Keystone SD Garnet Biotite Schist Geothermometry case study

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Overview

- What is Geothermometry
  - Concept Introduction
  - Applications
  - Questions
- Conducting a Case Study
  - Introduction to the Keystone Garnet Schist
  - Methods used
  - Discussion of Results
- How this Fits into the Geology of the Black Hills
- Summary

What is Geothermometry

Geothermometry: The process of calculating at what temperature a rock was heated to.

This presentation focuses on Garnet-Biotite geotherm which use Fe-Mg exchange.

Some of the other many methods

- Nepheline–feldspar: Na-K exchange
- Olivine–Orthopyroxene: Fe-Mg exchange
- Oxygen isotope thermometry: O^{18}-O^{16} exchange

(Winter, 2014)

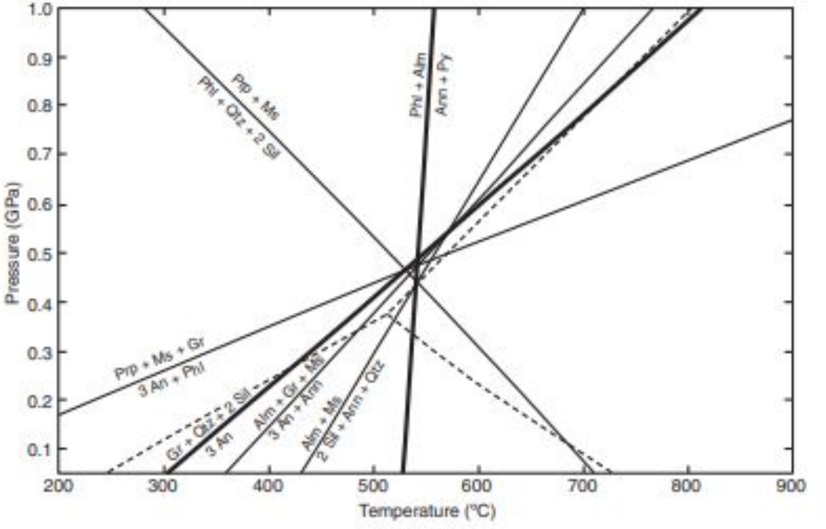


Fig. 1 Example geothermometry and geobarometry equations. Bold lines are the garnet– biotite geothermometer and the GASP geobarometer equations that were used in a case study of Mt. Moosilauke, New Hampshire. (Winter, 2014)

Garnet-Biotite Geothermometry

- These calculations are from a series of experiments Ferry and Spear published in 1978.
- The reactions they studied are called “reversed” because the move towards equilibrium from both directions.

$$K = K_D = \frac{(X_{Mg}/X_{Fe})^{Grt}}{(X_{Mg}/X_{Fe})^{Bt}} = \frac{(Mg/Fe)^{Grt}}{(Mg/Fe)^{Bt}}$$

$$\ell n K_D = -\Delta H^o/R \cdot (1/T) + \Delta S^o/R$$

$$T°C = \frac{52{,}090 + 2.494\,P(MPa)}{19.506 - 24.943\,\ell n K_D} - 273$$

1. Comparing the Mg and Fe between the Biotite and Garnet.
2. Next, by incorporating K_D with the gibbs free energy formula a temperature can be calculated.
3. Finally, the formula is rearranged and constants are added and a temperature in Celsius is calculated.

(Winter, 2014)

Applications of Geothermometry

- Exploiting geothermal fields
  - Hydrocarbonate exploration, assess reservoir temperatures
- Characterizing deep groundwater flow systems
- Understanding the genesis of ore deposits

(Abdelali et al., 2020)

Do you have any questions about geothermometry?

Keystone Garnet Schist

Location of sample: Hwy. 16A about 0.5 mile N of Keystone. (Saini-Eidukat, 2023)

Composition:

Major components

- quartz-biotite-garnet schist
- quartz-biotite-muscovite
- quartz-biotite schist

Minor components:

- biotite schist
- muscovite-biotite schist
- biotite-garnet schist
- graphitic schist
- quartz-microcline-biotite schist
- plagioclase-biotite schist
- quartzite
- quartz-cummingtonite-gunerite gneiss
- amphibolite.

(Redden, 1968)

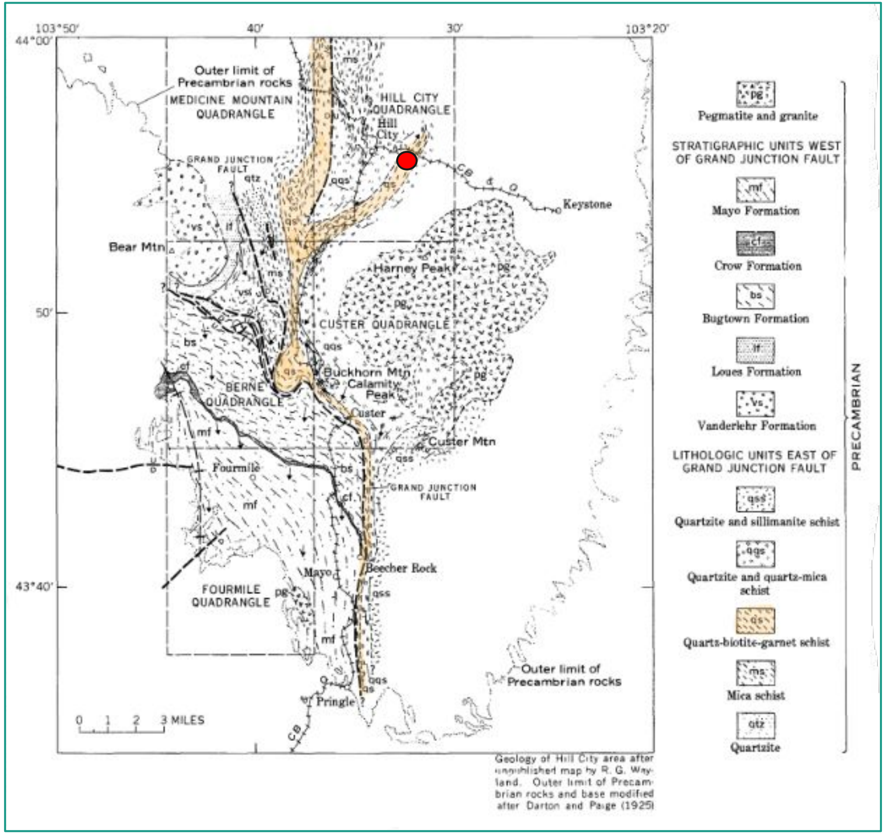


Fig 2. Rock unit map of the Black Hills (Redden, 1968)

Sample Location and Sample

Fig. 3. and 4. Garnet-biotite schist outcrop located on Hwy. 16A about 0.5 mile N of Keystone. (Saini-Eidukat, 2023)

(McCurry, 2023)

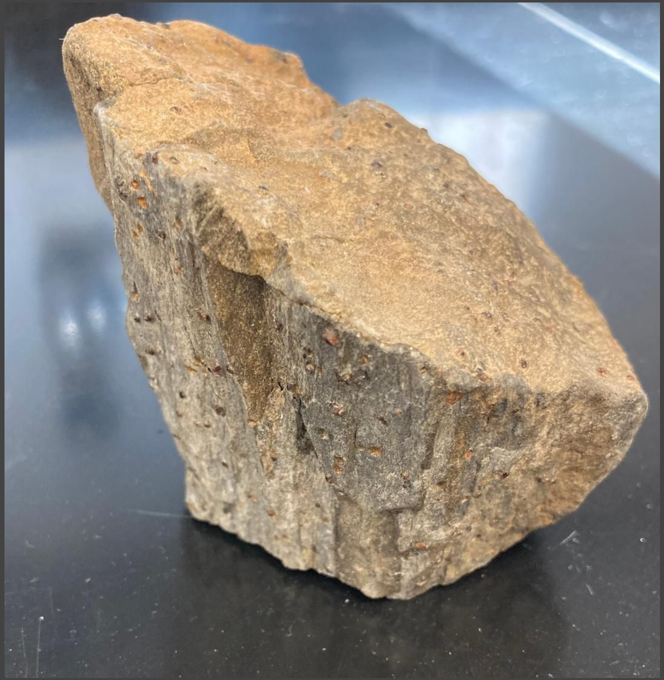
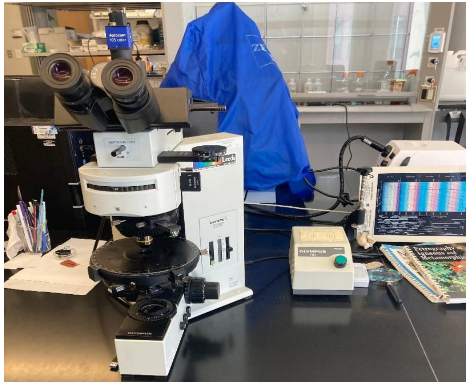


Fig. 5. Sample that was used during this experimentation.

Processes of Our Case Study

Fig. 6 Petrographic microscope Olympus model (BX60)

1



Petrographic Examination

Using both transmitted and reflective petrography.

2

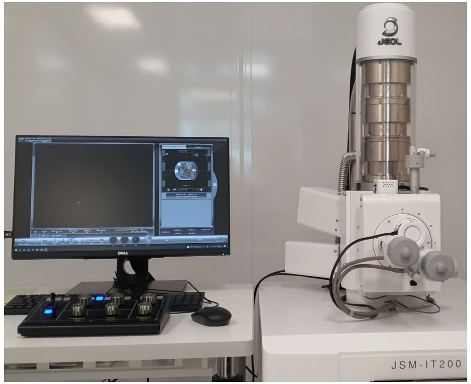


Fig. 7 Scanning electron microscope Jeol SEM model (IT200)

SEM Examination

Using backscattered electrons.

Creating a Thin Section

- Creating and polishing the billet
- Adhering billet to a slide
- Cutting the thin section
- Thinning and polishing the thin section

Fig. 8. The created thin section.

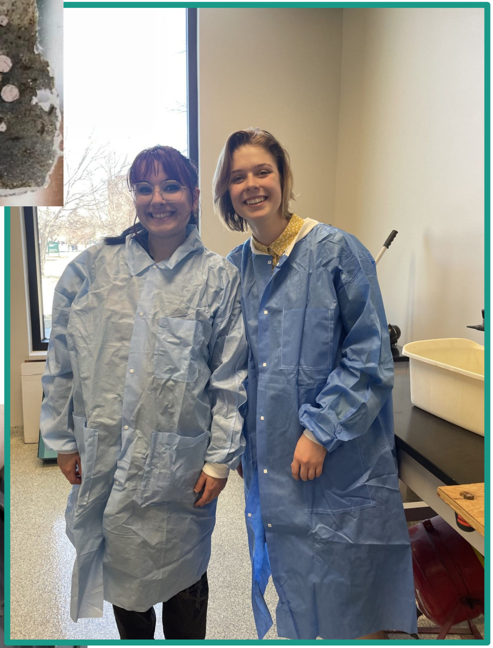


Fig. 9. The garnet gals preparing to cut the thin section.

Fig. 10. Polishing wheel.

Petrographic Examination

- Transmitted - plane polarized light was used to locate a garnet and biotite in equilibrium (touching.)
- Reflected light was then used to provide an estimation of what the area would look like in the (SEM) scanning electron microscope.

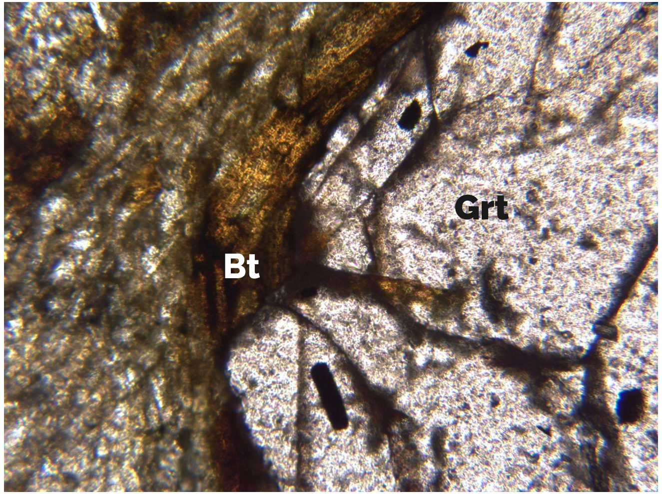


Fig. 11. FOV: 114mm Transmitted - Plane Polarized Light

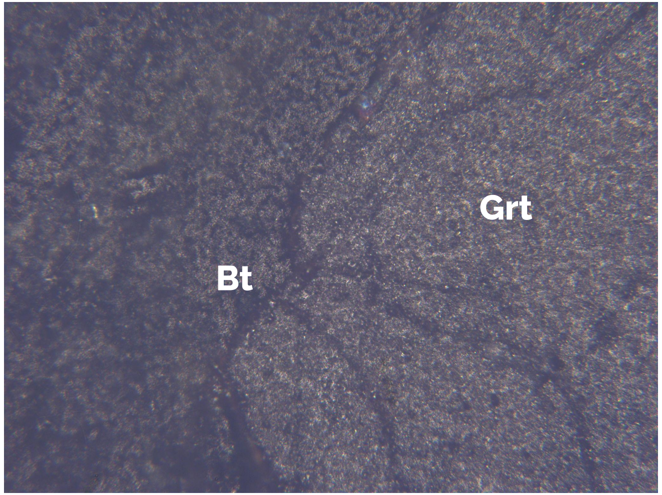


Fig. 12. FOV: 114mm Reflected

Grt - Garnet
Bt - Biotite

SEM Examination

01 | Carbon Coated

02 | Mounted using xyz tape

03 | Analyzed using Jeol SEM model (IT200)

04 | Utilized backscattered electrons to examine garnets

05 | Captured images of biotite-garnet using computer software

Fig. 13. carbon coating tools

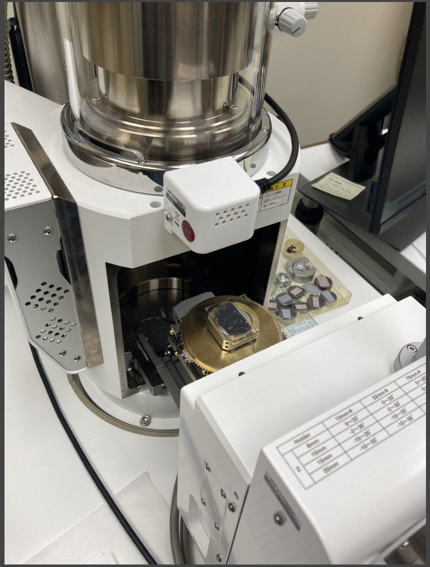


Fig. 14. Thin section in the microscope

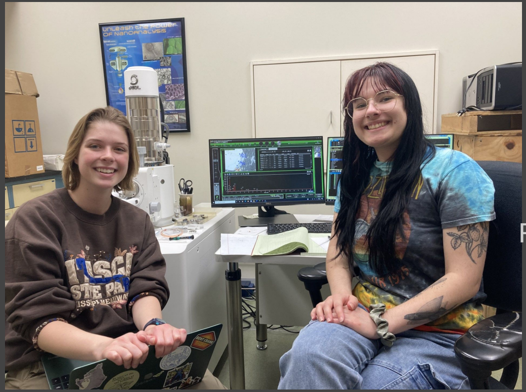
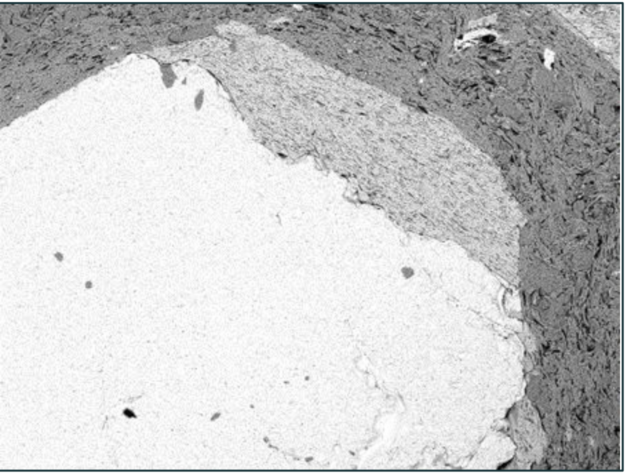


Fig. 15. The garnet gals at SEM lab

SEM Results

Fig. 16. Sem_BED-C_005



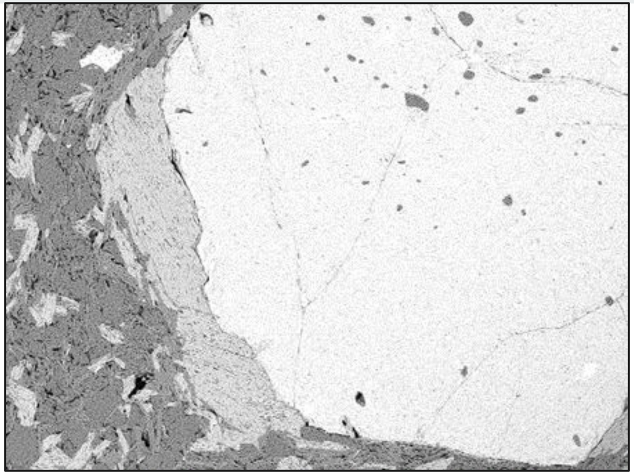
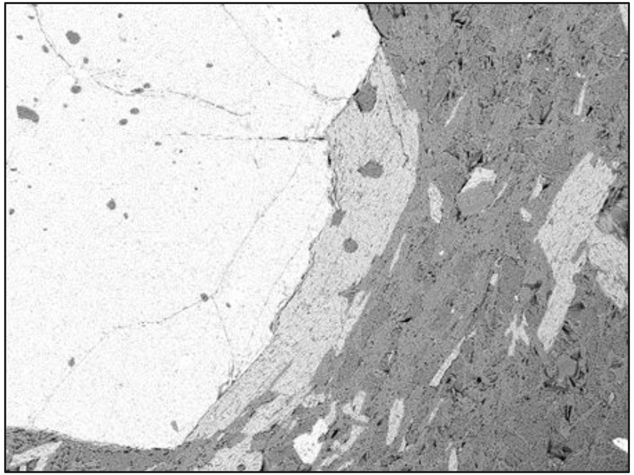


Fig. 17. Sem_BED-C_003

Fig. 18. Sem_BED-C_002



100 µm

Analysis of Data

Image 5

Sem_Bed_C002						
	Sets	**Mg-Fe Ratio Garnet**	**Mg-Fe Ratio Biotite**	**K_D**	**$\ell n K_D$ in K**	**$\ell n K_D$ in C**
	1	0.0255	0.2619	0.0973	677.7087	404.5587
	2	0.0336	0.265	0.1268	740.7422	467.5922
	3	0.0336	0.2468	0.1361	759.6262	486.4762
	4	0.0343	0.2717	0.1262	739.5103	466.3603

$$K = K_D = \frac{(X_{Mg}/X_{Fe})^{Grt}}{(X_{Mg}/X_{Fe})^{Bt}} = \frac{(Mg/Fe)^{Grt}}{(Mg/Fe)^{Bt}}$$

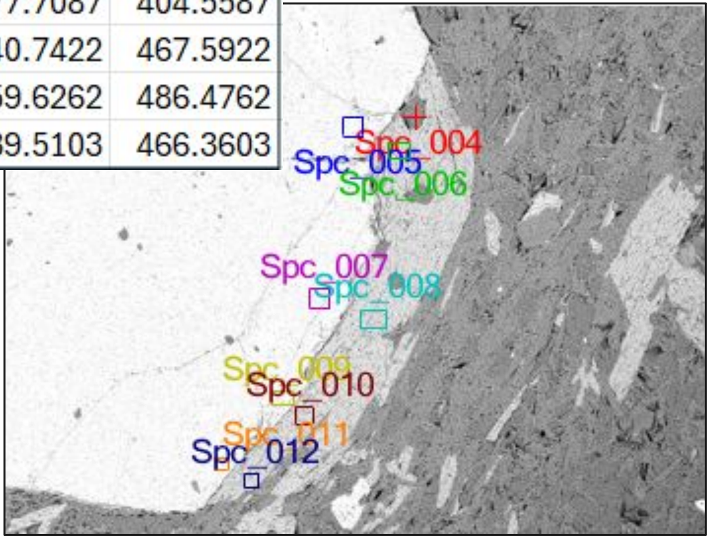


Fig. 19. Sem_BED-C_002

Image 6

Sem_BED-C_003						
	Sets	**Mg-Fe Garnet Ratio**	**Mg-Fe Biotite Ratio**	**K_D**	**ℓn K_D in K**	**ℓn K_D in C**
	1	0.0795053	0.583333333	0.136295	760.0178	486.8678
	2	0.077253219	0.582298137	0.13267	752.7051	479.5551
	3	0.071759259	0.6035313	0.118899	724.3736	451.2236
	4	0.089799477	0.597087379	0.150396	787.974	514.824

$$K = K_D = \frac{(X_{Mg}/X_{Fe})^{Grt}}{(X_{Mg}/X_{Fe})^{Bt}} = \frac{(Mg/Fe)^{Grt}}{(Mg/Fe)^{Bt}}$$

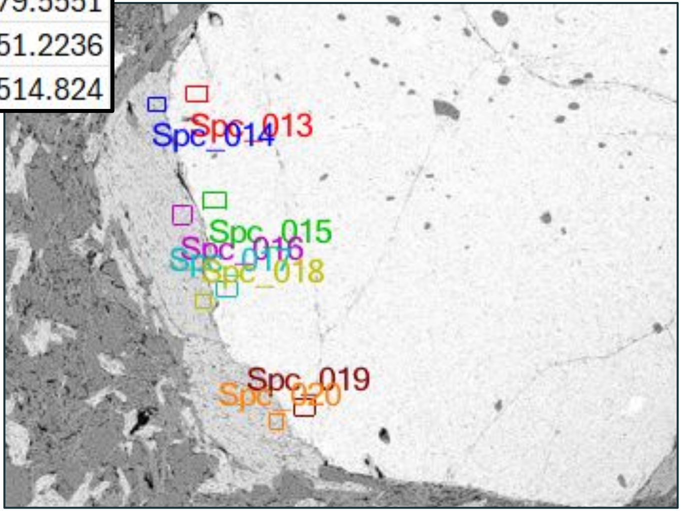


Fig. 20. Sem_BED-C_003

Image 8

Sem_BED-C_005						
	Sets	**Mg-Fe Garnet Ratio**	**Mg-Fe Biotite Ratio**	**K_D**	**ℓn K_D in K**	**ℓn K_D in C**
	1	0.082465278	0.587096774	0.140463	768.3585	495.2085
	2	0.082216265	0.544776119	0.150918	788.9947	515.8447
	3	0.086124402	0.540740741	0.159271	805.2239	532.0739
	4	0.07654321	0.540740741	0.141553	770.5279	497.3779

$$K = K_D = \frac{(X_{Mg}/X_{Fe})^{Grt}}{(X_{Mg}/X_{Fe})^{Bt}} = \frac{(Mg/Fe)^{Grt}}{(Mg/Fe)^{Bt}}$$

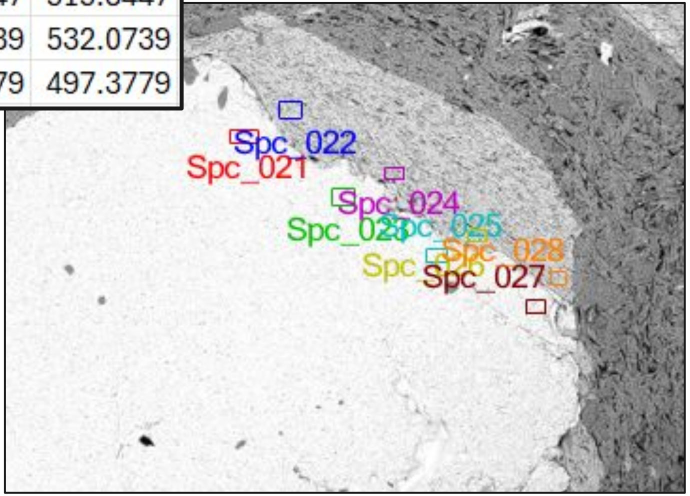


Fig. 21. Sem_BED-C_005

Results

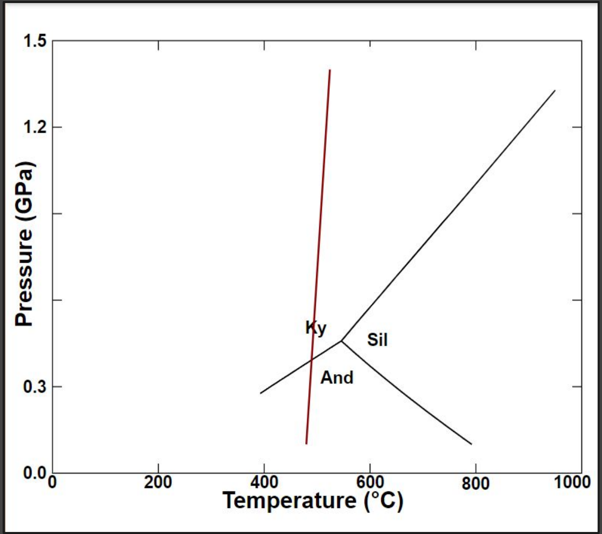


Fig. 22. Image 5 graph

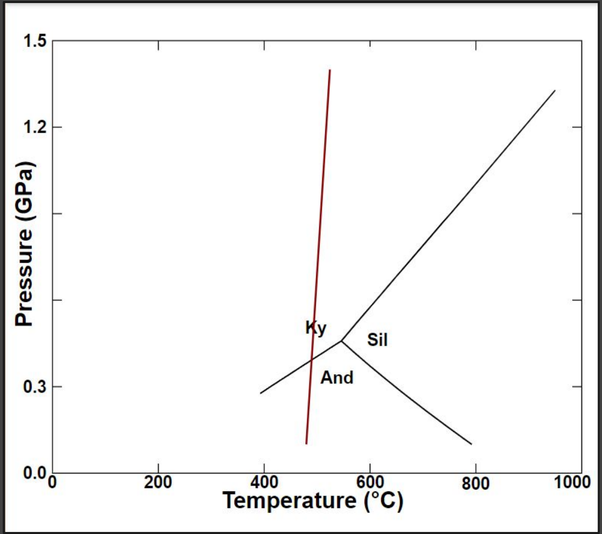


Fig. 23. Image 6 graph

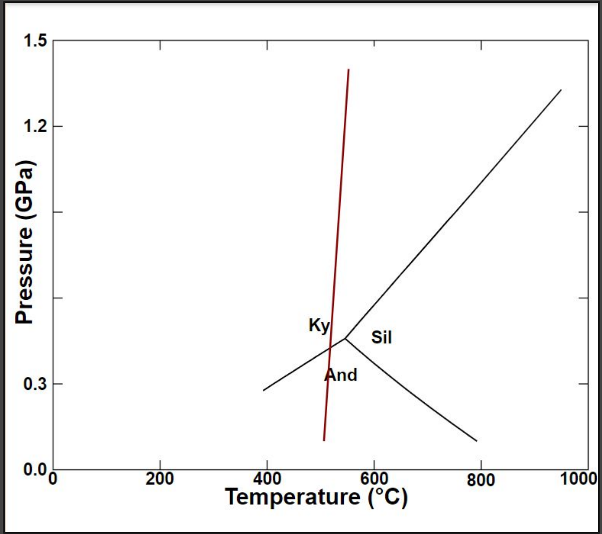
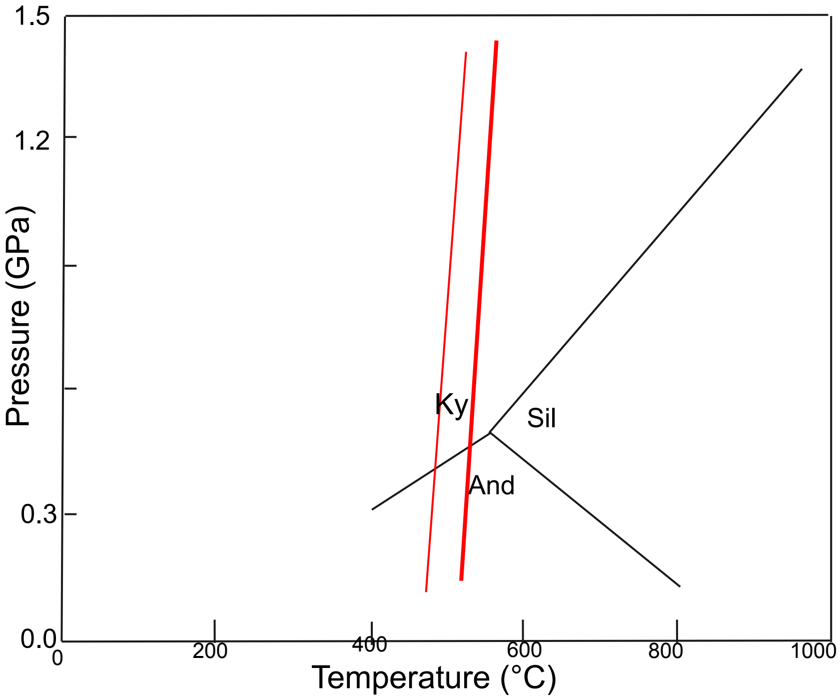


Fig. 24. Image 8 graph



Average temperature of entire system:
483.16 °C

- Isopleths
  - Steep slope indicates reaction is more sensitive to temperature than pressure

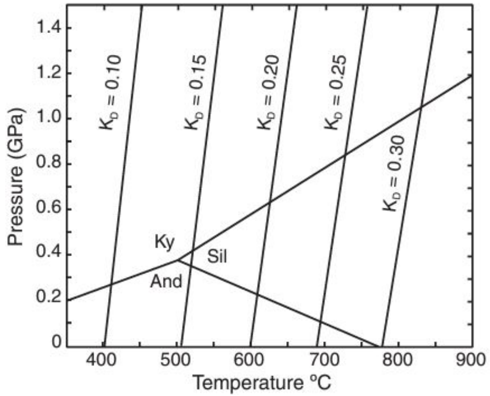
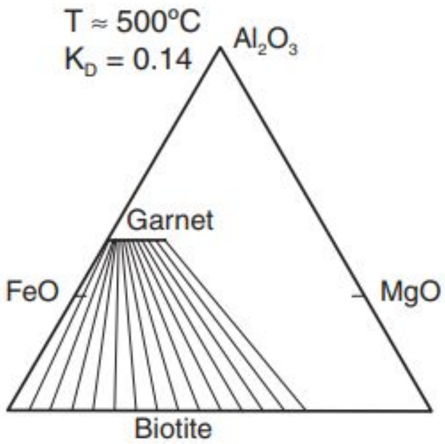


Fig. 25. Pressure−temperature diagram, showing lines of constant KD for garnet-biotite reaction Spear (1993). (Winter, 2024)



Big Picture of the Black Hills

- The formation of the Black Hills is connected to the formation of Laurentia, their formation is tied to the youngest stages of the Trans-Hudson orogeny.

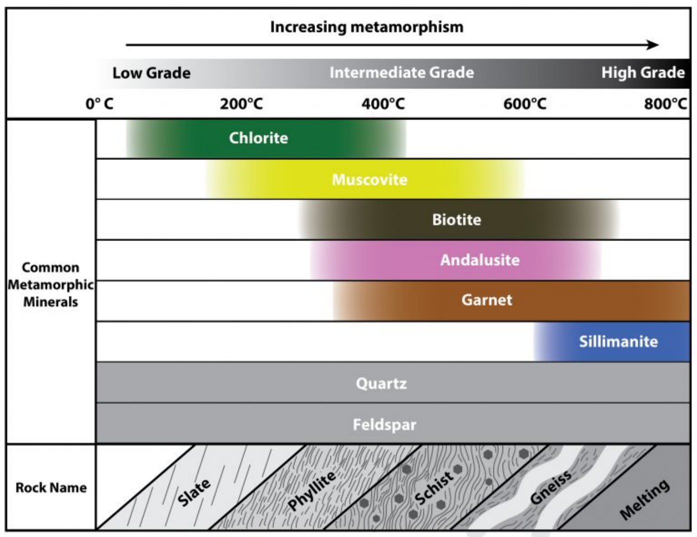
- Most of the metamorphic core represents ocean basin material from a basin that closed during the proterozoic.

- Then there are four recognized generations of metamorphism during the Trans-Hudson orogeny.

(KECK Geology Consortium, 2020)

Fig. 26. Bridal Veil Falls, Black Hills of South Dakota.

Fig. 27. Metamorphic Grades (McGoldrick, 2020)



When observing the big picture of the black hills the metamorphic contex is visible

- **The southern sillimanite zone experienced the highest metamorphism.**
- **The northern biotite zone experienced the lowest grade metamorphism.**

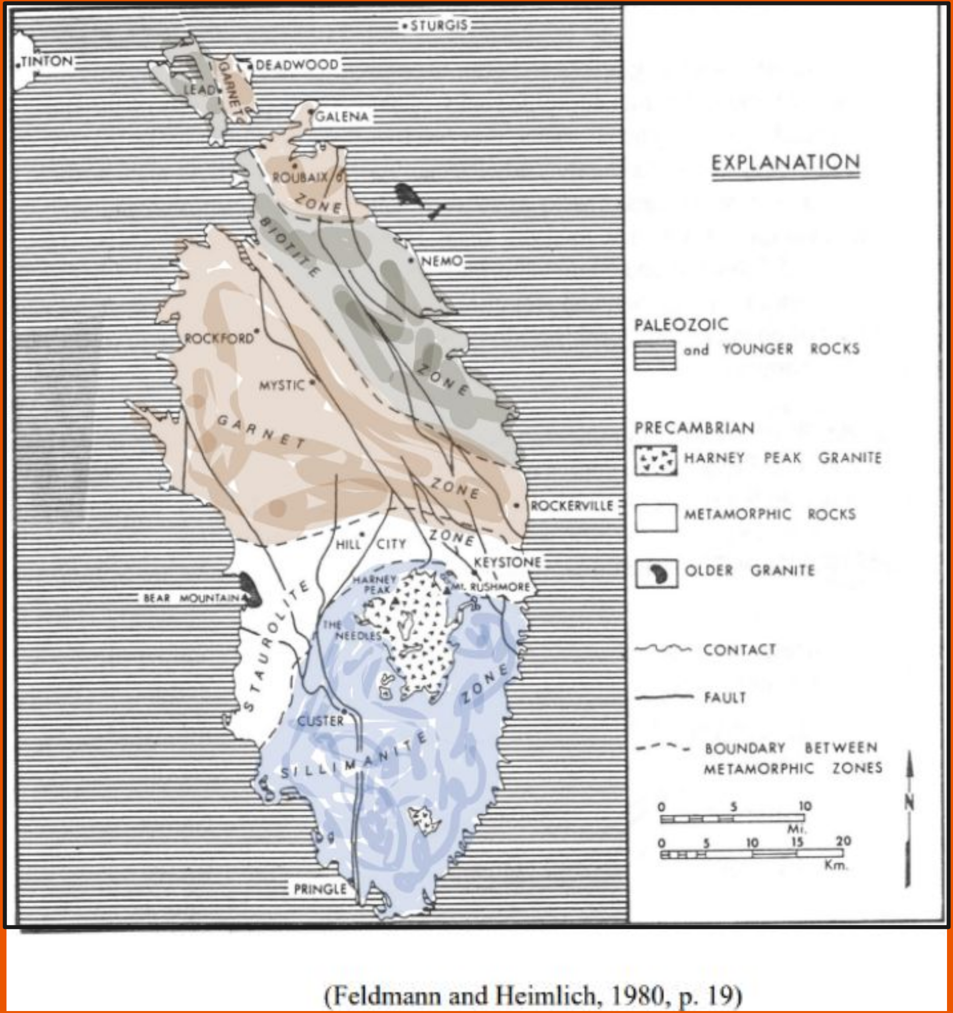


Fig. 28. Map of metamorphic and igneous portions of the Black Hills. (Saini-Eidukat, 2023)

Summary

Using the methods of petrographic analysis and scanning electron microscopy, we were able to determined that the keystone garnet biotite schist is formed at an average temperature of 483.16 °C.

This places the keystone garnet biotite schist in the context of the black hills one grade lower than the highest grade sillimanite area.

This information could be useful when exploiting geothermal fields and understanding the genesis of ore deposits.

Fig. 29 Our favorite Garnet Biotite Schist

Thank you Dr. Eidukat for you help completing this project.

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