Geothermometry of Black Hills Garnet Schist

By: Amelia Swanson

Outline

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- Petrography of Sample
- Guiding Question
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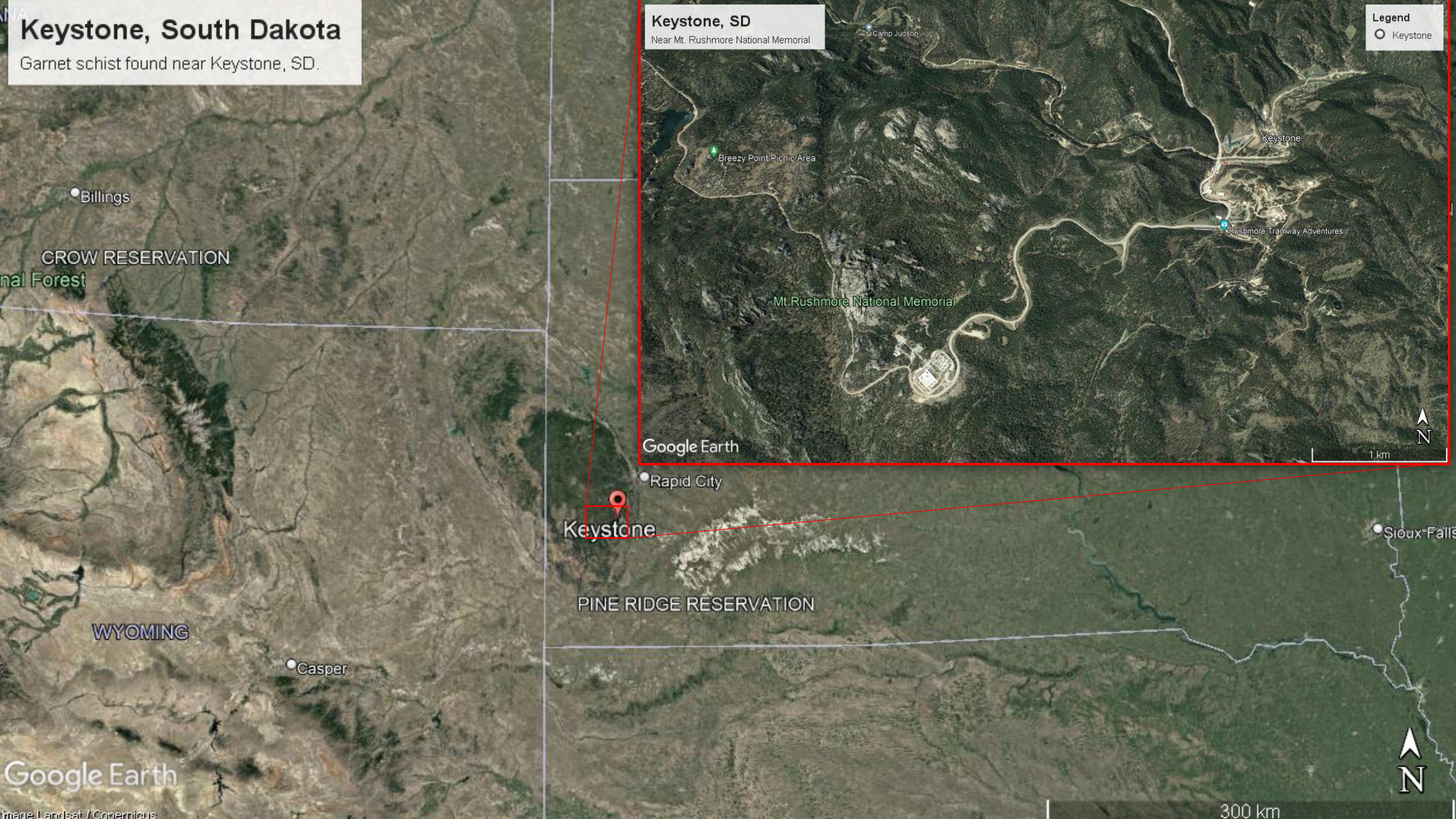
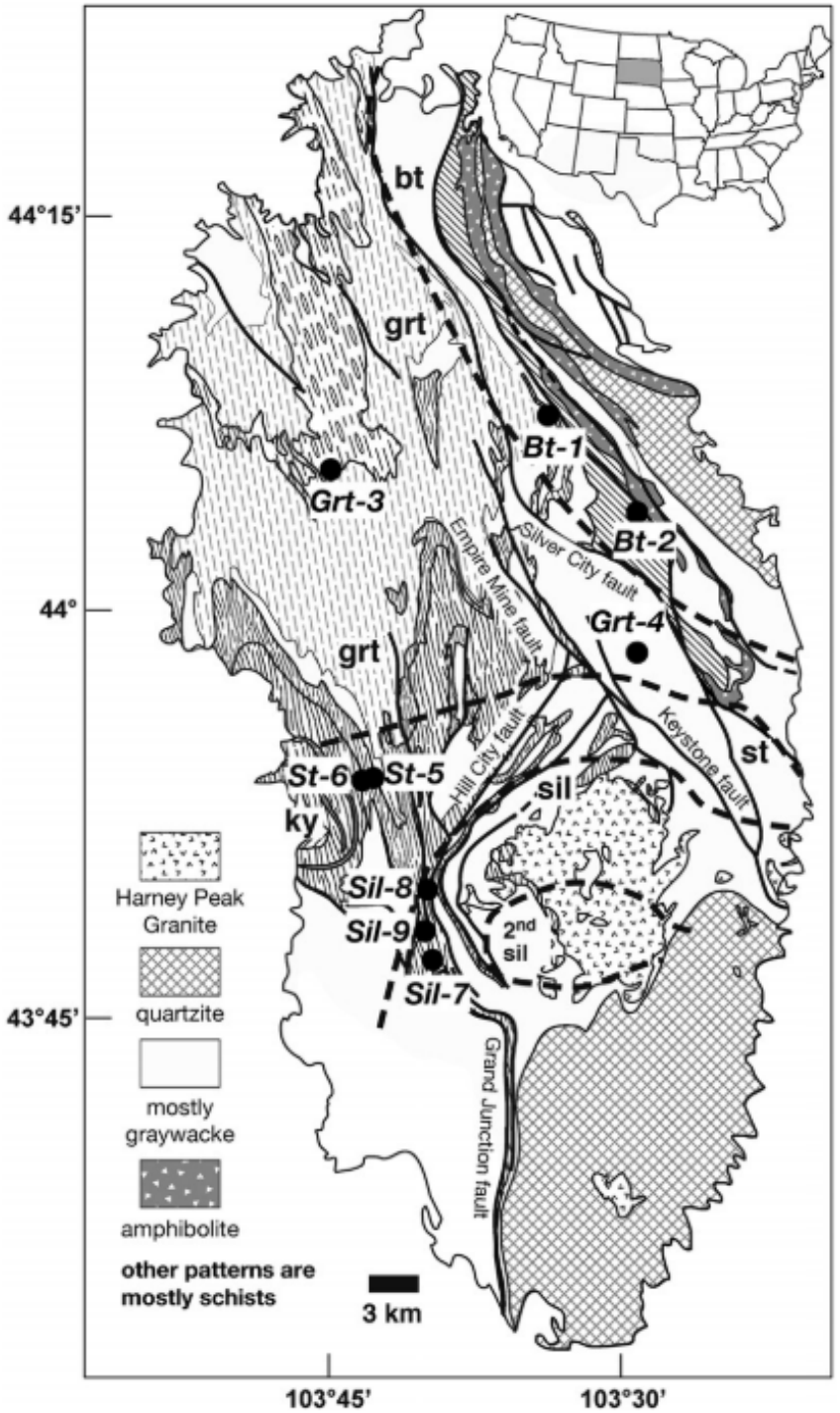
- SEM results
- Geothermometry
- Comparison to Helms and Labotka’s Data
- Summary/Conclusion
- References


Keystone, South Dakota
Garnet schist found near Keystone, SD.
Keystone, SD
Near Mt. Rushmore National Memorial
Legend
Keystone
Camp Judson
Breezy Point Picnic Area
Keystone
Rushmore Tramway Adventures
Mt Rushmore National Memorial
Google Earth
1 km
N
Billings
CROW RESERVATION
nal Forest
Rapid City
Keystone
Sioux Falls
PINE RIDGE RESERVATION
WYOMING
Casper
Google Earth
300 km
N

Background

- The Black Hills of South Dakota record a history of deformation, metamorphism, and igneous activity extending from ~2.5 to 1.7 Ga.
- My sample is a metamorphic rock that started as a sedimentary rock.
- About 1.6 billion years ago a mass of molten rock rose upwards through the crust. The intense heat and pressure created metamorphic rocks from the sedimentary rocks.



Huff and Nabelek (2007)

NSP (2021)

Petrography of Sample

Garnet Schist

Mode of Sample:

Garnet: 30%

Biotite: 24%

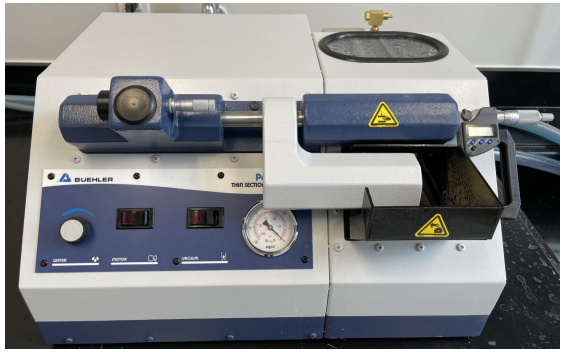
Muscovite: 25%

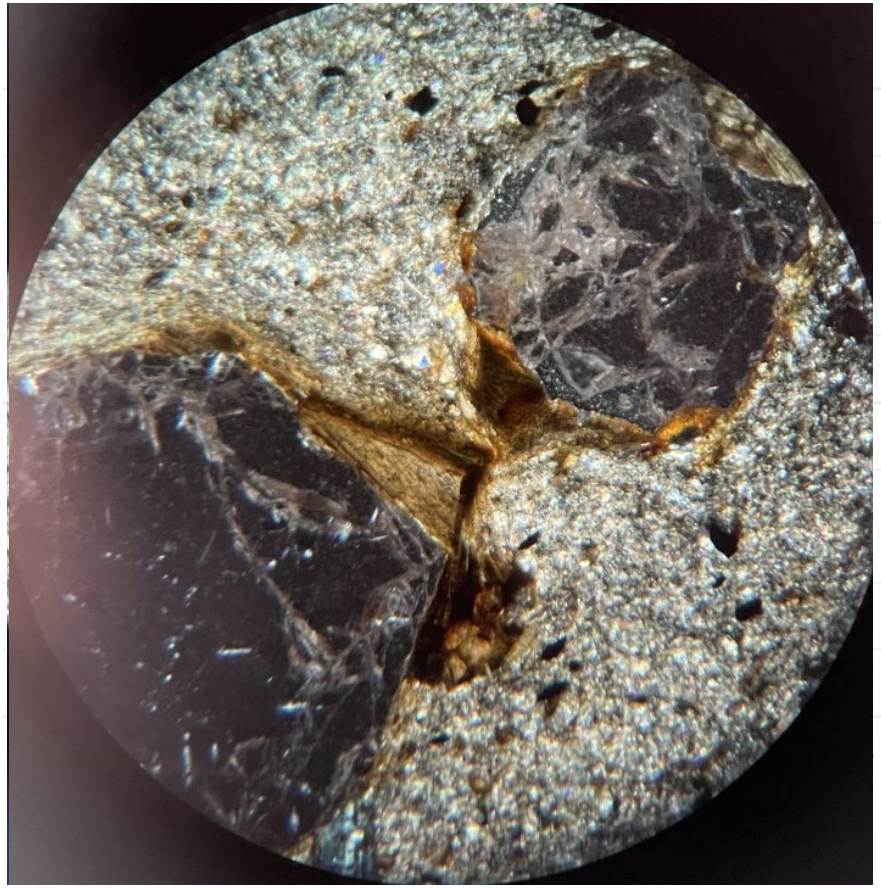
Quartz: 15%

Feldspars: 5%

Opaques: 1%

Matrix Minerals





What is Geothermometry?
How does this apply to my sample?

- Geothermometry is the evaluation of the temperature at which a rock has formed.
- Garnet – Biotite geothermometer uses the proximity of the crystals and the ratio of magnesium and iron in each mineral to calculate the temperature at which the rock formed.

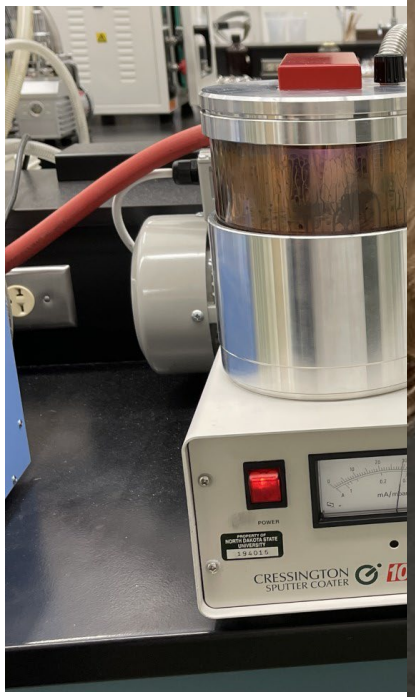
$$Fe_3Al_2Si_3O_{12} + KMg_3Si_3AlO_{10}(OH)_2 = Mg_3Al_2Si_3O_{12} + KFe_3Si_3AlO_{10}(OH)_2$$

$$T(^{\circ}C) = \frac{52{,}090 + 2.494P(MPa)}{19.506 - 12.943\,ln\,K_D} - 273$$

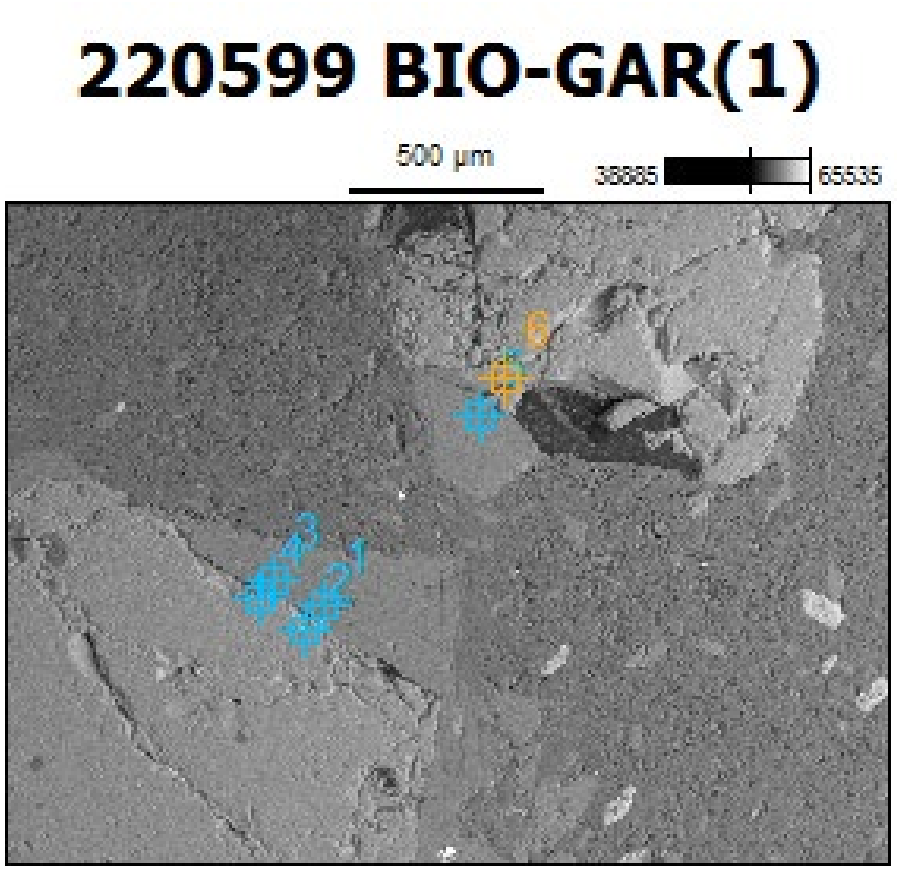
Methods

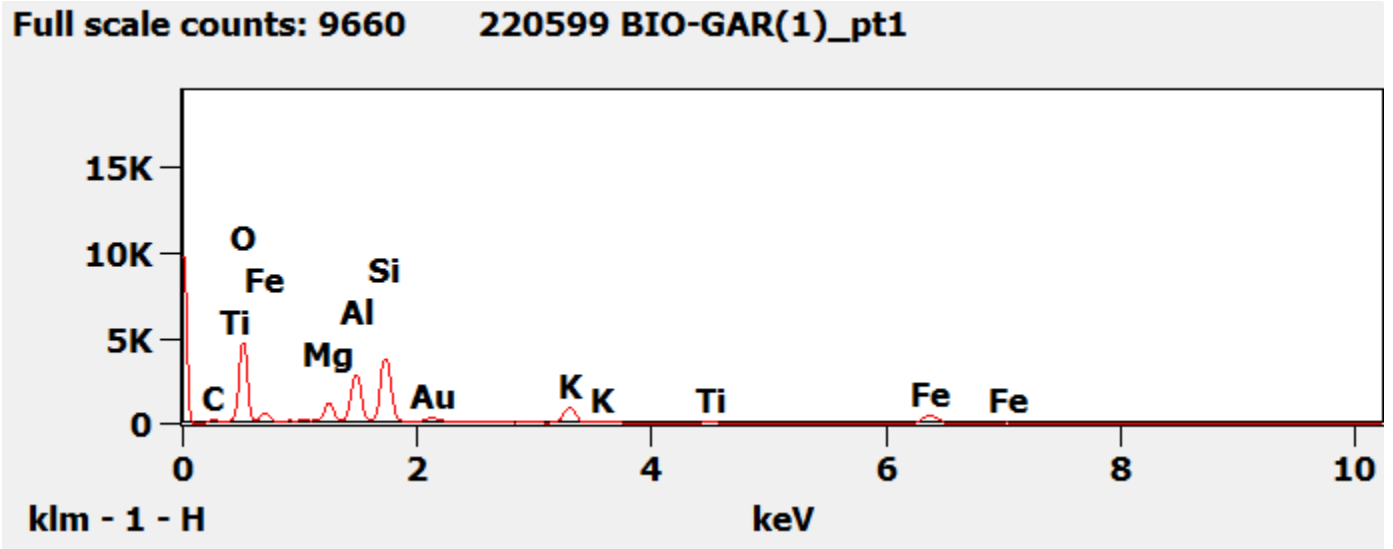
SEM – Scanning Electron Microscope

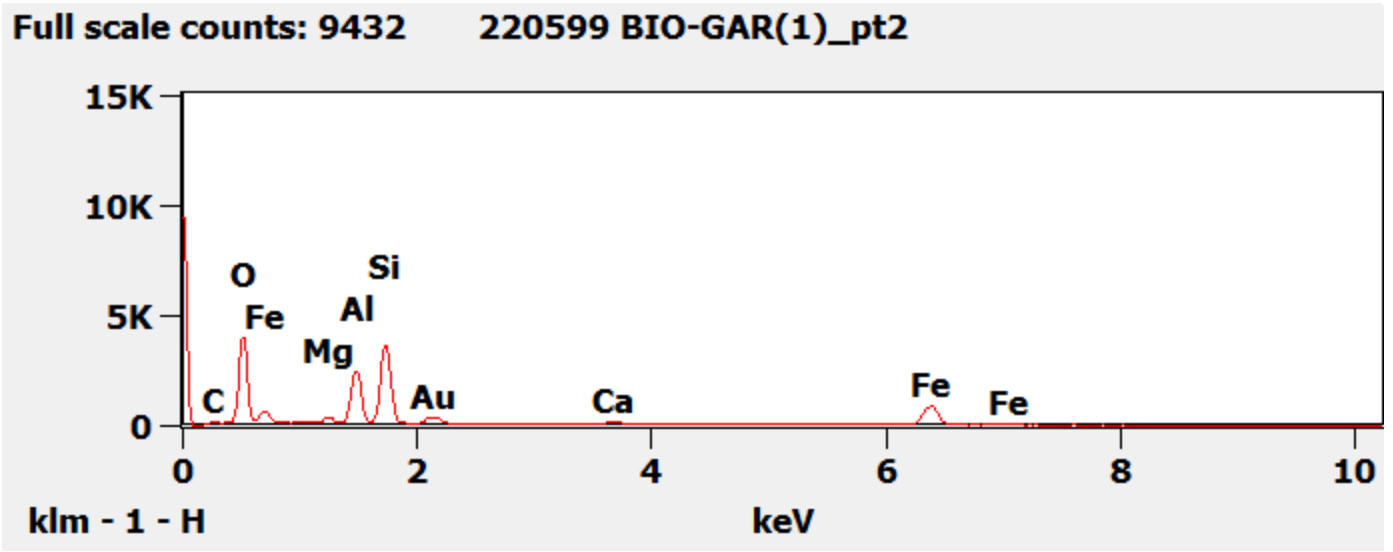
Geothermometry



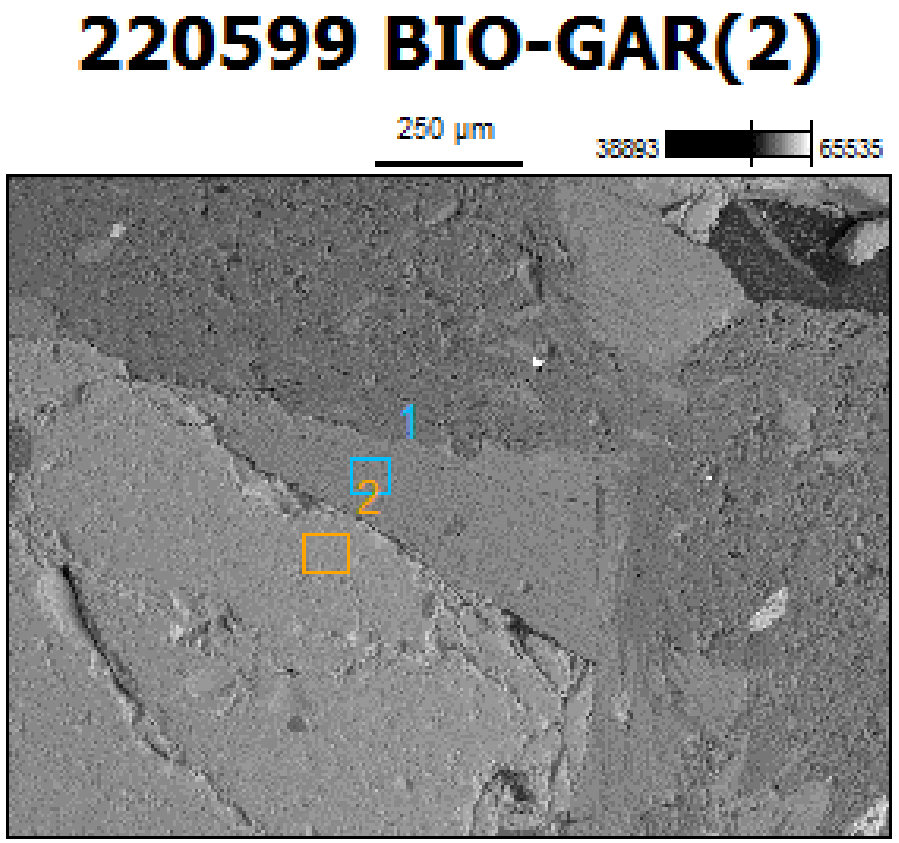
SEM Results

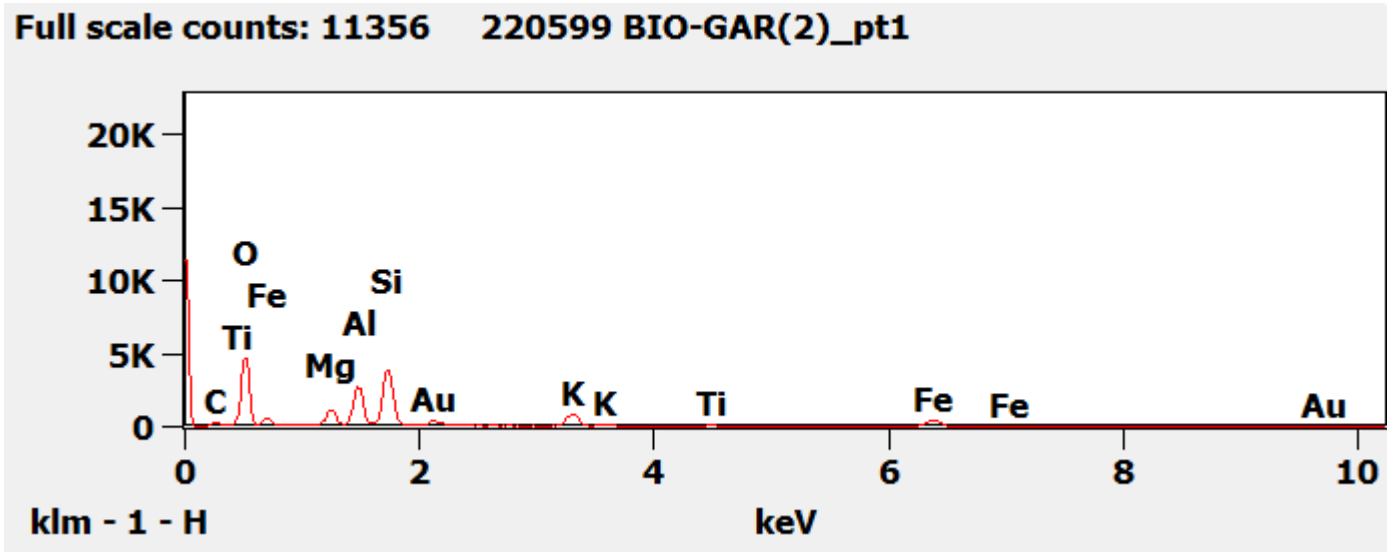

220599 BIO-GAR(1)
500 µm
38885
65535
1
2
3
4
5
6

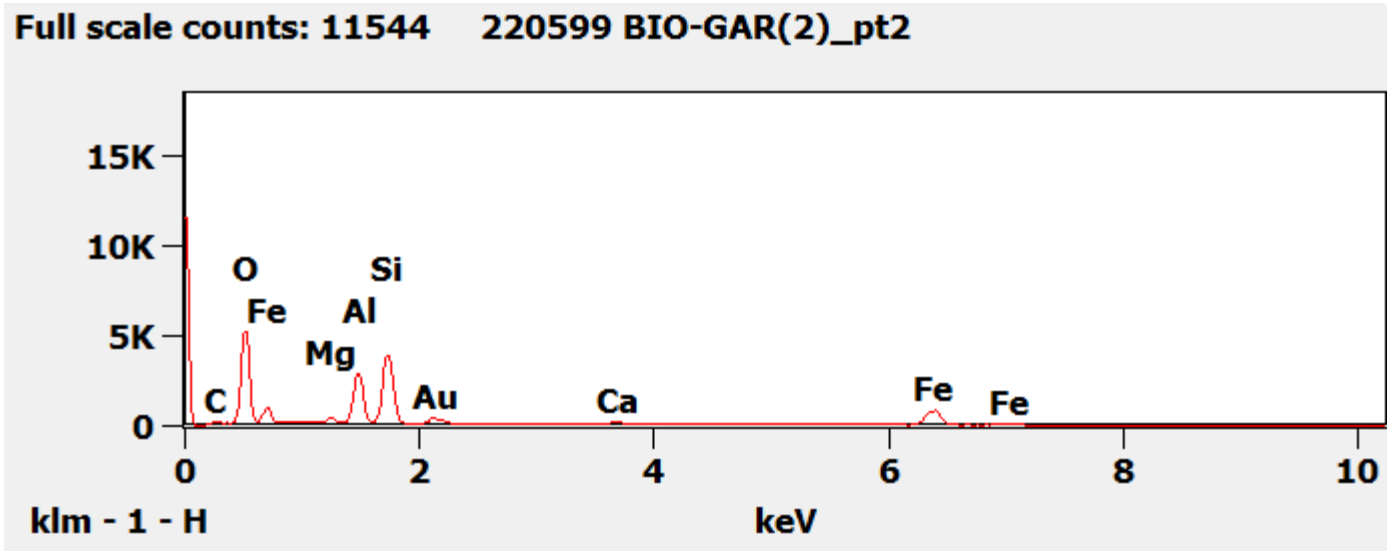

Full scale counts: 9660
220599 BIO-GAR(1)_pt1
15K
10K
5K
0
O
Fe
Ti
Si
Al
Mg
C
Au
K
K
Ti
Fe
Fe
0
2
4
6
8
10
klm - 1 - H
keV


Full scale counts: 9432
220599 BIO-GAR(1)_pt2
15K
10K
5K
0
O
Fe
Si
Al
Mg
C
Au
Ca
Fe
Fe
0
2
4
6
8
10
klm - 1 - H
keV

SEM Results


220599 BIO-GAR(2)
250 µm
38893
65535
1
2


Full scale counts: 11356
220599 BIO-GAR(2)_pt1
20K
15K
10K
5K
0
O
Fe
Si
Ti
Al
Mg
C
Au
K
K
Ti
Fe
Fe
Au
0
2
4
6
8
10
klm - 1 - H
keV


Full scale counts: 11544
220599 BIO-GAR(2)_pt2
15K
10K
5K
0
O
Si
Fe
Al
Mg
C
Au
Ca
Fe
Fe
0
2
4
6
8
10
klm - 1 - H
keV

The Garnet - Biotite Geothermometer

Table 27-2. Experimental results of Ferry and Spear (1978) on a Garnet-Biotite Geothermometer

T °C	Initial X(Fe-Bt)	Final X(Fe-Bt)	Final X(Fe-Grt)	Final (Mg/Fe)Grt	Final (Mg/Fe)Bt	K	T Kelvins	1/T Kelvins	lnK
799	1.00	0.750	0.905	0.105	0.333	0.315	1072	0.00093	-1.155
799	0.50	0.710	0.896	0.116	0.408	0.284	1072	0.00093	-1.258
749	0.50	0.695	0.896	0.116	0.439	0.264	1022	0.00098	-1.330
738	1.00	0.730	0.906	0.104	0.370	0.281	1011	0.00099	-1.271
698	0.75	0.704	0.901	0.110	0.420	0.261	971	0.00103	-1.342
698	0.50	0.690	0.896	0.116	0.449	0.258	971	0.00103	-1.353
651	0.75	0.679	0.901	0.110	0.473	0.232	924	0.00108	-1.459
651	0.50	0.661	0.897	0.115	0.513	0.224	924	0.00108	-1.497
599	0.75	0.645	0.902	0.109	0.550	0.197	872	0.00115	-1.623
599	0.50	0.610	0.898	0.114	0.639	0.178	872	0.00115	-1.728
550	0.75	0.620	0.903	0.107	0.613	0.175	823	0.00122	-1.741
550	0.50	0.590	0.898	0.114	0.695	0.163	823	0.00122	-1.811
601	0.50	0.500	0.800	0.250	1.000	0.250	874	0.00114	-1.386
601	0.25	0.392	0.797	0.255	1.551	0.164	874	0.00114	-1.807
697	0.75	0.574	0.804	0.244	0.742	0.329	970	0.00103	-1.111
697	0.25	0.468	0.796	0.257	1.137	0.226	970	0.00103	-1.487

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

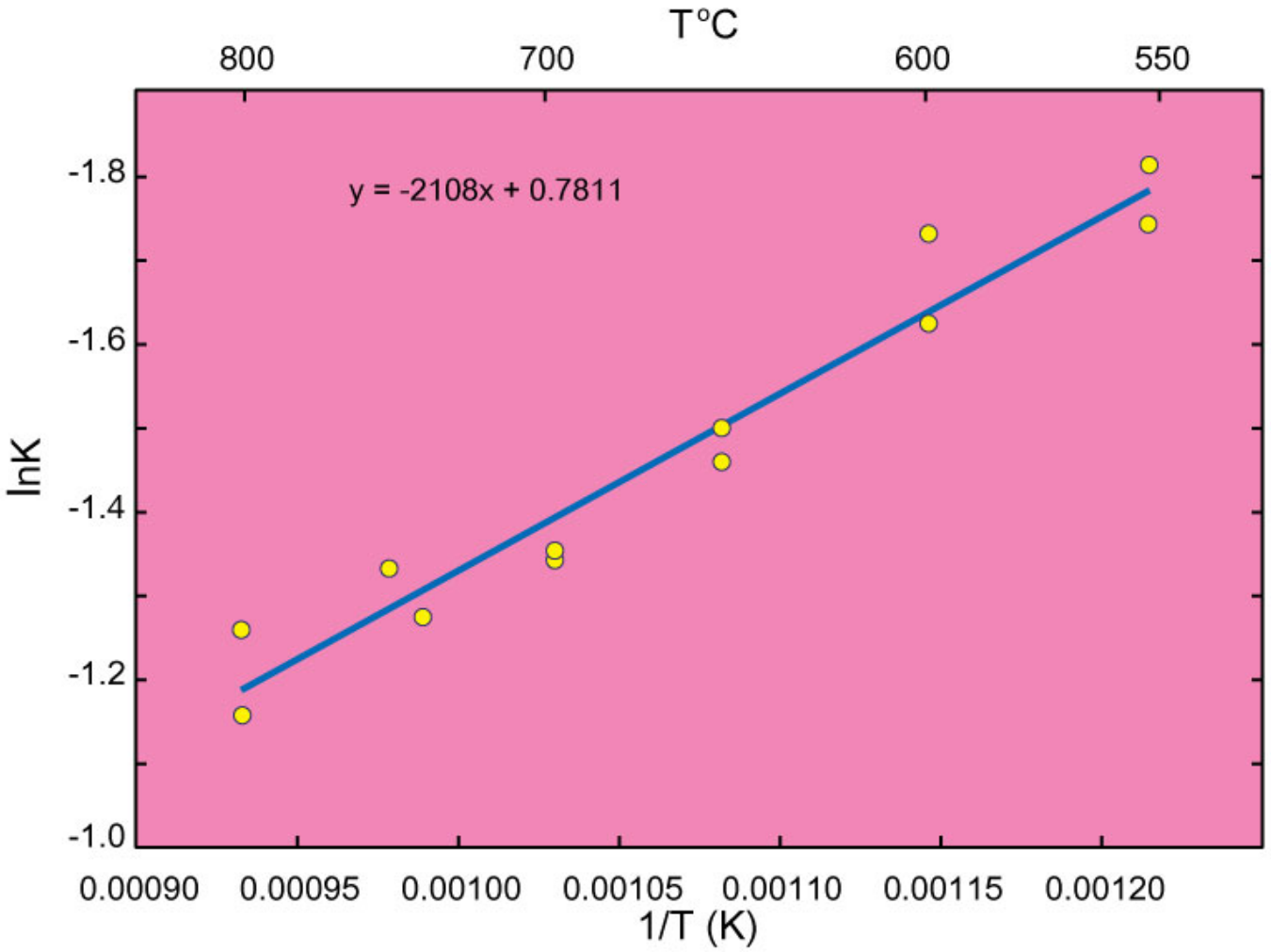
$$K = K_D = \frac{(0.105)^{Grt}}{(0.333)^{Bt}} = 0.315$$

$$T(^{\circ}C) = \frac{52{,}090 + 2.494P(MPa)}{19.506 - 12.943\, ln\, K_D} - 273$$

$$T\,(^{o}C) = \frac{52{,}090 + 2.494\,P(Mpa)}{19.506 - 12.943\,(-1.155)} = 799\,^{o}C$$

Winter (2010)

The Garnet - Biotite geothermometer



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

$$ln K_D = -2108 \cdot T(K) + 0.781$$

$$T(^{\circ}C) = \frac{52{,}090 + 2.494P(MPa)}{19.506 - 12.943\, ln\, K_D} - 273$$

Figure 27.5. Graph of ℓnK vs. 1/T (in Kelvins) for the Ferry and Spear (1978) garnet-biotite exchange equilibrium at 0.2 GPa from Table 27.2. Winter (2010) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Winter (2010)

The Garnet - Biotite geothermometer

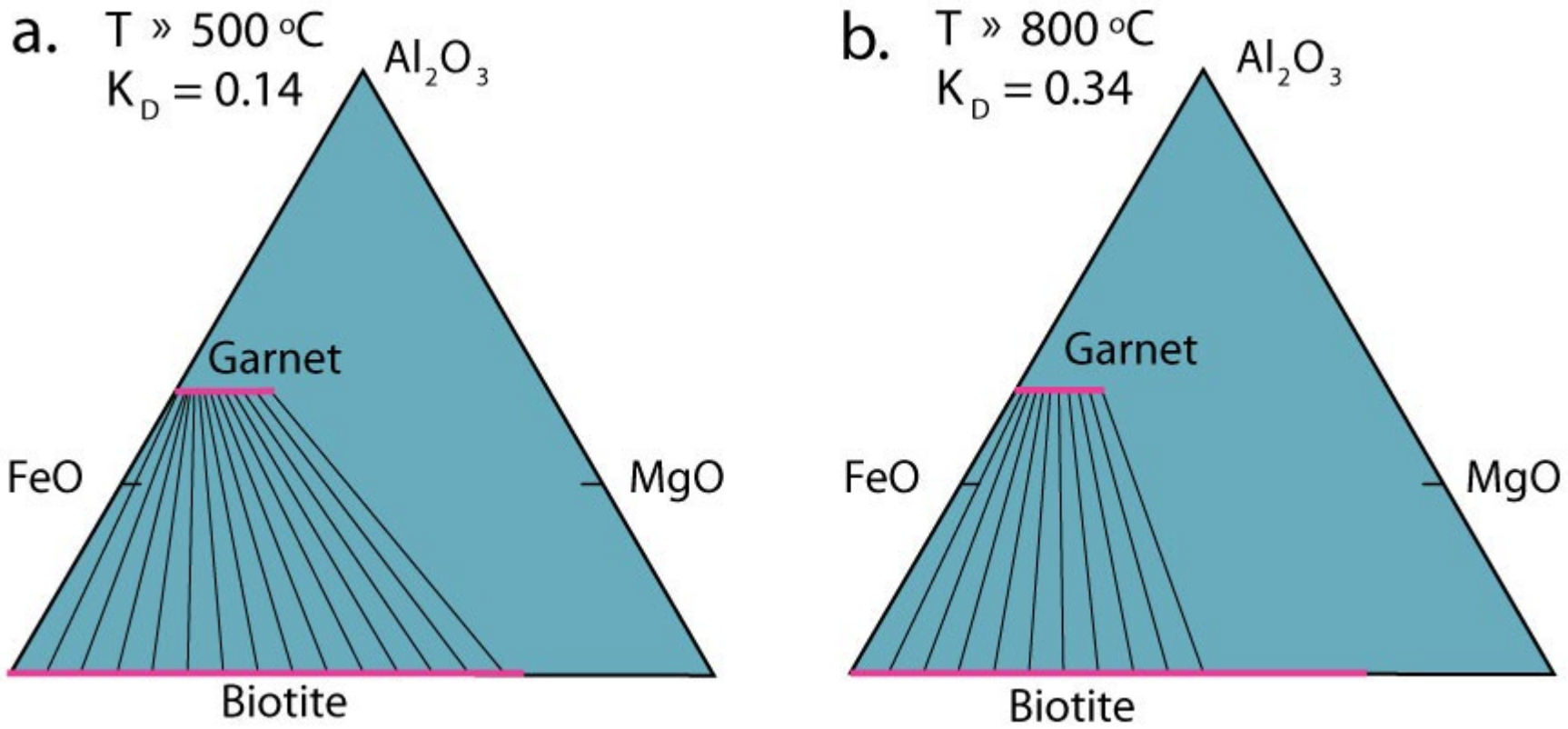
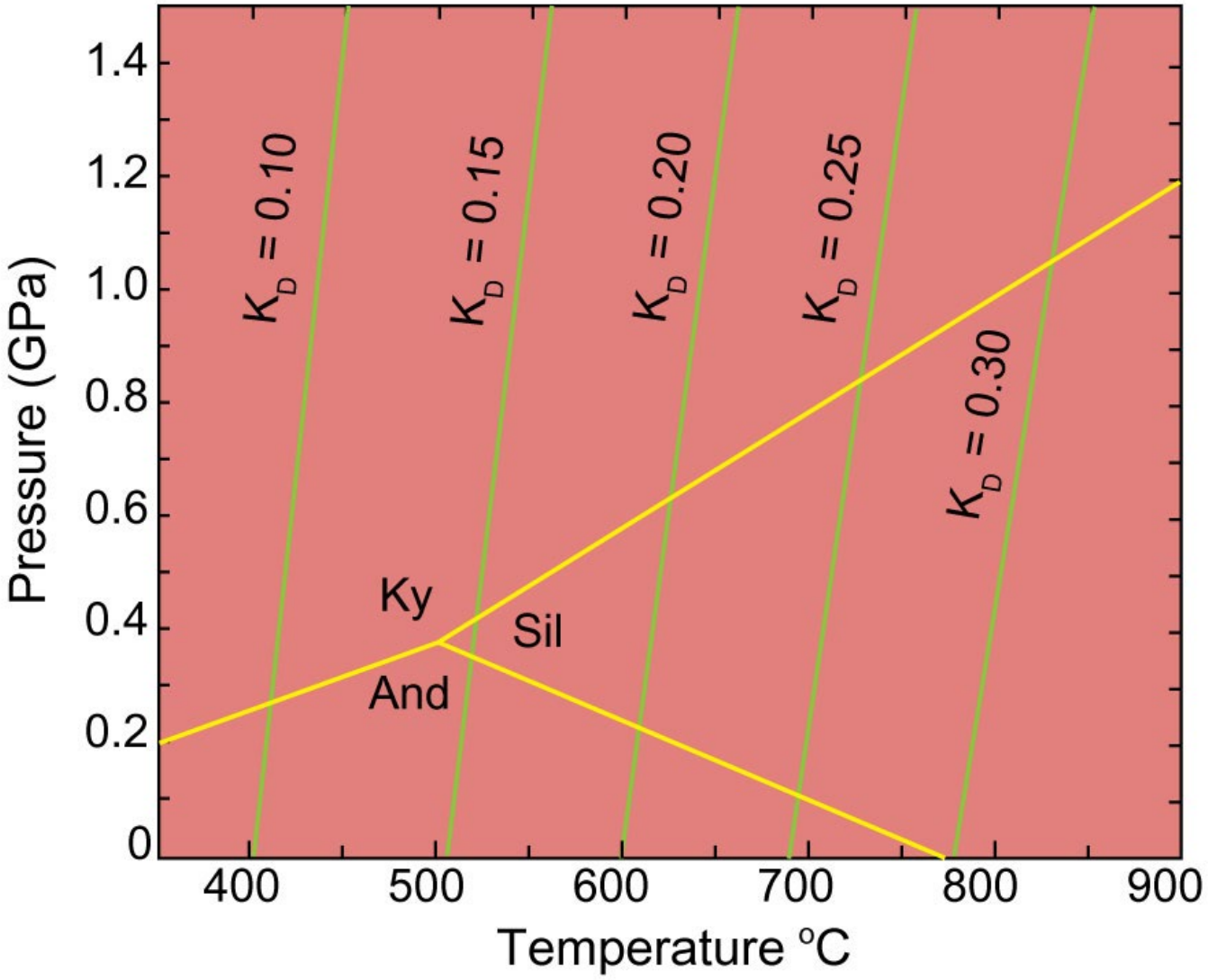


Figure 27.6. AFM projections showing the relative distribution of Fe and Mg in garnet vs. biotite at approximately 500°C (a) and 800°C (b). From Spear (1993) *Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths*. Mineral. Soc. Amer. Monograph 1.

Winter (2010)

The Garnet - Biotite geothermometer



$$T(^{\circ}C) = \frac{52{,}090 + 2.494P(MPa)}{19.506 - 12.943\, ln\, K_D} - 273$$

Figure 27.7. Pressure-temperature diagram similar to Figure 27.4 showing lines of constant K_D plotted using equation (27.35) for the garnet-biotite exchange reaction. The Al_2SiO_5 phase diagram is added. From Spear (1993) *Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths*. Mineral. Soc. Amer. Monograph 1.

Winter (2010)

My Geothermometer Data

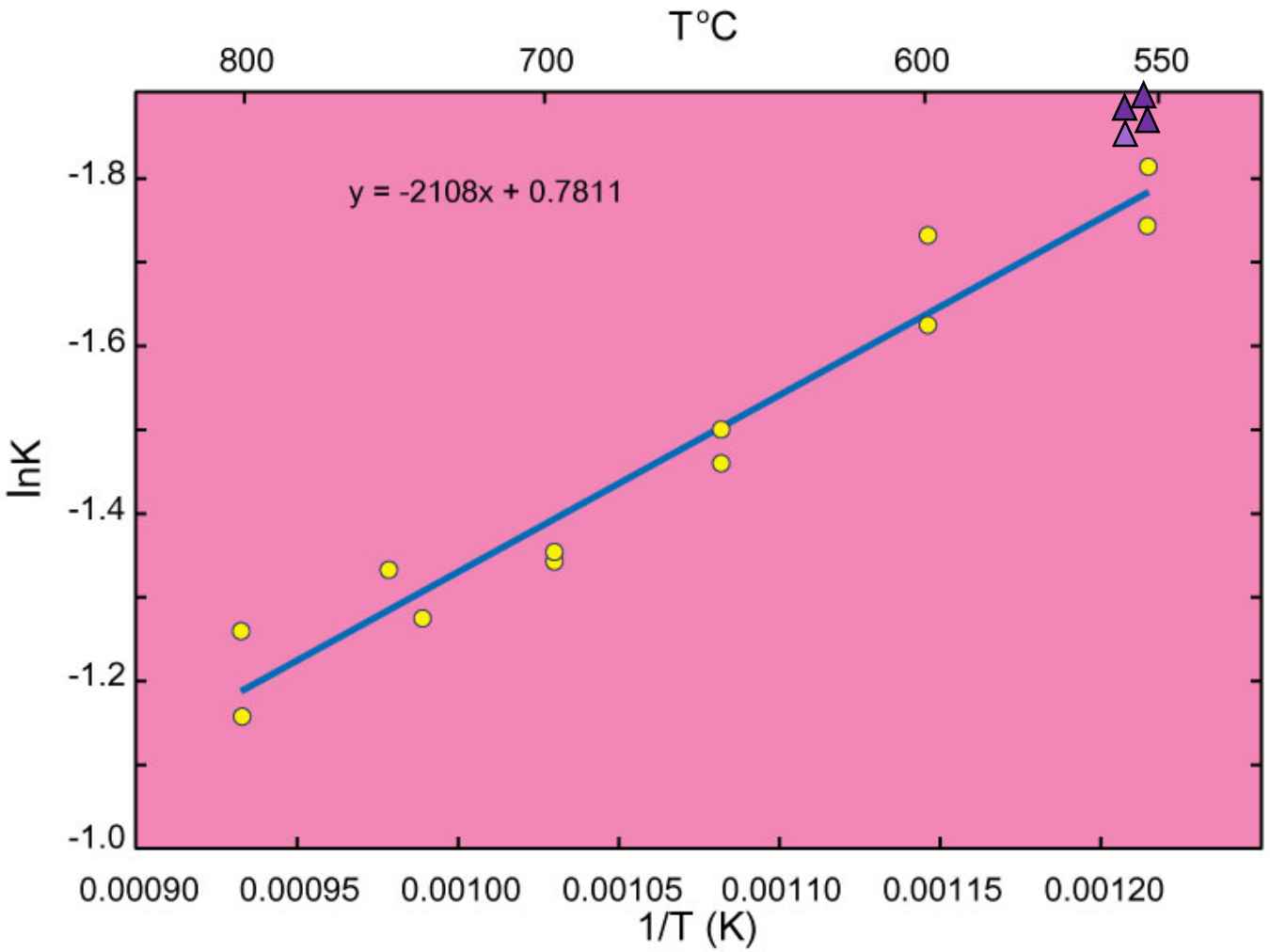
SEM Sample	Biotite or Garnet	Atom % of Mg	Atom % of Fe	Mg:Fe Ratio	K_D	T kelvins	1/T kelvins	ln(K)	T °C
220599 BIO-GAR(1)_pt1	Biotite	4.27	7.35	0.58	0.121	729.19	0.00137	-2.112	448.58
220599 BIO-GAR(1)_pt2	Garnet	1.00	14.23	0.07					
220599 BIO-GAR(1)_pt3	Biotite	4.50	7.18	0.63	0.1139	713.82	0.0014	-2.173	433.86
220599 BIO-GAR(1)_pt4	Garnet	1.04	14.57	0.07					
220599 BIO-GAR(1)_pt5	Biotite	4.27	7.53	0.57	0.149	785.25	0.00127	-1.904	504.60
220599 BIO-GAR(1)_pt6	Garnet	1.15	13.61	0.08					
SEM Sample	Biotite or Garnet	Atom % of Mg	Atom % of Fe	Mg:Fe Ratio	K_D	T kelvins	1/T kelvins	ln(K)	T °C
220599 BIO-GAR(2)_pt1	Biotite	4.21	7.75	0.54	0.1351	757.82	0.00132	-2.001	477.43
220599 BIO-GAR(2)_pt2	Garnet	0.98	13.35	0.07					

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

$$ln K_D = -2108 \cdot T(K) + 0.781$$

$$T(^{\circ}C) = \frac{52{,}090 + 2.494P(MPa)}{19.506 - 12.943\, ln\, K_D} - 273$$

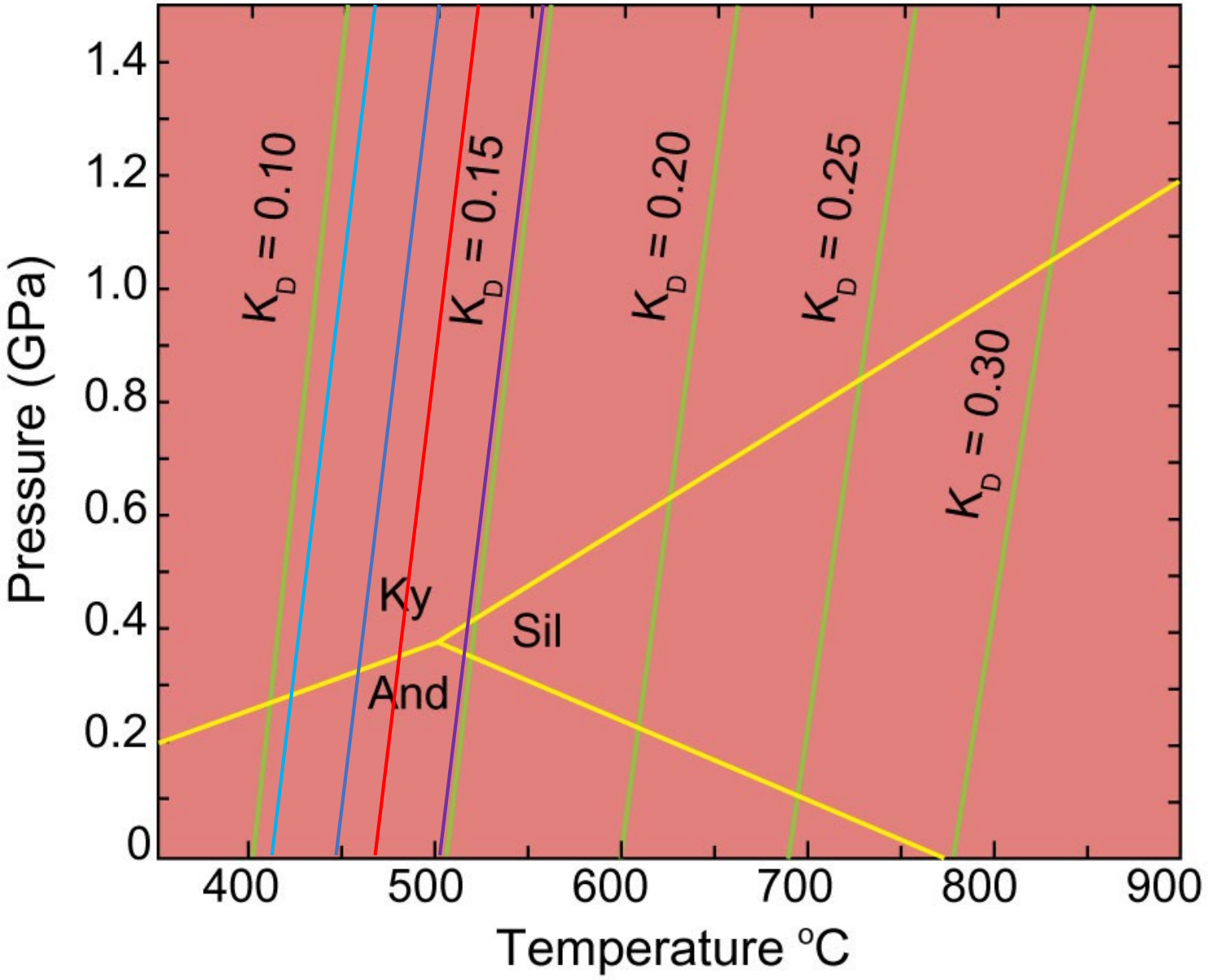
The Garnet - Biotite geothermometer



Key
SEM Point Data
SEM Area Data

Figure based on Winter (2010)

The Garnet - Biotite geothermometer



KEY

SEM Sample

220599 BIO-GAR(1)_pt1

220599 BIO-GAR(1)_pt2

220599 BIO-GAR(1)_pt3

220599 BIO-GAR(1)_pt4

220599 BIO-GAR(1)_pt5

220599 BIO-GAR(1)_pt6

SEM Sample

220599 BIO-GAR(2)_pt1

220599 BIO-GAR(2)_pt2

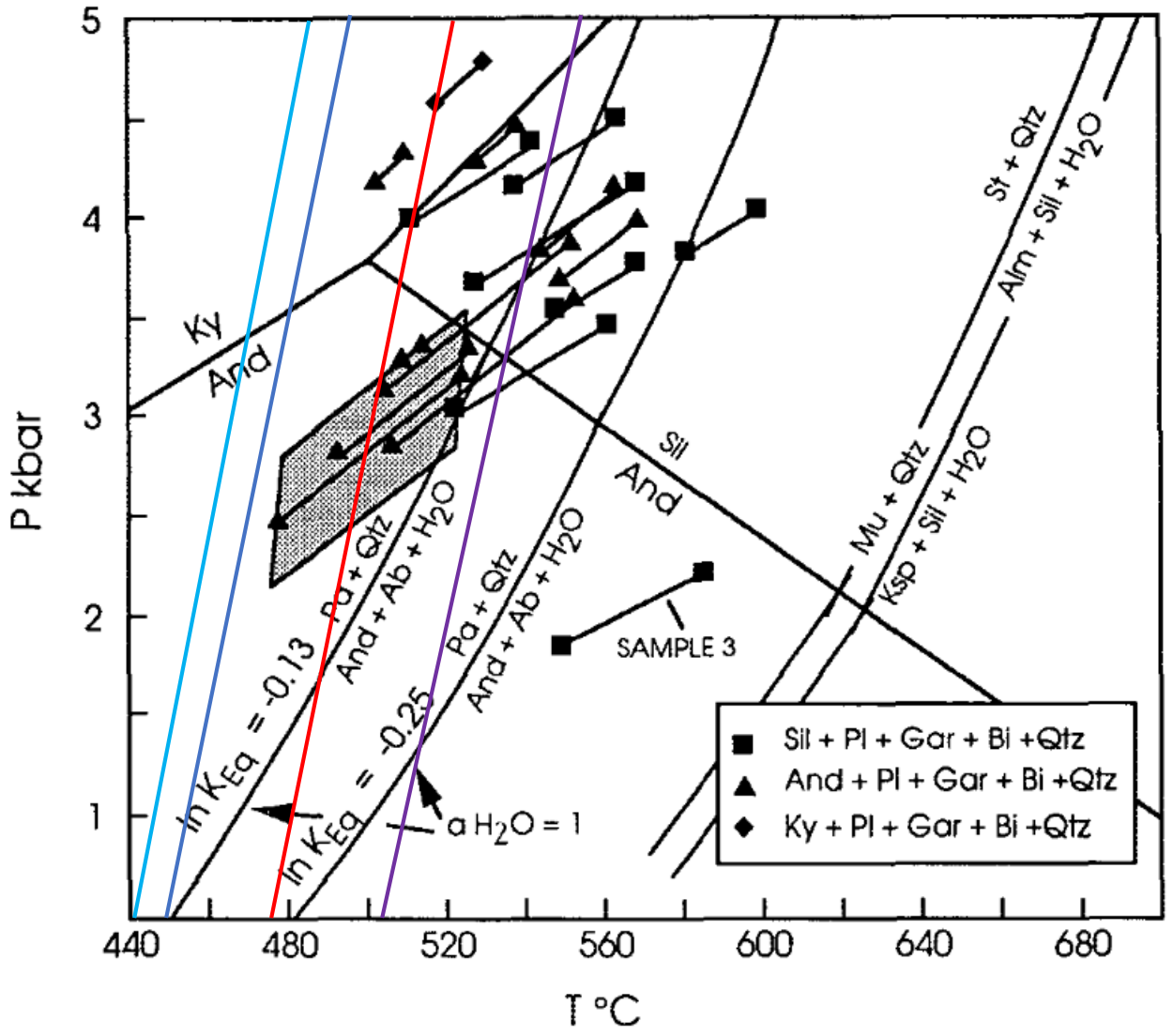
Ferry And Spear (1978)

$$T(^{\circ}C) = \frac{52{,}090 + 2.494P(MPa)}{19.506 - 12.943\, ln\, K_D} - 273$$

Figure based on Winter (2010)

Comparison to Helms and Labotka's Data

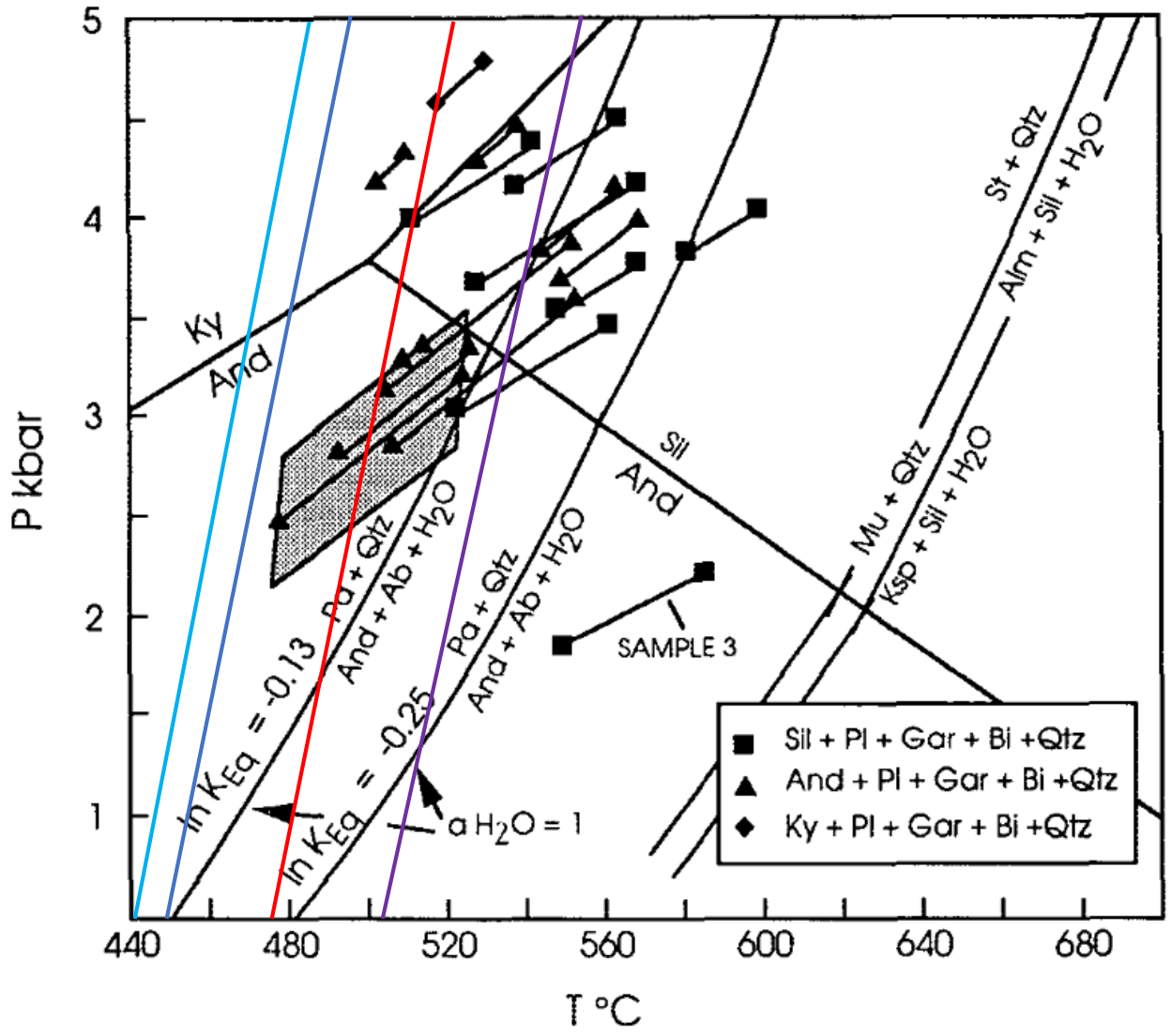
- Geobarometry indicates that metamorphism occurred between 2.0 and 4.4 kbar. Geothermometry indicates that temperature increased from 469-500 °C in the garnet zone to 528-555 °C in the sillimanite zone on the northern flank of the Harney Peak granite.



Helms and Labotka (1991)

Summary/Conclusion

- Geothermometry of my data indicates that metamorphism near Keystone, South Dakota had a temperature of 433 – 504 ^{o}C.
- Based on data by Helms and Labotka, their results yielded a similar outcome to my garnet – biotite geothermometer with temperatures ranging from 469-500 °C in the garnet zone.



Helms and Labotka (1991)

References

Helms T. S. and Labotka T. C. (1991) Petrogenesis of Early Proterozoic pelitic schists of the southern Black Hills, South Dakota: Constraints on regional low-pressure metamorphism: *Geological Society of America Bulletin*. **103**, 1324-1334.

Huff T. A. and Nabelek P. I. (2007) Production of carbonic fluids during metamorphism of graphitic pelites in a collisional orogen—an assessment from fluid inclusions. *Geochimica et Cosmochimica Acta.* **71**, 4997–5015.

NPS (2021) Geologic activity. *National Parks Service*. Available at: https://www.nps.gov/moru/learn/nature/geologicactivity.htm [Accessed April 25, 2022].

Winter J. D. (2010) *Principles of Igneous and Metamorphic Petrology, 2nd Edition*: Pearson Prentice Hall, New Jersey.