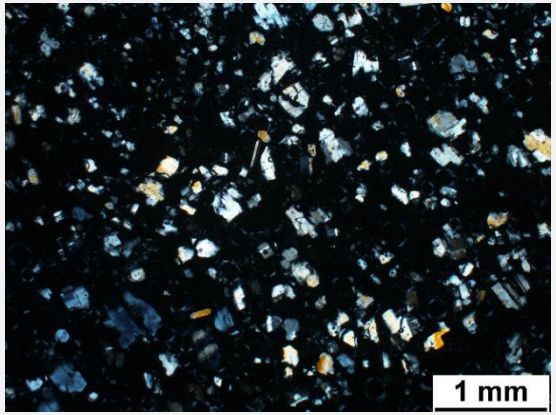
This Study & Previous Study

This study and several previous studies show the same indication, that the tremendous eruption of YTT was produced by **at least two different caldera systems**. Northern caldera deposits have more diverse variations both in mineralogy and mineral chemistry, the presence of crystal clots, antecryst along with the interpretation from geophysics data that northern caldera is smaller than southern caldera, indicates that in small scale area of the northern chamber **the processes which occur between crystals and surrounding rocks are more intensively** than in the southern part.

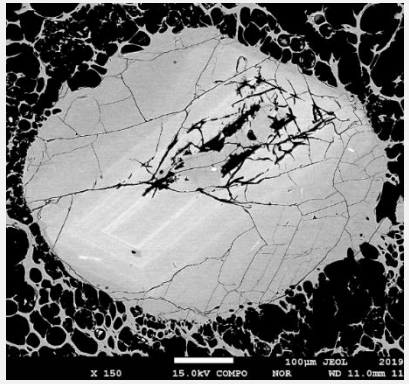
Future Works

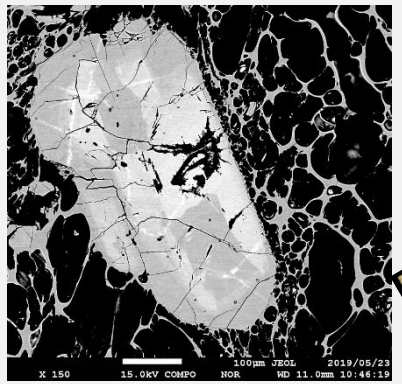
- More detail mineral characterization (add sample for Petrography, EPMA)
- P-T Estimation
- CSD Analysis from pumices thin section and individual crystal
- Melt Inclusion Study
- FTIR Analysis
- Mineral dating (K-Ar) / (Ar-Ar)
- CL Study in quartz

NORTHERN AREA

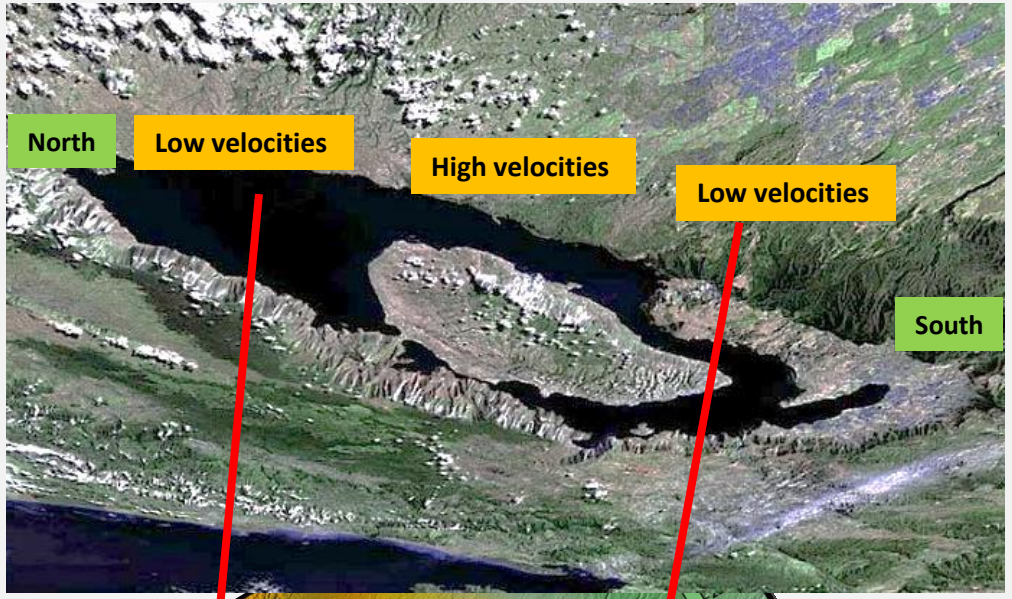


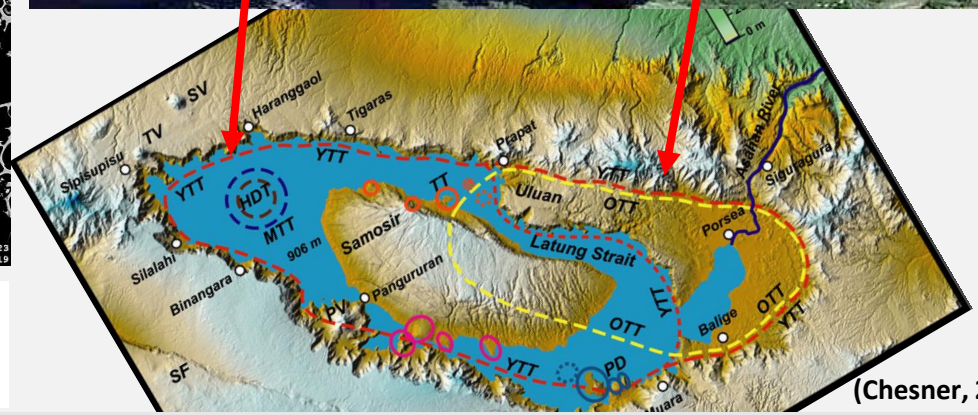
Crystal clots of Plagioclase are only found on YTT deposits located at northern part.





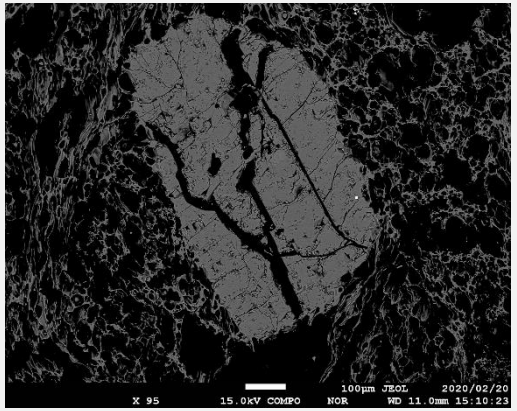
Disequilibrium texture (Oscillatory, reverse, and patchy zoning) and anhedral shape (curved edges) are common in plagioclase form norther part

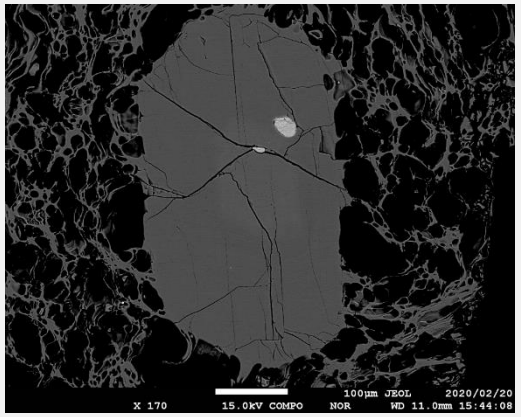




(Chesner, 2011)

SOUTHERN AREA





Plagioclase from the southern part generally has a more euhedral shape without the presence of a disequilibrium texture.

Small chamber (Northern Chamber)

- Hotter temperature, consequently a **greater pressure drop** (decompression rate estimation from north deposits is relatively greater than in the south)
- **Crystal clots** occurrences and **anhedral shape of crystal** (relatively show curved form at the edges of crystals) as a sign of **more intensive interaction between each crystals**.
- The appearance of crystals with a **disequilibrium texture is more common**: patchy zoning, oscillatory zoning as **indication of abrupt changes in temperature and pressure.**