Petrography of the Sonju Lake Intrusion

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History of the Sonju Lake Intrusion(SLI)

- Part of the failed continental rift from 1.1 Ga
- Part of a larger intrusion, the Duluth Complex
- Located in Minnesota, United States of America, about 50 mi NE of Duluth
- About 3 km of layers exposed on surface
  - Believed to continue south-southwest 20 km under glacial material
- Study done by Stevenson exposed the intrusion in 1974

Mechanisms of Cooling

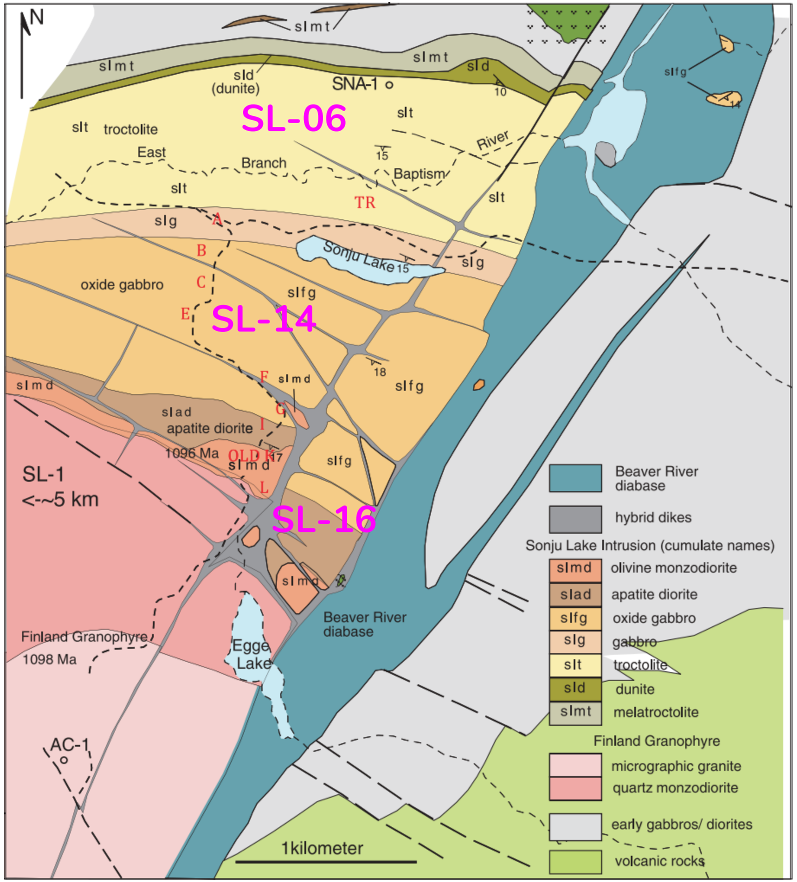
- Long-standing view of mafic intrusion cooling was large body of magma with crystals dropping out
    - Known as cumulate model
- However, model has its flaws
    - Considers km's large magma body, but no such modern example comes close
    - Plagioclase should float in basaltic magma, not sink
    - Olivine and pyroxene would have to be large crystals before they could overcome surrounding yield strength
- Lundstrom and Gajos proposes potential "top-down" processes based on silicic plutons
    - Includes "top-down" sill injections or emplacements
    - Also potential for in-situ crystallization
- Still much research to be done to determine the mechanism(s)

Stratigraphy

- Intrusions known for their systematic and gradual change in mineralogy/composition, resulting in a predictable sequence of rocks
- 1200 m thick spread over 9 km^2
- Over top lies the Finland granophyre of the Beaver Bay Complex
    - Silicic pluton, similar size
- SLI from bottom to top is characterized as a dunite, troctolite, gabbro, oxide-rich gabbro, and an apatite oxide gabbro
- Along border of SLI and FG exists alternating layers of mafic and felsic material

Our Samples

- SL-06 was taken from slt and has been identified as a troctolite
- SL-14 was taken from slfg and has been identified as an oxide rich gabbro
- SL-16 was taken from slad and has been identified as an apatite diorite

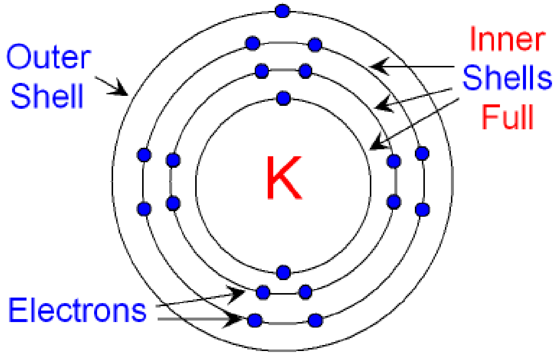


Guiding Question:

How do the ratios of elements and minerals in our hand samples change throughout the stratigraphic column of the Sonju Lake Intrusion, and how do they compare to the ratios already calculated in previous literature?

Methods

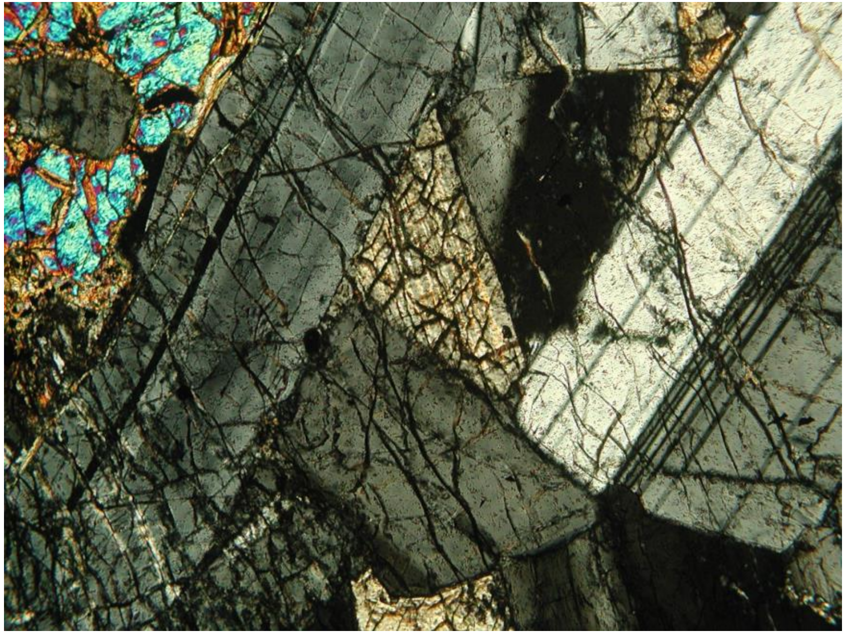
- Selected samples from 3 different spots on the intrusion
- Used the rock saw to cut our samples
- Used the Buehler machine to grind the rock down
- Polished samples with the 1 micron diamond grit
- Samples were taken to the SEM and analyzed
    - Electron beam shot at sample
    - An electron hits inner shell of the atom, knocking out an electron
    - Electron drops because inner shell needs to be filled
    - This release energy in the form of an x-ray and is measured by multiple detectors
    - The distance of the drop indicates the intensity of the x-ray that is unique to every element



gcscscience.com

Pyroxene

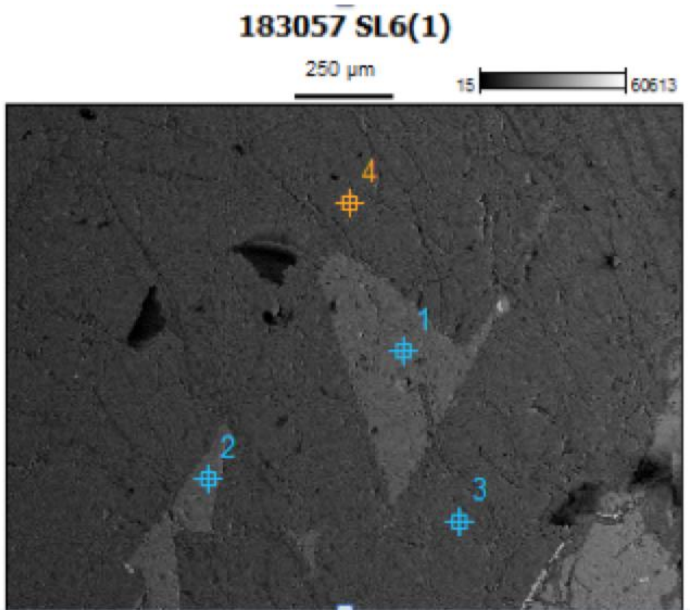
- Single-chain inosilicate
- Variety of forms of pyroxene
  - Substitution on atoms based on coordination numbers
- Most common form found in SLI is augite: $Ca(Fe,Mg)Si_2O_6$



Objective: 20x

Interstitial Pyroxene

- In SL-06 sample, only pyroxene found was interstitial
  - Euhedral grains form first
  - Pyroxene forms in left over space
- In Miller-Ripley (1996), they noted halfway through *slt*, there was augite troctolite with 8% inverted pigeonite that significantly changed to augite-poor troctolite
- Associated with magmatic recharge event
- Possible cause of outlier in pyroxene composition



SL-06

Pyroxene: Measured vs. Standard (weight)

Sample SL-16	
Element	Point 1
Na	0.28
Ca	13.14
Mg	5.17
Ti	0.49
Al	0.49
Fe	16.86
Si	23.78
O	39.14

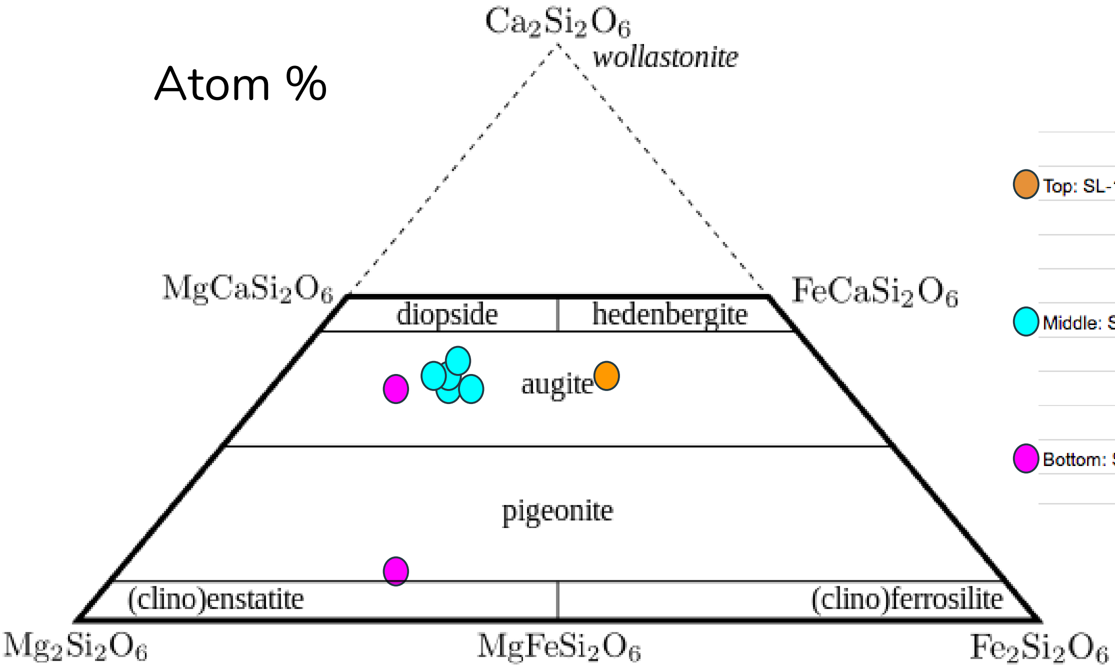
		Sample SL-14				
Element	Point 1	Point 2	Point 3	Point 4	Point 5	Avg.
Na	0.31	0.33	0.26	0.33	0.27	0.3
Ca	15.17	12.64	13.23	16.75	14.64	14.486
Mg	9.09	9.54	9.15	8.84	8.42	9.008
Ti	0.6	0.57	0.58	0	0.63	0.595
Al	1.11	1.21	1.16	0.32	1.17	0.994
Fe	10.6	8.78	8.83	9.88	8.57	9.332
Si	25.24	24.52	25.08	26.41	24.92	25.234
O	37.88	42.42	41.71	37.47	41.39	40.174

	Sample SL-06		
Element	Point 1	Point 2	Avg.
Na	0.14		0.14
Ca	14.21	2.53	8.37
Mg	10.04	14.1	12.07
Ti	0.4		0.4
Al		0.7	0.7
Fe	7.29	14.83	11.06
Si	25.02	26.12	25.57
O	41.4	41.71	41.555

Sodium	0.97 %	Na
Calcium	15.26 %	Ca
Magnesium	9.26 %	Mg
Titanium	2.03 %	Ti
Aluminum	4.57 %	Al
Iron	4.73 %	Fe
Silicon	22.58 %	Si
Oxygen	40.62 %	O

Pyroxene Quadrilateral

Atom %



https://en.wikipedia.org/wiki/Pyroxene

		Point 1				
	Ca	38.92				
Top: SL-16	Mg	25.25				
	Fe	35.83				
		Point 1	Point 2	Point 3	Point 4	Point 5
	Ca	40.17	36.46	38.19	43.57	42.23
Middle: SL-14	Mg	39.67	45.38	43.52	37.96	40.04
	Fe	20.15	18.15	18.3	18.47	17.73
		Point 1	Point 2			
	Ca	39.47	6.94			
Bottom: SL-06	Mg	46	63.85			
	Fe	14.53	21.28			

Normalized Values

Fe/Mg in Pyroxene

Assuming Ca was negligible, one would expect a change in the Fe/Mg ratio throughout the depth of the intrusion.

SL-16 (top):

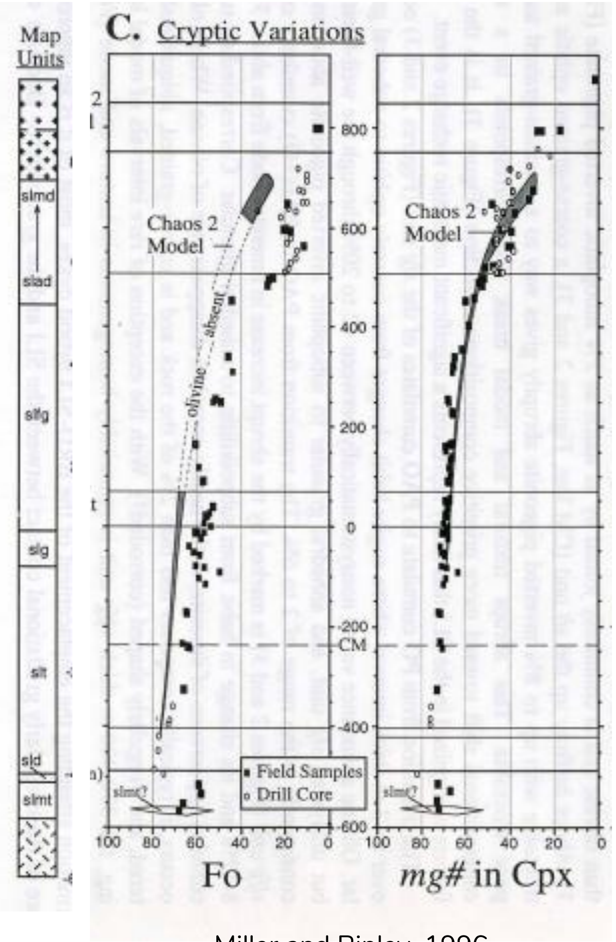
Ratio	Point 1
Mg	41.3
Fe	58.7

SL-14 (middle):

Ratio	Point 1	Point 2	Point 3	Point 4	Point 5	Avg.
Mg	66.31	71.43	70.4	67.27	69.31	68.944
Fe	33.69	28.57	29.6	32.73	30.69	31.056

SL-06 (bottom):

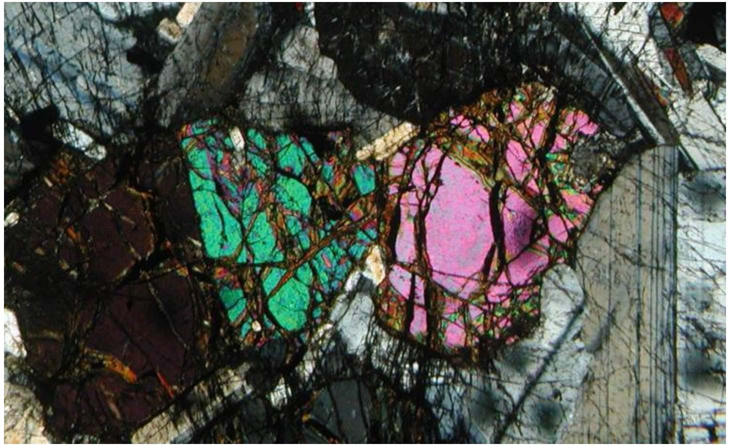
Ratio	Point 1	Point 2	Avg.
Mg	76	68.6	72.3
Fe	24	31.4	27.7



Miller and Ripley, 1996

Olivine $(Mg,Fe)_2SiO_4$

- Nesosilicate
- Two types
  - Forsterite - Mg endmember: Mg_2SiO_4
  - Fayalite - Fe endmember: Fe_2SiO_4
- Found in higher abundances lower in layered mafic intrusions
- Ratio of Fe:Mg increases as samples are analyzed higher in stratigraphic column

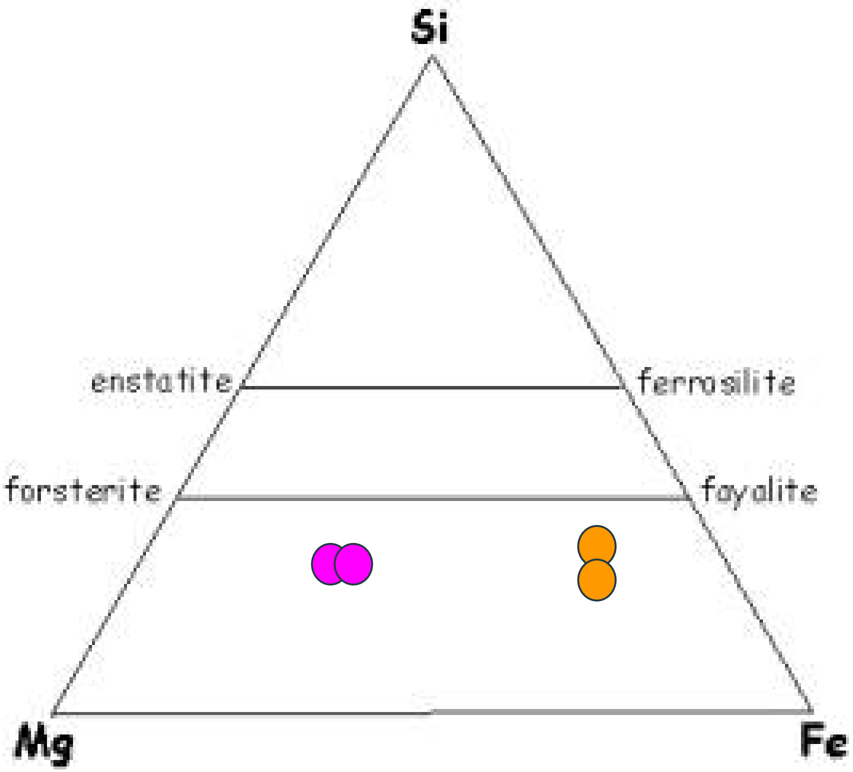


Objective: 2.5x

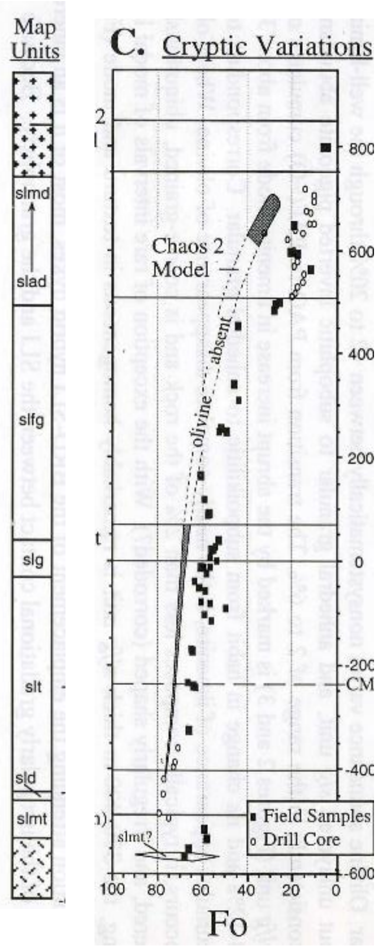
Olivine Weight %

	SL-06	SL-14(NA)	SL-16	WebMineral
O	41.45		39.14	41.74
Si	14.67		23.78	18.32
Mg	19.45		16.66	25.37
Fe	14.83		16.86	14.57

Olivine Ternary Diagram



		Point 1		Point 3
Top: SL-16	Mg	15.97		17.35
	Fe	84.03		80.92
		Point 1	Point 2	
Bottom: SL-06	Mg	65.14	65.78	
	Fe	34.85	34.21	



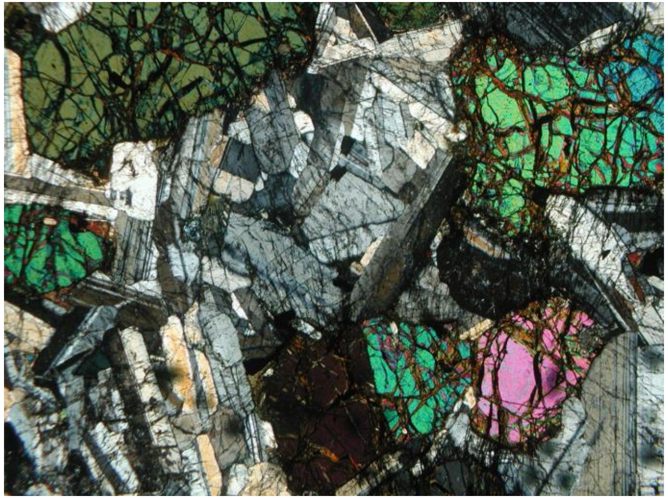
A cryptic variation chart creating by Ripley and Miller(1996) showing chemical composition change throughout the Sonju Lake Intrusion.

Cryptic Layering

Systematic variation in the chemical composition of certain minerals with stratigraphic height in a layered sequence. (Winter, 2010)

Plagioclase

- Plagioclase is a tectosilicate part of the feldspar group
- Plagioclase can be found within the entire intrusion
- The plagioclase in the bottom of the intrusion should have a higher Ca-Na ratio vs the top of the intrusion



Objective: 2.5x

Plagioclase wt. %

	SL-06 avg.	SL-14	SL-16	Webmineral
O	44.34	44.9	45.23	47.27
Na	2.83	4.05	5.37	4.25
Al	15.96	15.27	14.19	9.96
Si	24.89	26.95	28.99	31.12
Ca	8.08	8.08	5.7	7.40

Plagioclase: Measured vs. Expected SL-06

Plagioclase						
Element	SL-06-1-3	SL-06-1-4	SL-06-2-3	SL-06-4	Average	Ideal Atom %
O	59.7	59.87	57.74	60.09	59.35	61.5
Na	2.58	2.39	2.86	2.71	2.64	Na + Ca = 7.7
Mg			3.01		0.75	
Fe			3.34		0.84	
Si	19.11	18.79	18.9	19.1	32.78*	Si + Al = 31
K			0.15		0.04	
Ca	5.42	5.35	2.89*	5.11	5.29	Na + Ca = 7.7
Al	13.19	13.34	11.12	12.99	32.78*	Si + Al = 31

Plagioclase: Measured vs. Expected SL-14

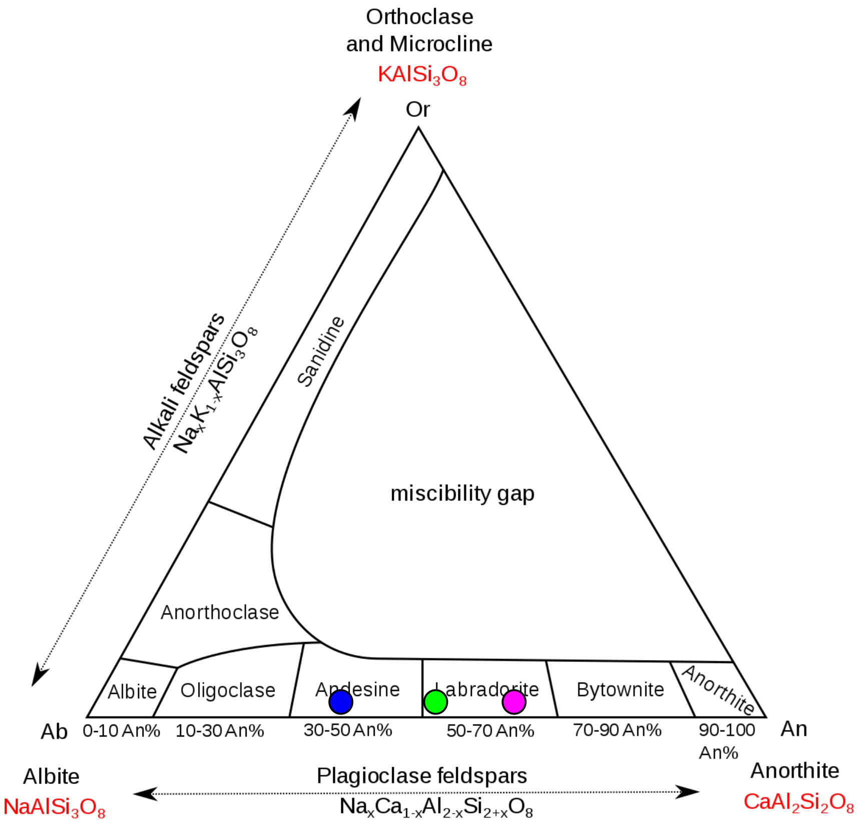
Plagioclase				
Element	SL-14-1-1	SL-14-2-1	Average	Ideal
O	67.71	58.42	63.07	61.5
Na	3.74	3.7	3.72	Na + Ca = 7.7
Si	19.71	20.83	20.27	15.4
K	0.27	0.22	.25	
Ca	3.96	4.55	4.27	Na + Ca = 7.7
Al	11.6	12.29	11.95	15.4

Plagioclase: Measured vs. Expected SL-16

Plagioclase		
Element	SL-16-1-2	Ideal
O	59.21	61.5
Na	4.9	Na + Ca = 7.7
Si	21.62	15.4
K	0.28	
Ca	2.98	Na + Ca = 7.7
Al	15.38	15.4

Plagioclase

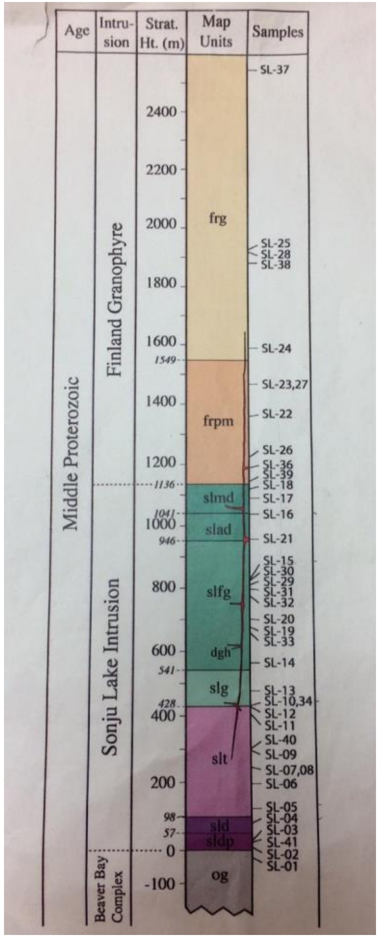
Sample	SL-06 🟣	SL-14 🟢	SL-16 🔵
Ca	5.29	4.27	2.98
Na	2.64	3.72	4.9
% Ca	66.71%	53.44%	37.81%



https://en.wikipedia.org/wiki/Feldspar

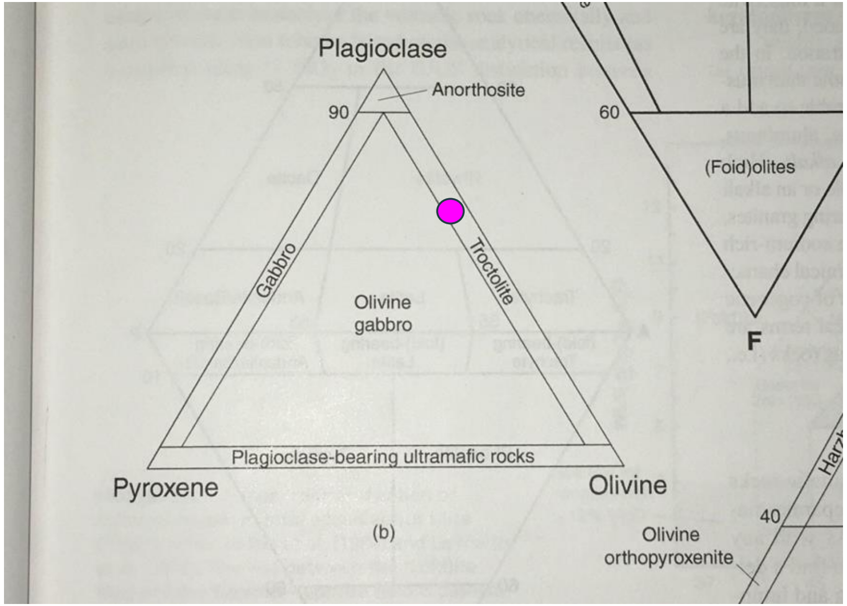
Changes in Mineral Assemblages

- Along with elemental changes within minerals, there are also mineral changes throughout the stratigraphic column
- Ex: Olivine decreases up into the intrusion, while tectosilicates increase



SL-06 Mineral Assemblages

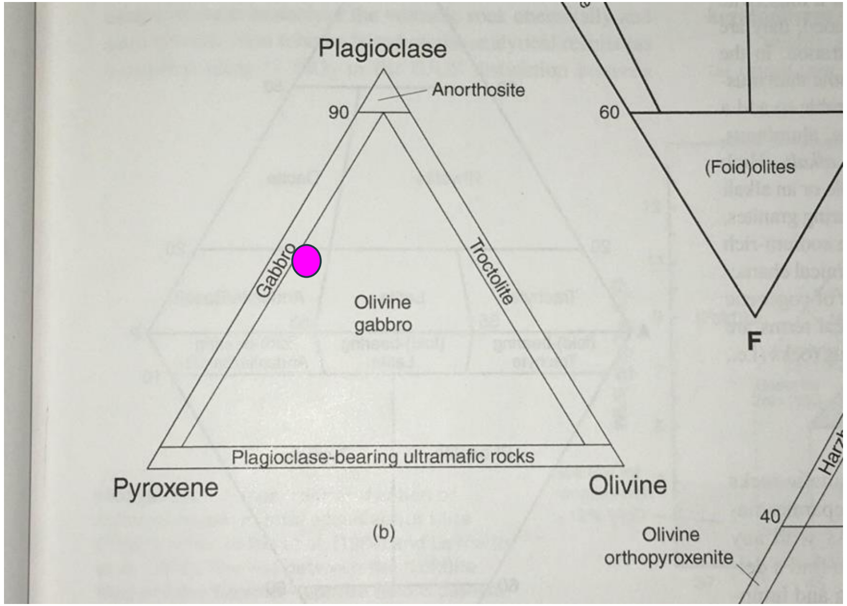
- Plagioclase 65%
- Olivine 32%
- Pyroxene 3%
- We concluded troctolite from our thin section, which matched previous data



Winter Fig. 2.2

SL-14 Mineral Assemblages

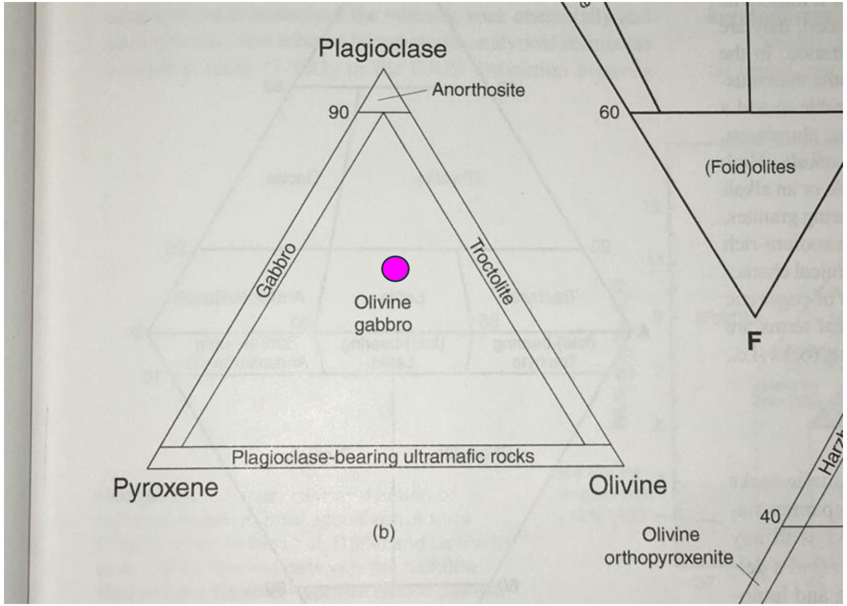
- Plagioclase 50%
- Iron Oxides 10%
- Pyroxene 30%
- Olivine 10%
- We concluded that it was borderline gabbro, olivine gabbro
- Called an oxide-rich gabbro in literature



Winter Fig. 2.2

SL-16 Mineral Assemblages

- Plagioclase 45%
- Olivine 25%
- Pyroxene 20%
- Iron Oxides 10%
- We concluded Olivine Gabbro from our thin section, which closely matches the diorite from literature



Winter Fig. 2.2

Errors

Errors in Methods:

- Destroying thin sections (Buehler machine, polishing, overpolishing)
- Incorrectly mapping and being unable to find all minerals necessary
- Not collecting enough data points to accurately convey an average element composition

Conclusion

- After our analysis of the Sonju Lake Intrusion with SEM and thin section mineral estimation it was determined that our data fits well with the previous literature that has been written about this area.
- In the pyroxene and olivine we saw that our ratio of Fe/Mg increased moving towards the top of the intrusion.
- In the plagioclase we saw that the Na/Ca ratio increased moving towards the top of the intrusion.

Acknowledgements

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- Dr. Eidukat for his guidance in this project

References

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Thank You