SEM and petrographic analysis of Sudbury Impact ejecta collected from Thunder Bay, Ontario

KAYLEIGH ALME

NORTH DAKOTA STATE UNIVERSITY

PETROLOGY 422

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Background

Sudbury Impact

- 1850 Ma
- Possibly enstatite chondrite in composition
- Second largest known impact site (diameter ~260 km)
- Third oldest

Ejecta

- Based on models, ejecta layer supposed to be very thick but where is it?
- Southern part of western Ontario and north MN, WI, MI: Animikie Shelf
- Iron formations and shales being depositing about the same time as impact
- Excellent place to start looking for the ejecta layer

(Addison, et al., 2005)

Ejecta Layer

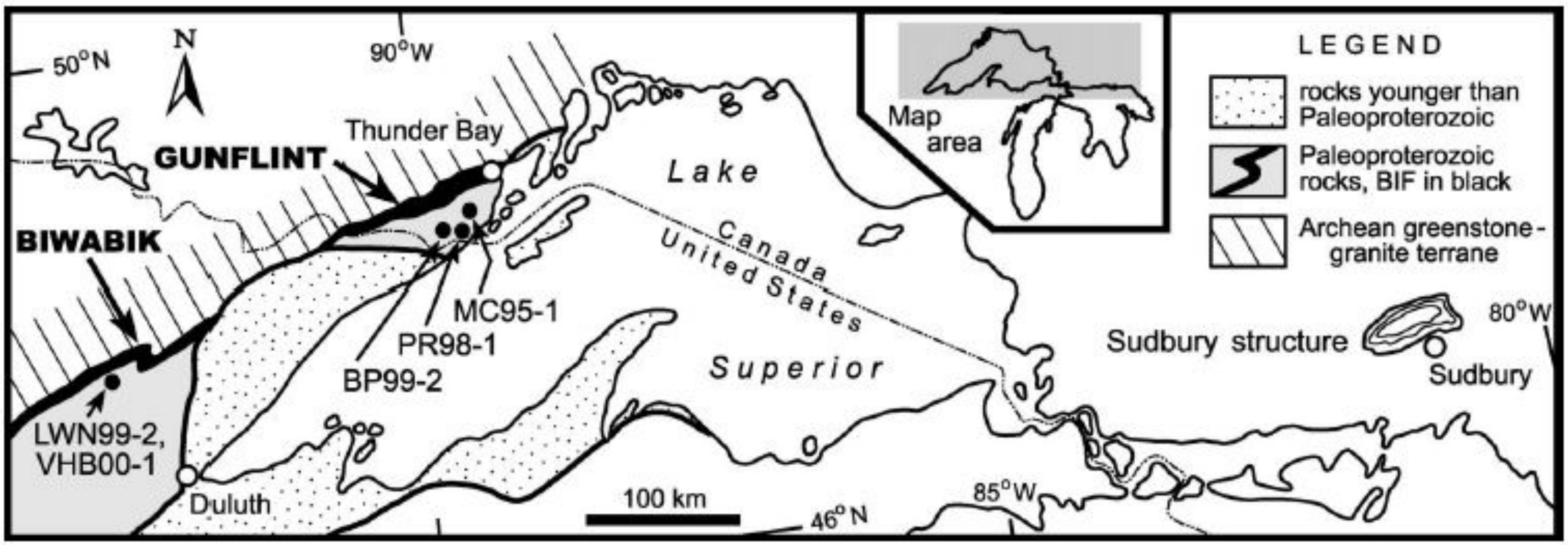
Addison, et al, took diamond drill cores in 5 different locations- 2 in MN and 3 in Canada

Ontario drill holes approximately 650 km W-NW from SIS

Minnesota drill holes approximately 875 km west of SIS

Discovered ejecta material between the Gunflint and Rove formations in Ontario; near the probable Biwabik-Virginia boundary in MN

(Addison, et al., 2005)

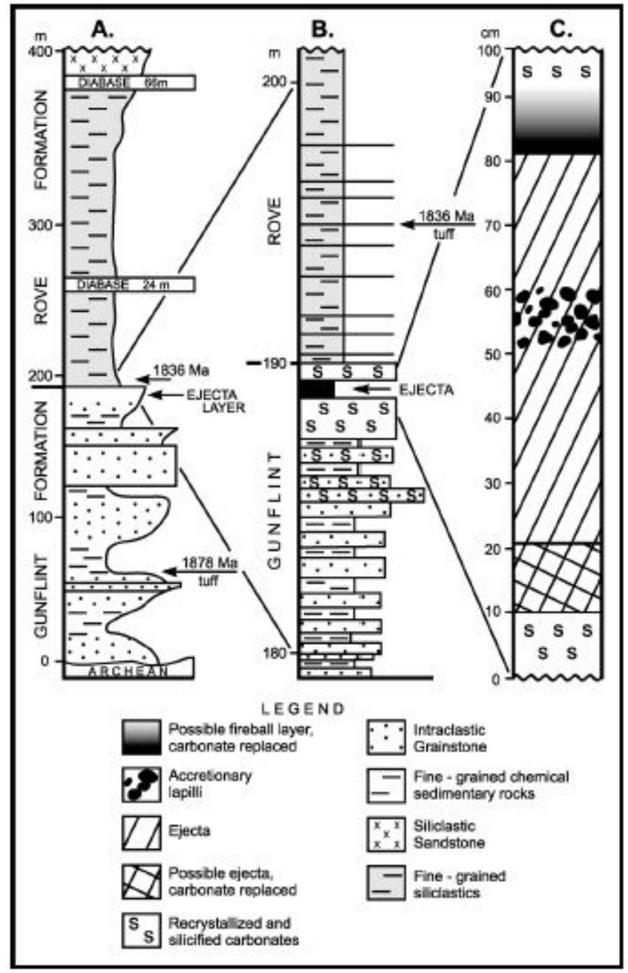


(Addison, et al., 2005)

Column A shows an overview of the Gunflint and Rove formations from drill core 89MC-1.

Column B is a detailed view of the Gunflint-Rove boundary.

Column C is the detail of the ejecta layer from drill core BP99-2, which had the most complete and least altered layer.



(Addison, et al, 2005)

Layer features

Accretionary lapilli (found in the Ontario cores)

Poor boundaries due to carbonate replacement

Quartz and feldspar grains (some PDFs in Ontario cores)

Spherules

- Glassy material that has gone through devitrification
- Clay minerals, carbonates, less commonly chert and microcrystalline quartz

(Addison, et al., 2005)

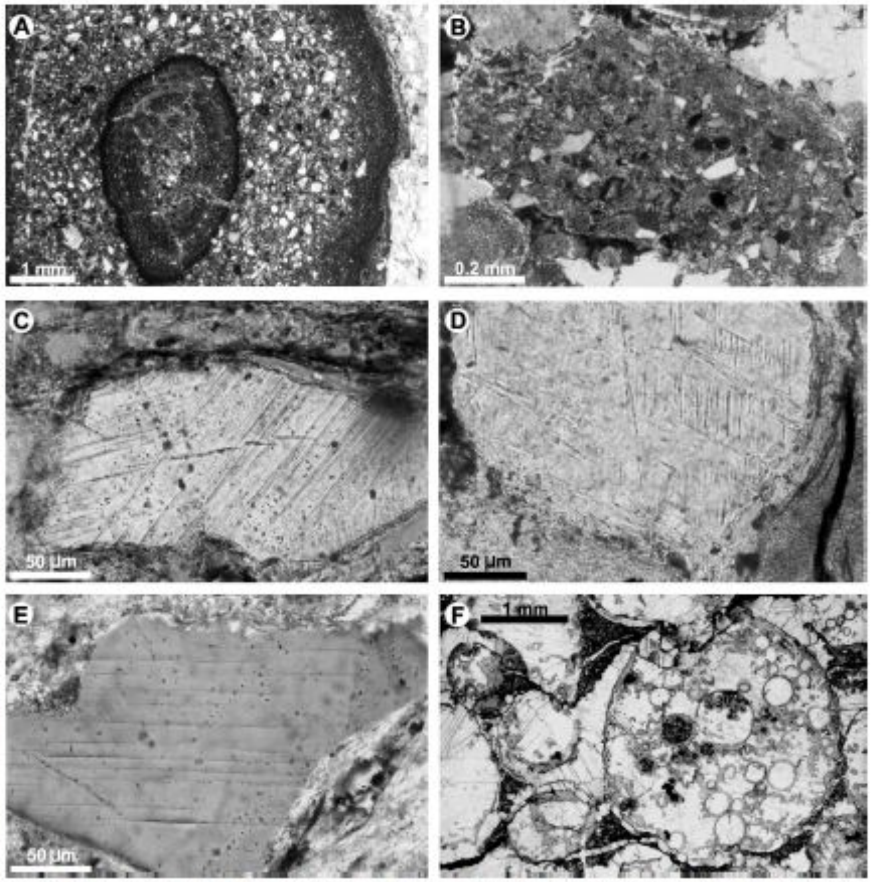


Figure 3. A: Accretionary lapillus having dark core with lighter, coarser quartz and feldspar grains and dark, finer-grained concentric outer accreted layers of secondary replacement carbonate and silicate minerals (core BP99-2, slide JN29A). B: Accreted grain cluster in carbonate matrix showing randomly oriented quartz and feldspar grains similar to those in accretionary lapilli cores (core BP99-2, slide JN24). Note absence of fine-grained outer concentric layers typical of accretionary lapilli (cf. A). C: Quartz grain with two decorated planar deformation feature (PDF) sets, surrounded by carbonate (primarily dolomite) replacement matrix (core BP99-2, slide JN32). D: Laddered PDFs in feldspar (core PR98-1, slide 10). E: Quartz grain with possible planar fractures, some weakly decorated with bubbles and some almost without decoration. Planar fractures are distinguished by their width, typically (5–10 µm) and spacing between fractures (15–20 µm), whereas PDFs typically have widths of <2–3 µm and spacings of 2–10 µm (French, 1998). Widths of features here are typical of PDFs, whereas spacings are typical of both PDFs and planar fractures (core PR98-1, slide 10). F: Spheres-within-sphere feature, likely originally glass, now devitrified and replaced by carbonate (primarily dolomite), which has destroyed most interior detail. Matrix is also carbonate (core LWN99-2, slide H1-3-8). Other photomicrographs are available in Appendix DR1 (see footnote 1 in text).

(Addison, et al., 2005)

Conclusions

The silicates in the ejecta layer are evidence for a continental impact.

The Sudbury Impact is the likely source of this material due to no other impacts known to be relatively close to the ejecta.

The ejecta layer thicknesses indicated a much layer debris zone than the 260 km distance between the Ontario and Minnesota drill cores.

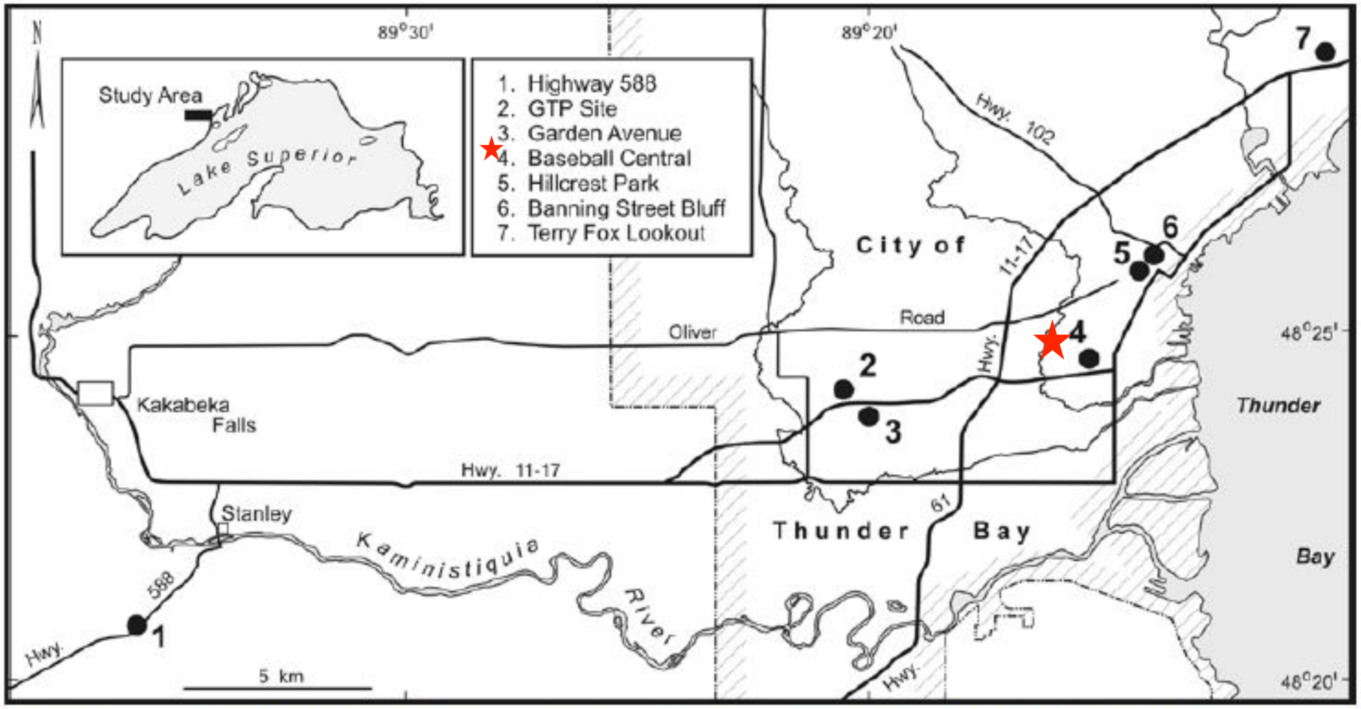
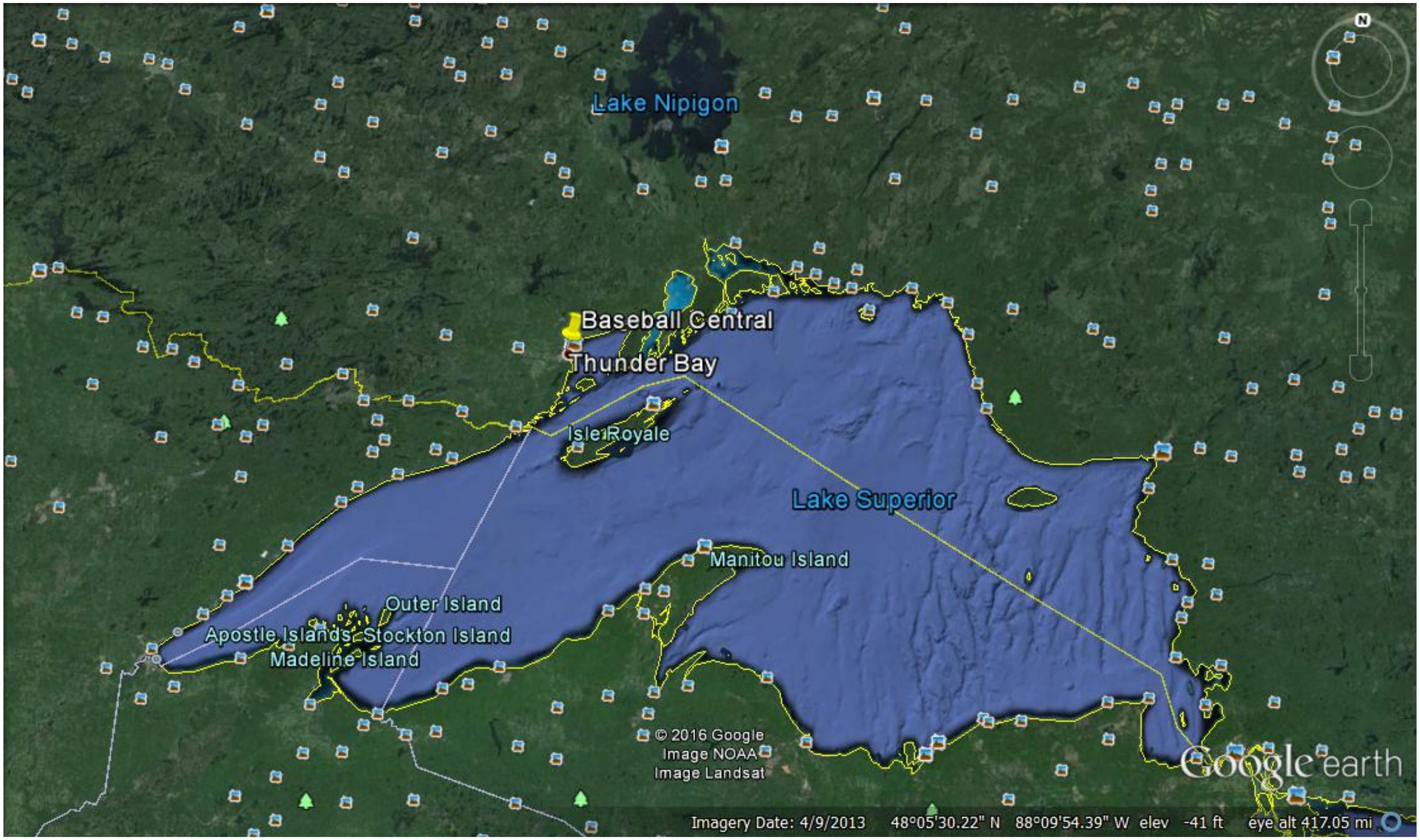


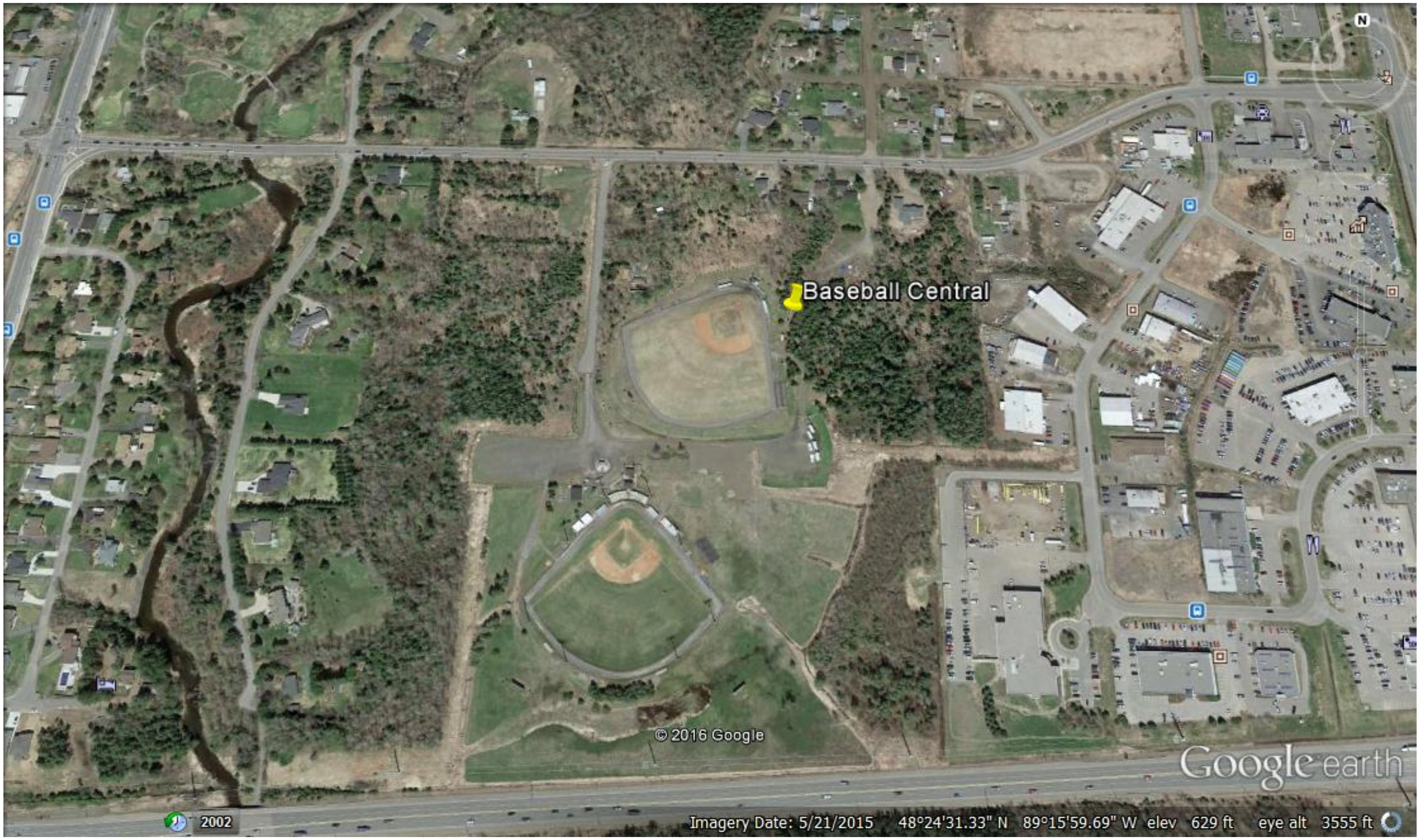
Figure 10. Debrisite containing Sudbury impact event ejecta in and near The City of Thunder Bay. Note: one site in a private citizen's yard is not shown to protect their privacy. Sites 2-6 are either on private property or in city parks and, as such, are "No Hammer" and "No Collecting" zones.

(Addison and Brumpton, 2012)

Site / Feature	Highway 588 ditches	GTP abandoned railway rock cut	Garden Avenue Quarry area	Private yard, Thunder Bay	Banning St. bluff below	Baseball Central, Central Ave.	Highway 11-17 at Terry Fox Lookout	Hillcrest Park, Thunder Bay
Stromatolites or microbialite mats in situ below debrisite base	yes	no	yes	yes	no	no	no	yes
Ripped up stromatolite or microbialite clasts in debrisite	yes	yes	??	yes	yes	no	no	no
Subrectangular Gunflint blocks, >0.5 m maximum dimension in debrisite	no	??	no	yes	yes	yes	no	yes
Fractured black chert or chert-carbonate more or less in situ below ejecta base	yes	yes	no	no	no	no	no	no
Angular chert clasts and shards, sub-cm to 3 dm max. dimension in debrisite	yes	yes	yes	yes	yes	yes	yes	yes
Post-depositional anastomosing chert in debrisite	no	no	no	no	yes	no	no	yes
Alteration profile (possible paleosol) below base of debrisite	no	no	no	yes	no	yes	yes	yes
Devitrified vesicular glass with carbonate in-filled vesicles	yes	yes	yes	yes	yes	yes	??	yes
Accretionary lapilli	yes	no	no	no	no	no	no	yes
Microtektites in debrisite thin sections	??	??	no	no	no	??	yes	no
Gunflint Formation iron granules	yes	yes	no	yes	yes	no	??	no
PDF in quartz or feldspar grains/shards	yes	no	no	no	??	no	??	yes
Isotropic quartz containing crystallites	no	yes	yes	no	??	yes	no	no
Subrounded to angular quartz & feldspar grains in debrisite matrix	yes	yes	yes	yes	yes	yes	yes	yes
Top of debrisite deposit visible	no	no	no	no	no	no	yes	no
Bottom of debrisite deposit visible	yes	??	no	yes	no	yes	yes	yes
Approximate debrisite thickness (m)	0.4	0.4	0.5	0.6	~2	~2	2.7	~4

(Addison and Brumpton, 2012)


Lake Nipigon
Baseball Central
Thunder Bay
Isle Royale
Lake Superior
Manitou Island
Outer Island
Apostle Islands
Stockton Island
Madeline Island
© 2016 Google
Image NOAA
Image Landsat
Google earth
Imagery Date: 4/9/2013 48°05'30.22" N 88°09'54.39" W elev -41 ft eye alt 417.05 mi


Baseball Central
© 2016 Google
Google earth
2002
Imagery Date: 5/21/2015 48°24'31.33" N 89°15'59.69" W elev 629 ft eye alt 3555 ft

Sudbury Impact Ejecta from Baseball Central, Thunder Bay

Goal:

Perform petrographic and SEM analysis and literature comparison to determine some minerals in this site's Sudbury Impact ejecta.

Methods

Create thin section

- Cut block of rock to fit on petrographic slide using rock saw
- Polish one side of the rock
- Adhere the rock to the slide polished side down using a 10:3 resin to hardener ratio
- Using the Buehler thin section cutter, cut and grind down glued sample until about .4 mm in thickness.
- Hand lap using 600 and 1000 grit until desired thickness is achieved sonicating before moving grit sizes

Methods

Prepare slide for SEM analysis

- Polish slide with 1 micron grit on polishing disk
- Sonicate
- Polish slide with .25 micron grit on polishing disk
- Sonicate

Map out slide and determine points of interest

Take pictures of slide in petrographic microscope

Carbon coat slide

SEM analysis

SEM-EDS

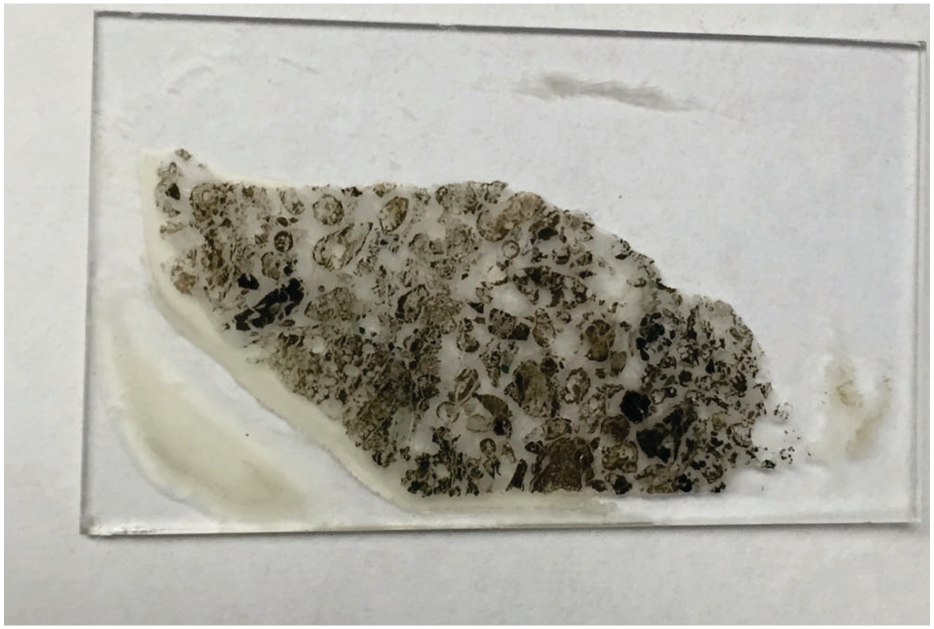
Electron beam aimed at sample

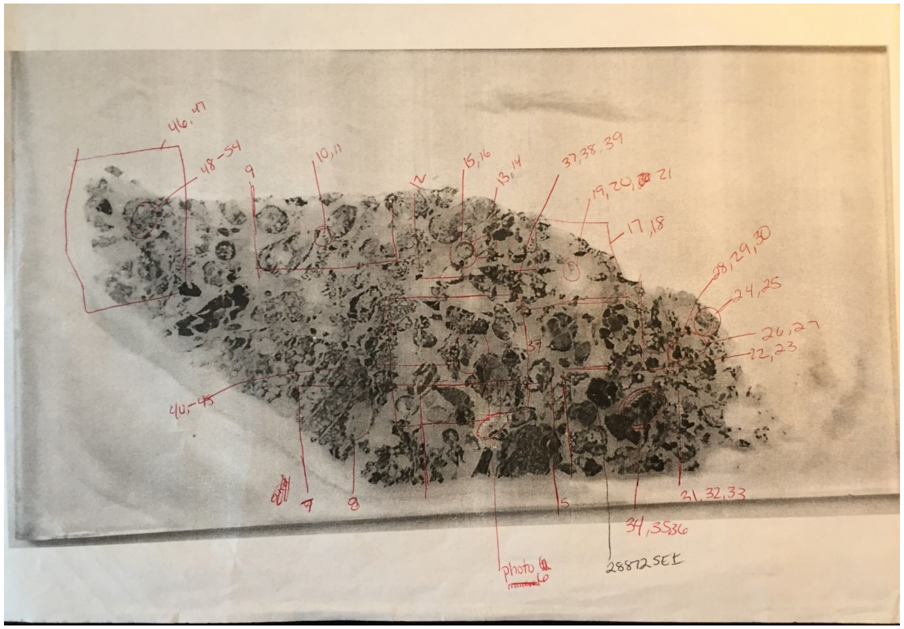
Back scatter electrons provide image

X-rays provide elemental data

Thin Section Trials..

Thin sections from left to right:
First thin section made, broken in half during polishing
Second thin section had resin issues
Third thin section worked, is now carbon coated




46,47
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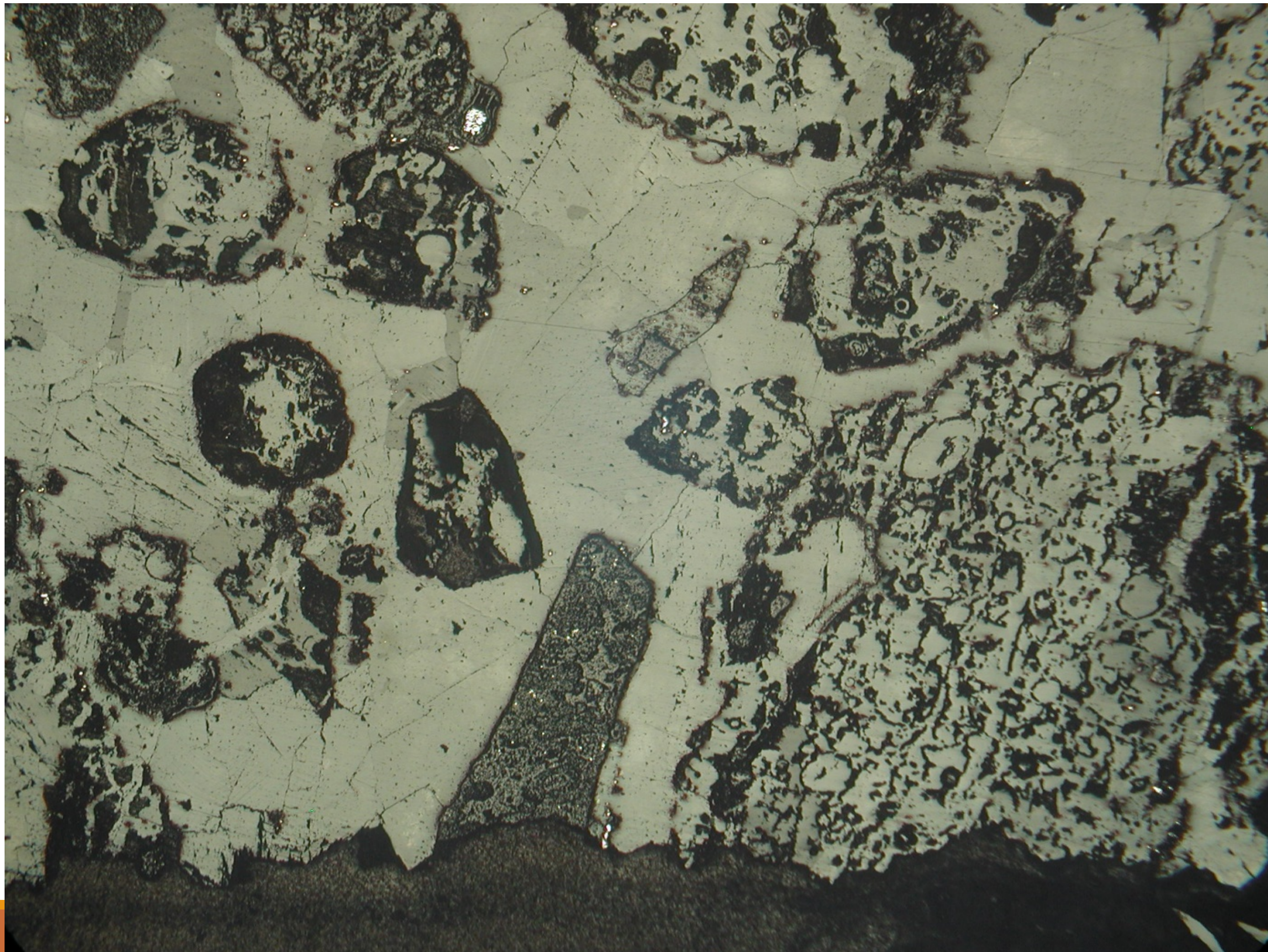
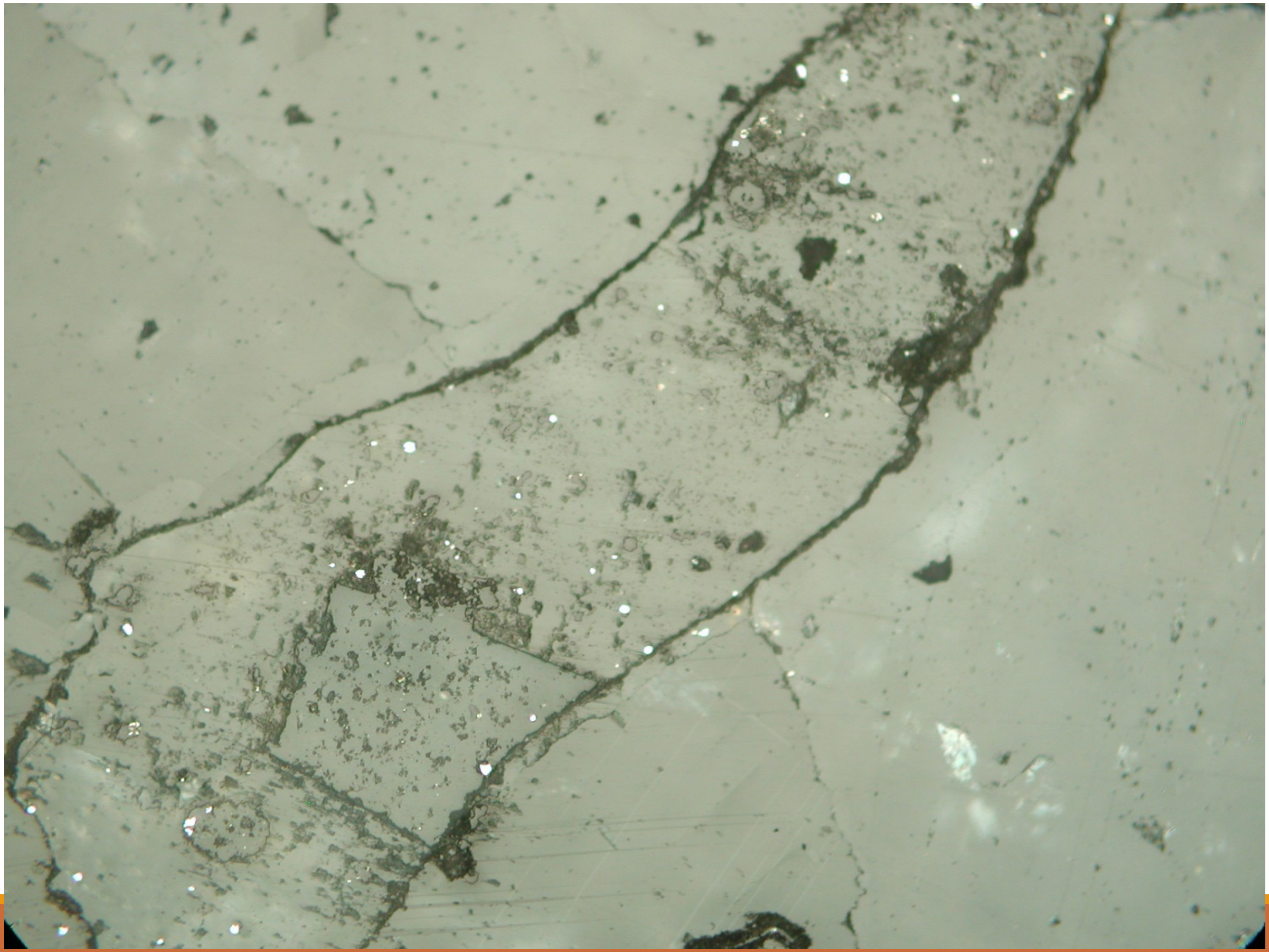
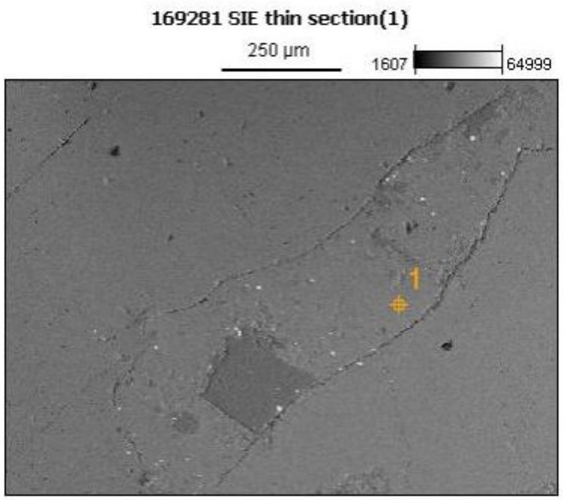


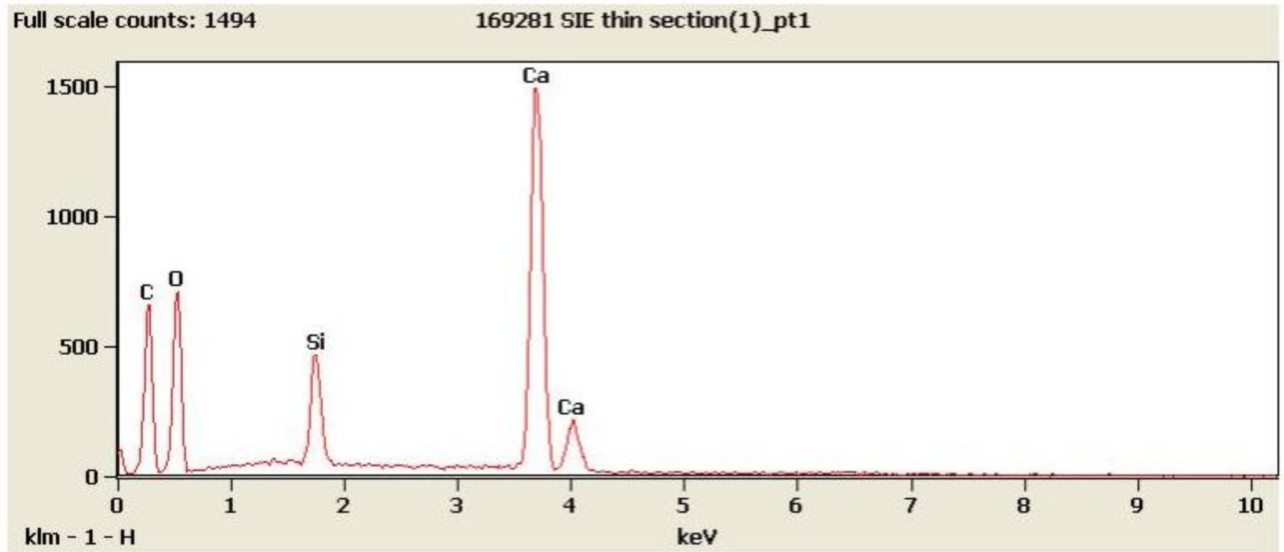
2.5X FOV = 8mm. Mineral of interest circled in red. Reflected light.



Zoom in on mineral. 20x FOV =1.05 mm. Notice bright flecks (pyrite). Reflected light.



Mag: 120x



Weight %

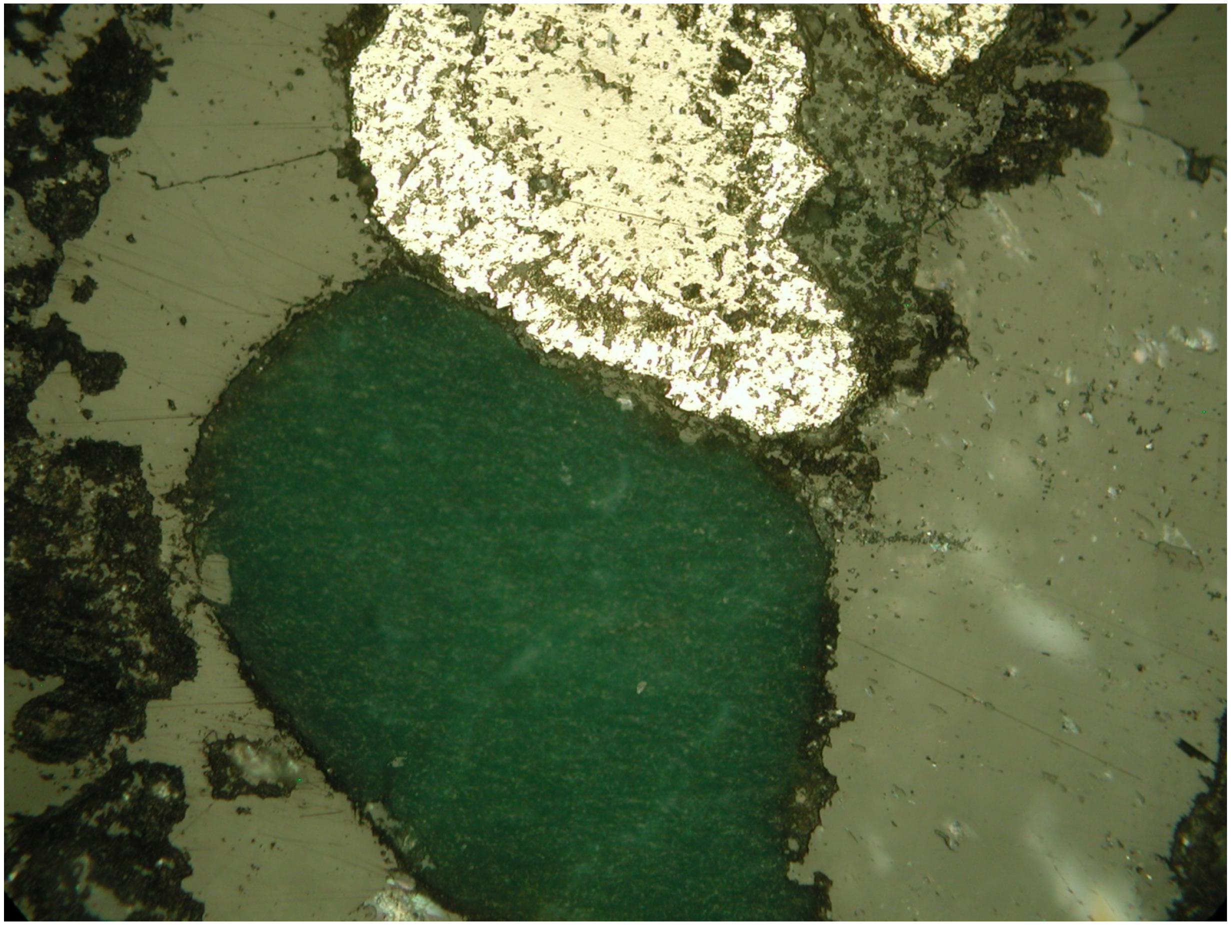
	C-K	O-K	Si-K	Ca-K
169281 SIE thin section(1)_pt1	36.51	32.20	3.08	28.21

Thought to be $CaCO_3$ but:

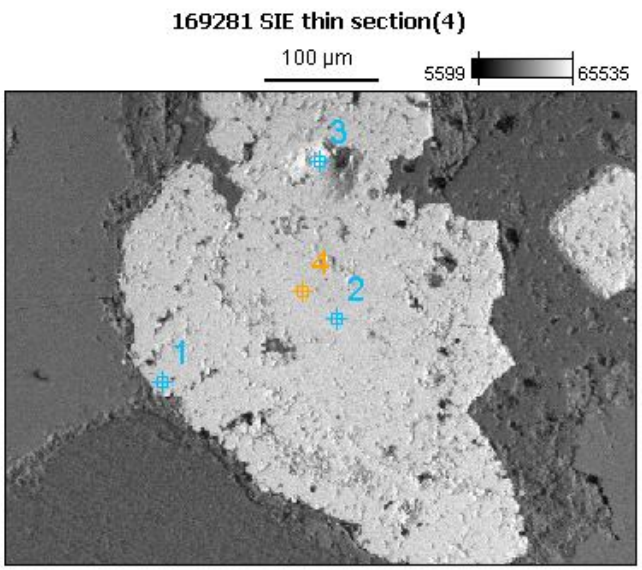
1. Wt% are off. Ideal values should be: Ca- 40.04% C- 12% O-47.96%

2. Carbon values are off due to the coating, but not sure how much

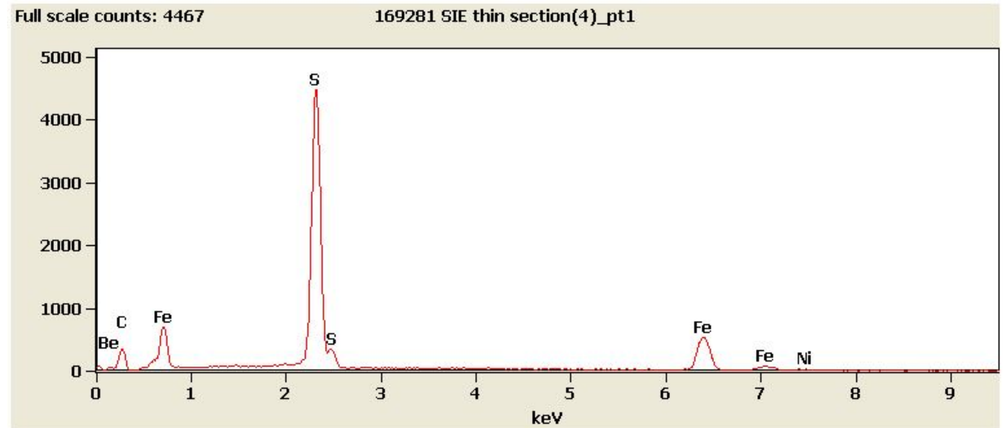
Still not sure what this mineral is.

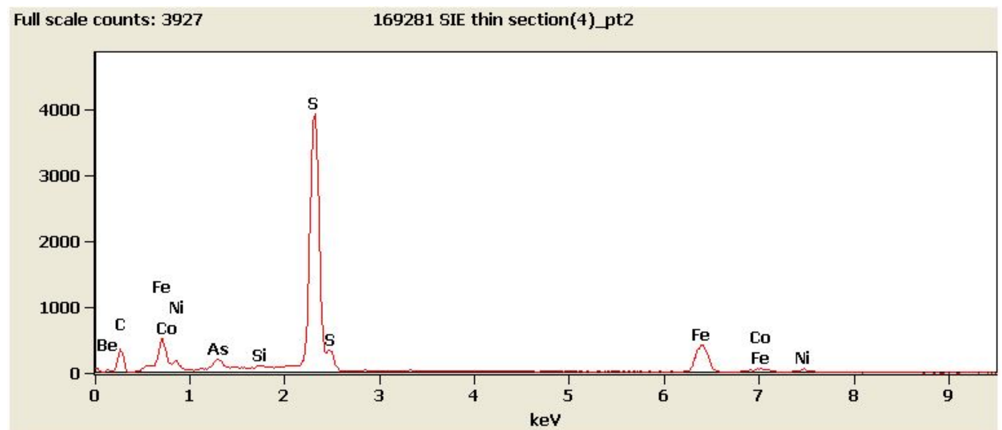


10x FOV = 2mm,
Mineral of interest is
bright and zoned. XP



250x



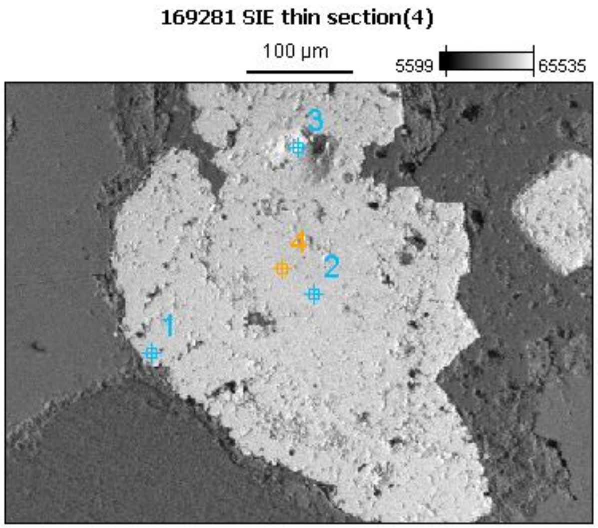


Pt 1: Used wt% and atomic weight to determine atomic% then found empirical formula. Combined Be, Fe, and Ni (Be,Fe,Ni)S_2 - possibly marcasite

Pt 2: Same process, however ran into problem with the high level of Be. No Al, therefore isn't beryl. More analysis is needed.

Weight %

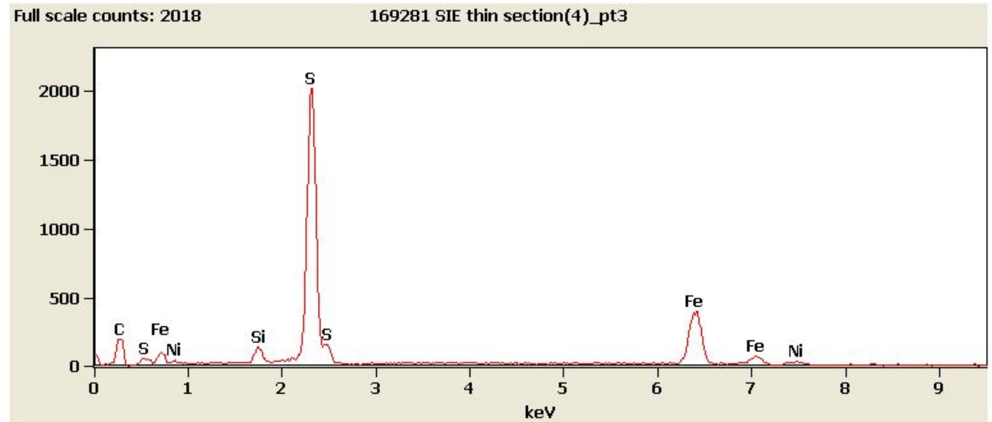
	Be-K	Mg-K	Si-K	S-K	Fe-K	Co-K	Ni-K	As-L
169281 SIE thin section(4)_pt1	6.41			52.73	39.24		1.61	
169281 SIE thin section(4)_pt2	32.97		0.28	34.96	22.56	2.42	4.36	2.44
169281 SIE thin section(4)_pt3			1.47	43.64	49.33		5.57	
169281 SIE thin section(4)_pt4		1.62	0.27	54.51	35.75	3.28	4.57	

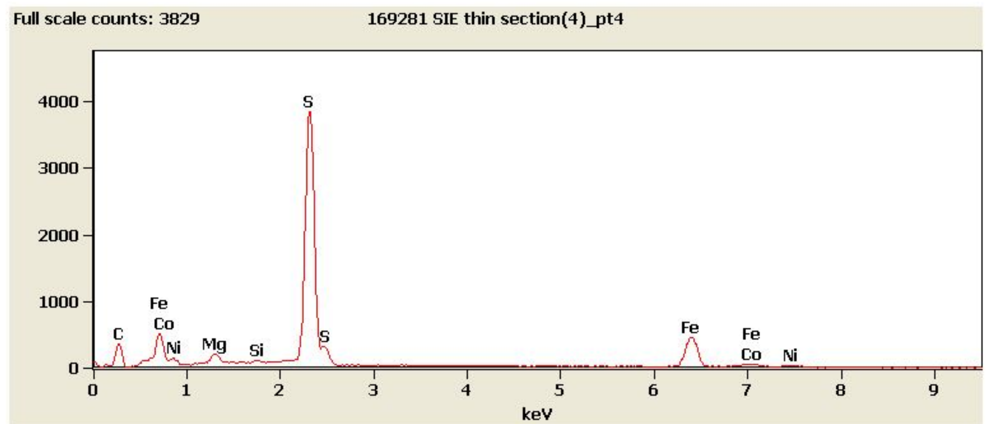


250x

Pt 3: Probably pyrite, perhaps marcasite. Odd Si shows up. Left it out of calculation. $(Fe,Ni)S_2$

Pt 4: Again, excluded Si, and grouped Mg, Fe, Co, and Ni together.
$(Fe, Ni, Mg, Co)S_2$ - pyrite





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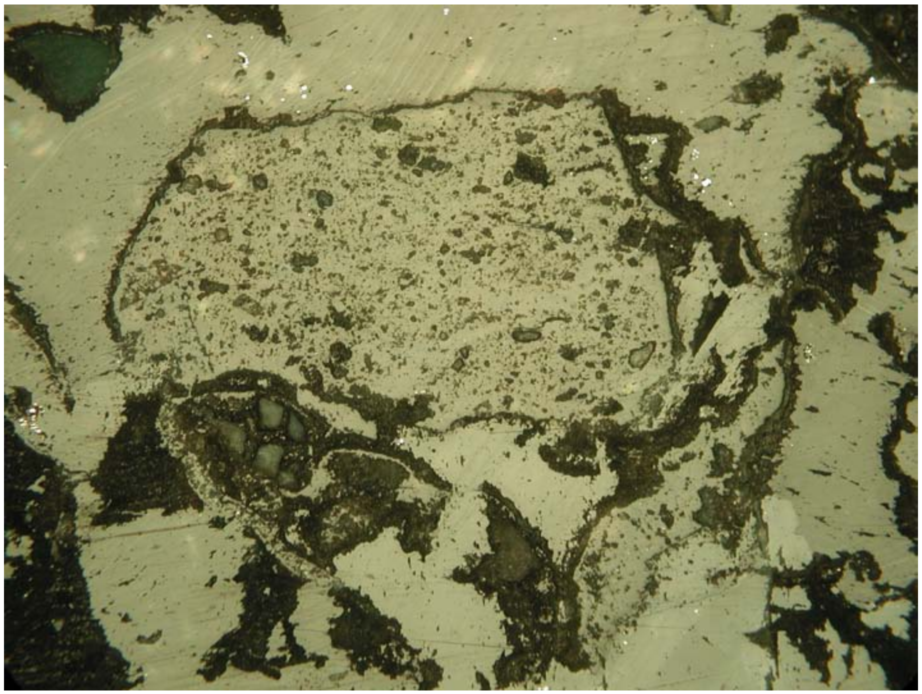
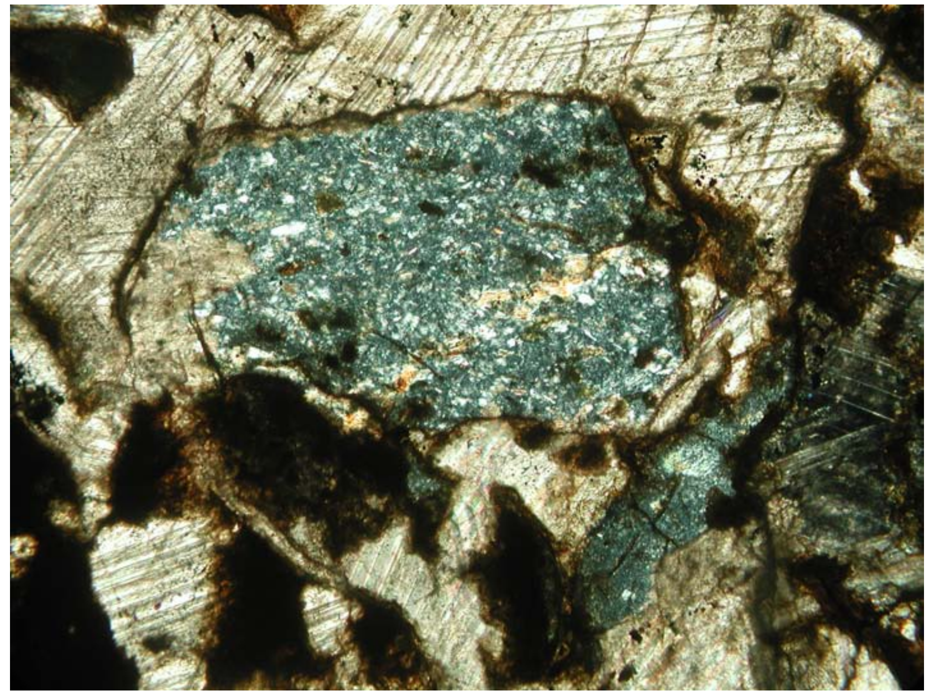
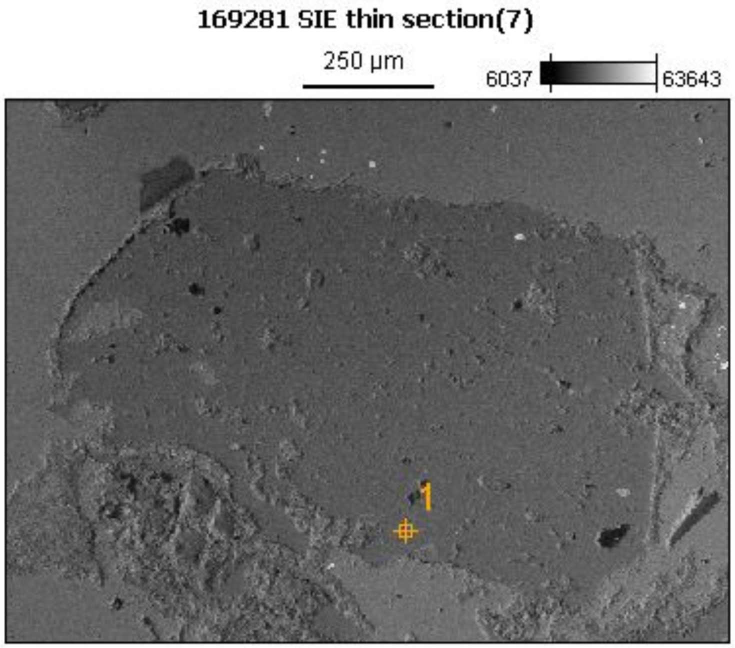
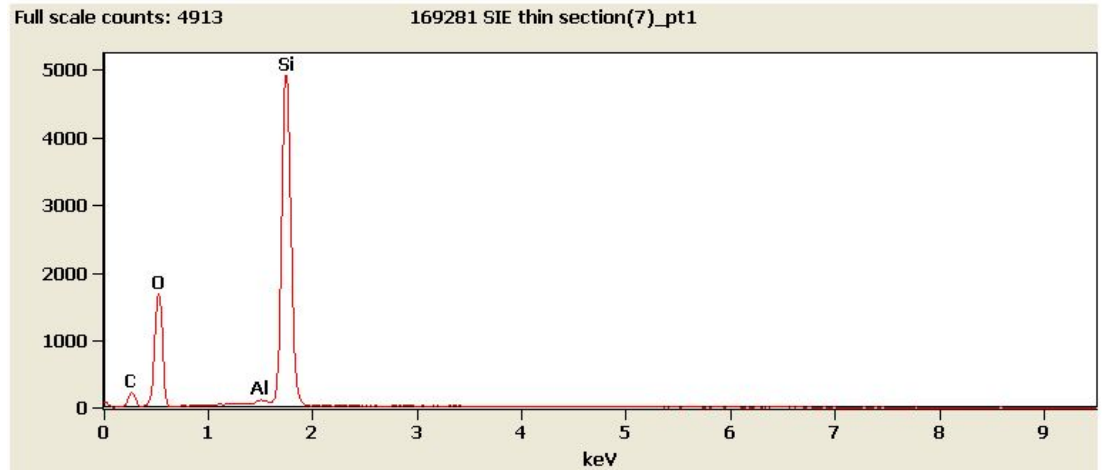
 

Both pictures in 10x FOV = 2mm. Left image is under reflected light, while right image is under XP. Ultra fine grained, probably microcrystalline quartz. Surrounded by calcite. Possibly the crystallites mentioned in Addison and Brumpton, 2012?



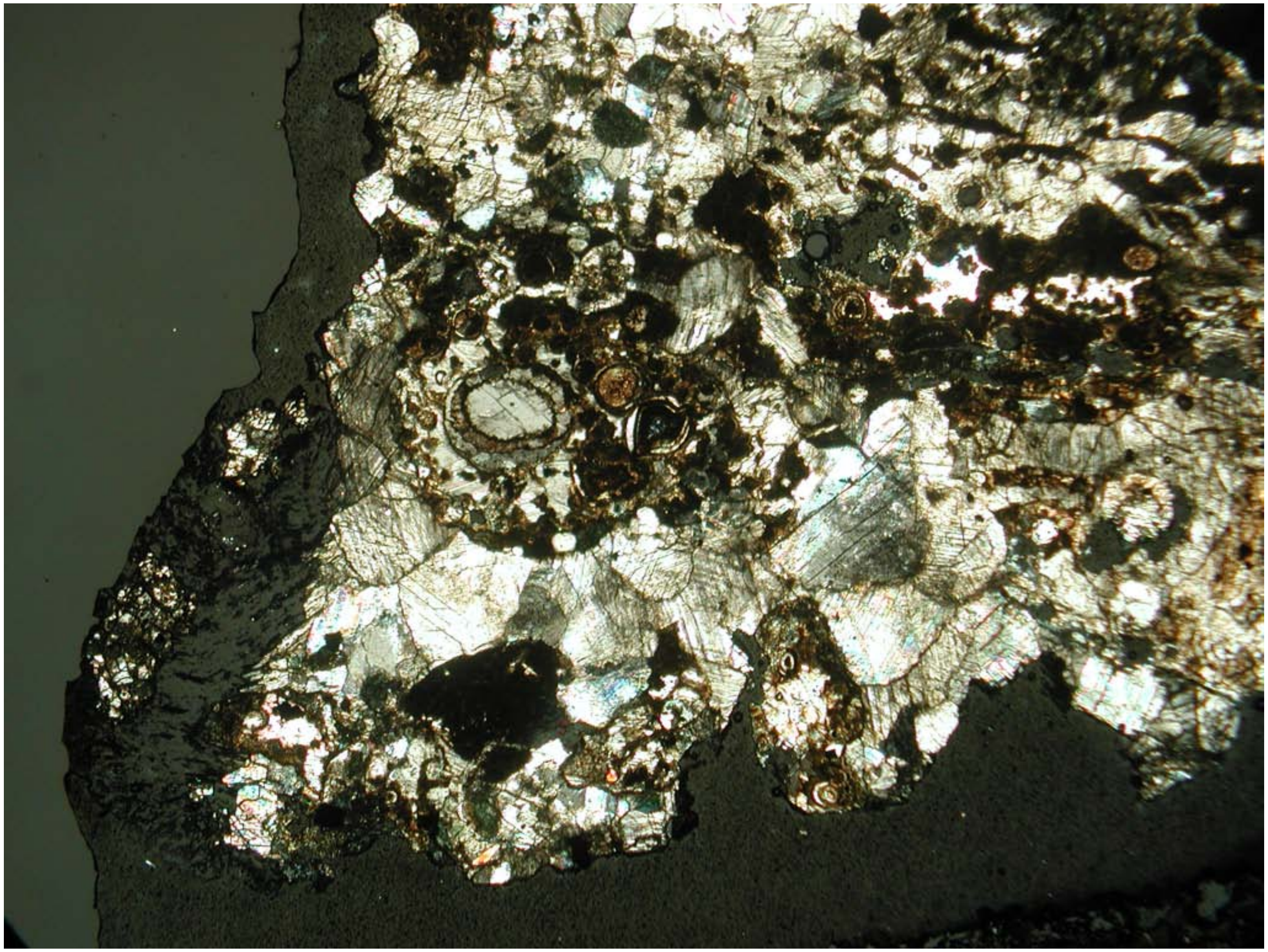


100x

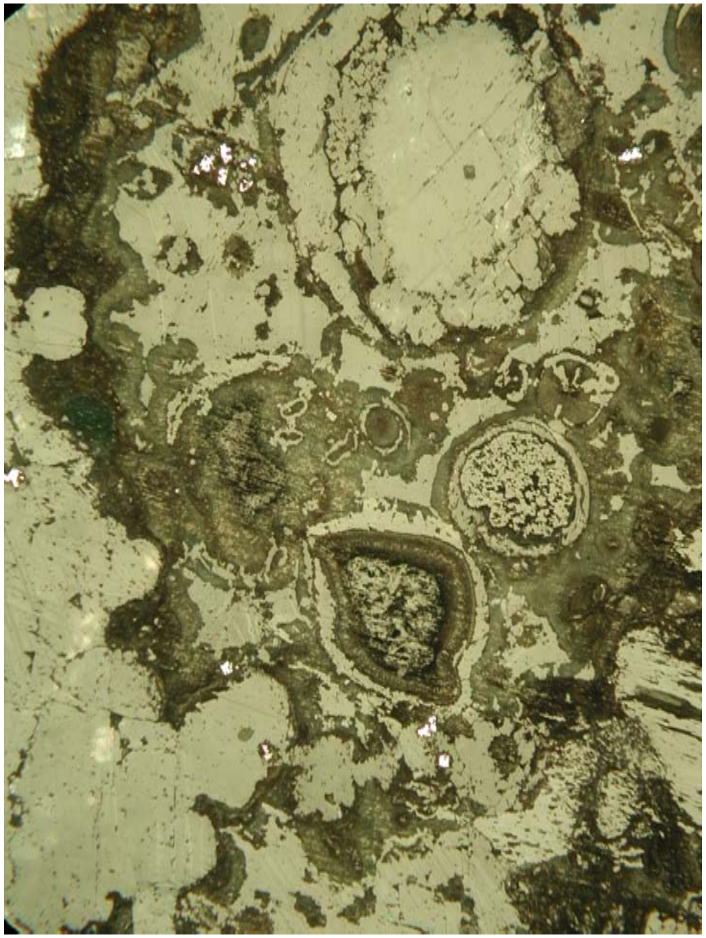
Weight %

	O-K	Al-K	Si-K
169281 SIE thin section(7)_pt1	48.28	0.24	51.48

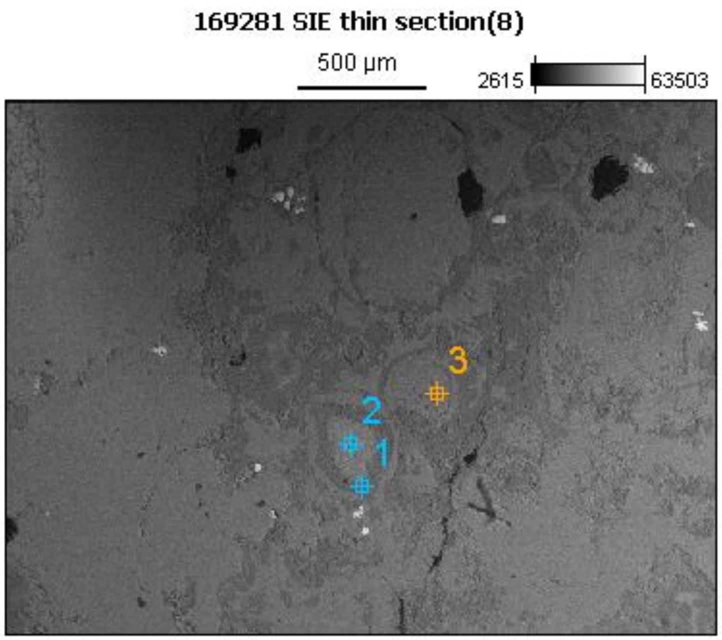
Calculations using the weight percent confirms that this mineral is composed of SiO_2.



2.5x POV = 8 mm . Spherules circled. Calcite clearly seen. XP

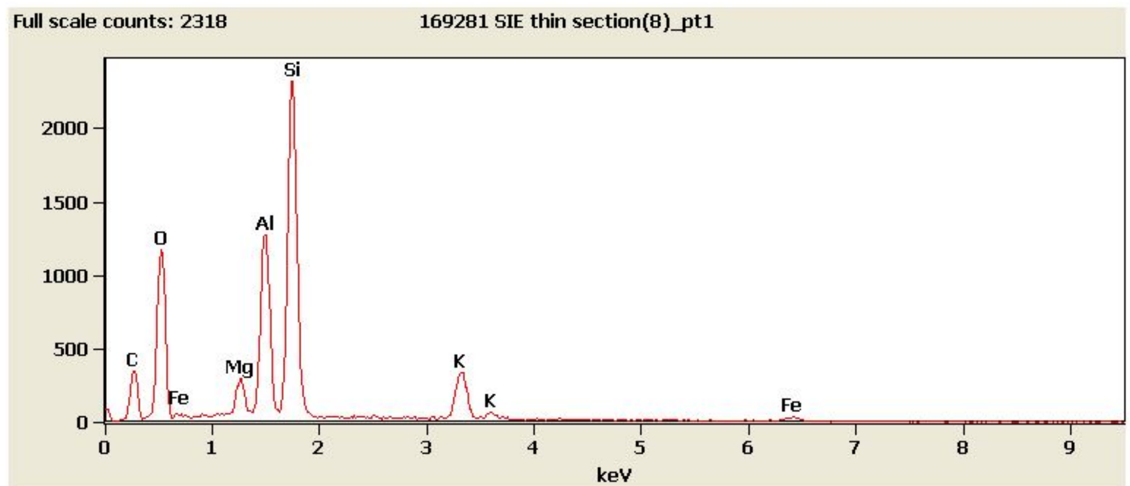


Zoom of circled material. Showing more detail of the spherules. Both images are 10x FOV=2mm. Left is shown with reflected light while the right is shown with XP. In the uppermost spherule, note the calcite, while the other spherules have darker minerals. Possible biotite?



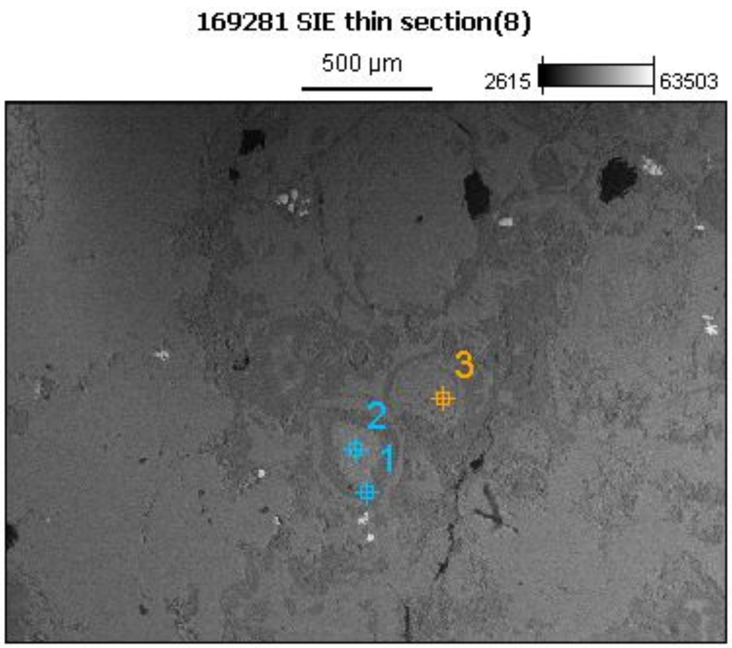
50x

Using the weight percentages, it is likely that this mineral is part of the biotite family. However, more tests should be run because the percentages were pretty inconclusive.



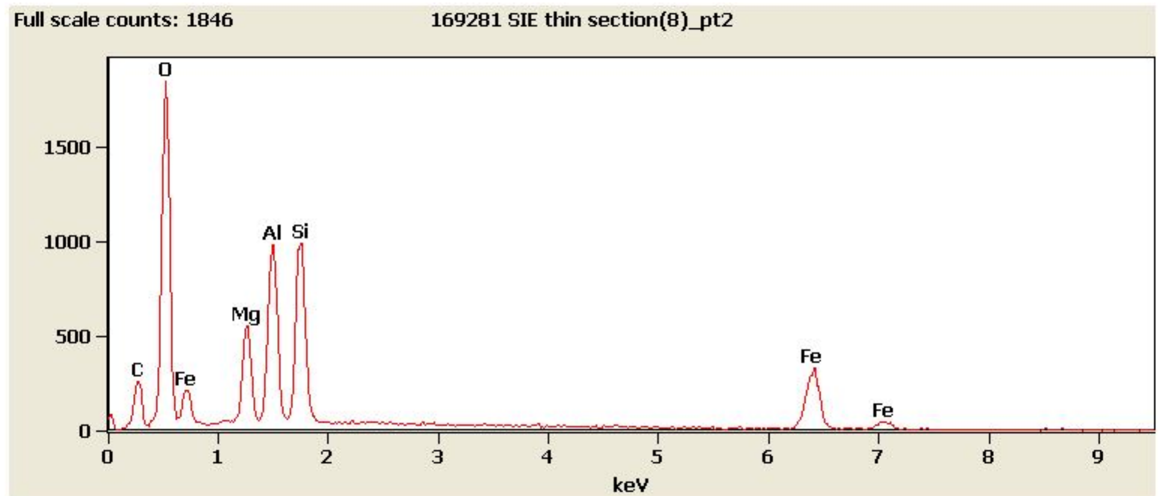
Weight %

	O-K	Mg-K	Al-K	Si-K	K-K	Ca-K	Fe-K
169281 SIE thin section(8)_pt1	42.62	2.39	14.18	29.62	8.70		2.50
169281 SIE thin section(8)_pt2	39.09	6.31	12.30	13.32			28.99
169281 SIE thin section(8)_pt3	49.30	0.96	4.64	9.16	2.49	32.31	1.13



50x

In this spherule, the calculations lead to a formula of roughly $(Fe,Mg)_2(Al,Si)_2O_6$, or pyroxene.



Weight %

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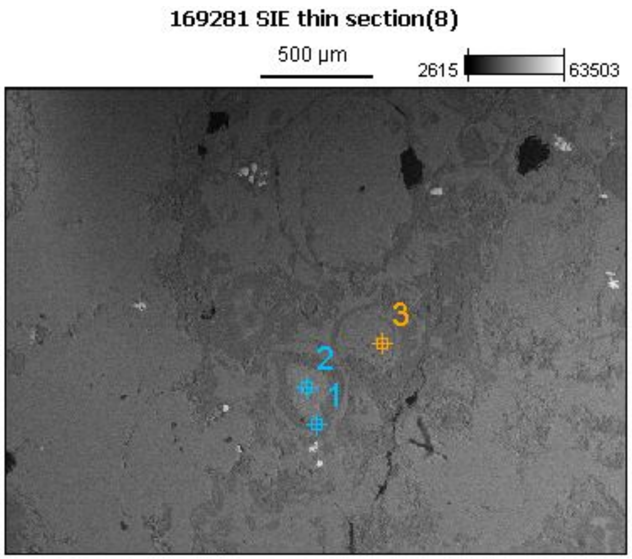

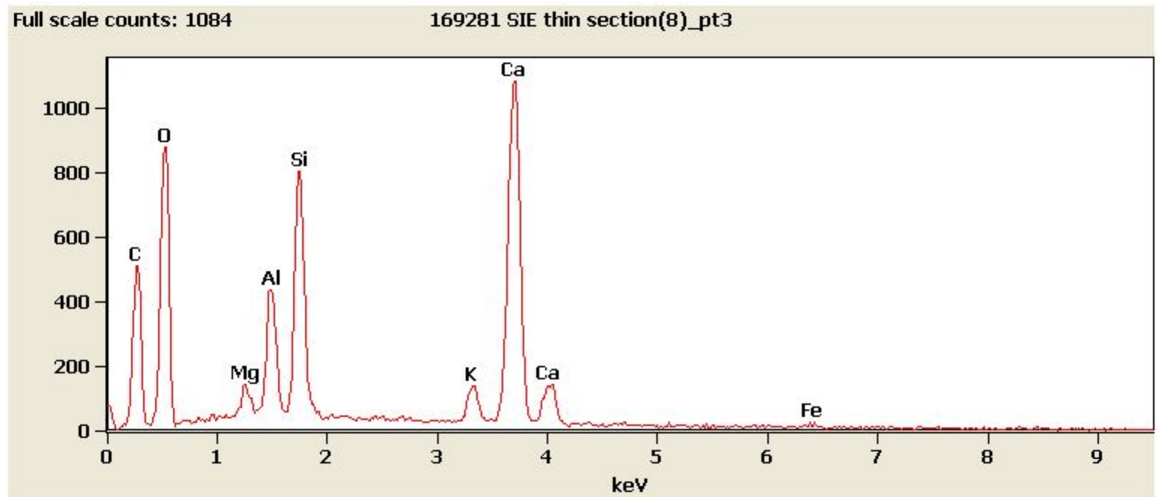

Weight %

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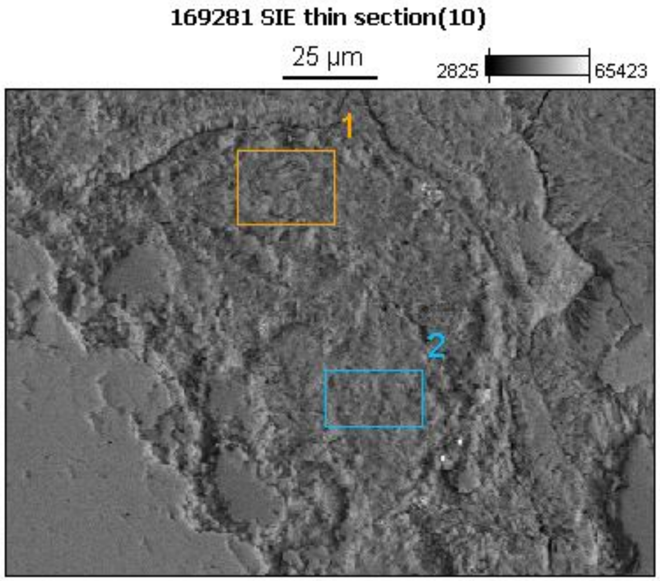
169281 SIE thin section(8)_pt3	49.30	0.96	4.64	9.16	2.49	32.31	1.13

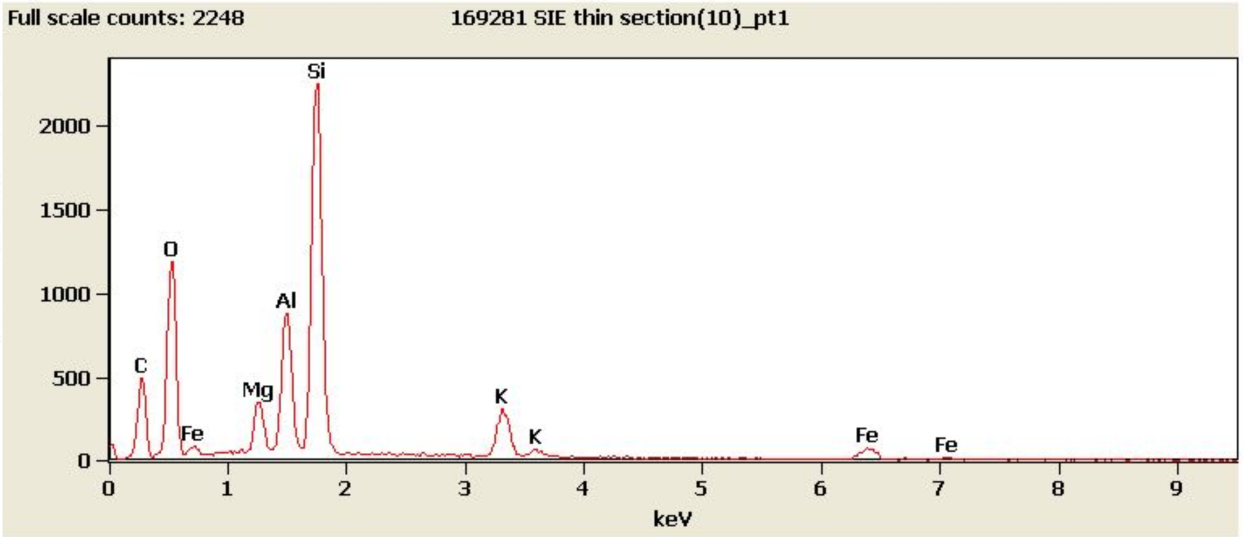
50x

This mineral is still a mystery. The higher carbon register could indicate that there is carbon in the mineral itself. If there is, this will throw off the other weight percent measurements.



800x

This mineral is possibly related to biotite, with weight percentages mostly matching to the ideal weight percentages. Unfortunately, the H and F cannot be determined in SEM because both are very light. More analysis of the bright blue minerals should be conducted.



Weight %

	O-K	Mg-K	Al-K	Si-K	K-K	Fe-K
169281 SIE thin section(10)_pt1	41.64	3.40	10.00	30.20	8.07	6.70
169281 SIE thin section(10)_pt2	40.45	3.90	9.06	31.97	8.42	6.19

Conclusions

Minerals such as sulfides and some silicates were relatively easy to identify with SEM. However, if carbonate is possibly in the sample, it will be difficult to tell how much carbon is in a mineral versus the carbon coating.

The petrographic microscope is an excellent tool for determining the larger minerals in the sample, such as the calcite matrix.

Many of the minerals are still mysteries. More SEM analysis should take place with multiple points being chosen along a mineral grain.

Acknowledgements

Thank you to Dr. Hopkins of the Soils Department at NDSU for allowing the cutting of numerous thin sections to take place on the Buehler thin section machine in his lab.

Thanks to Dr. Saini-Eidukat of the Geosciences Department at NDSU for the use of his equipment and supplies for the cutting and polishing of rock samples.

Thank you to the staff at the Electron Microscopy Center at NDSU for the use of the Scanning Electron Microscope and facility.

Thank you!