GEOTHERMOMETRY OF GARNET SCHIST NEAR KEYSTONE, SOUTH DAKOTA

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Geothermobarometry

- Definition: the temperature (and in some cases pressure) dependence of metamorphic reactions between coexisting minerals to estimate the temperature and pressure conditions of metamorphism (Winter, 2010)
- Geothermometry: the evaluation of the temperature at which a rock formed
- Geobarometry: the evaluation of the pressure at which a rock formed

Geologic Background

- The Black Hills of South Dakota are located along the eastern edge of the Archean Wyoming craton and the south-western margin of the early Proterozoic Trans-Hudson orogen
- The area is of great scientific interest because it contains the only significant surface exposures of Precambrian rocks in the region

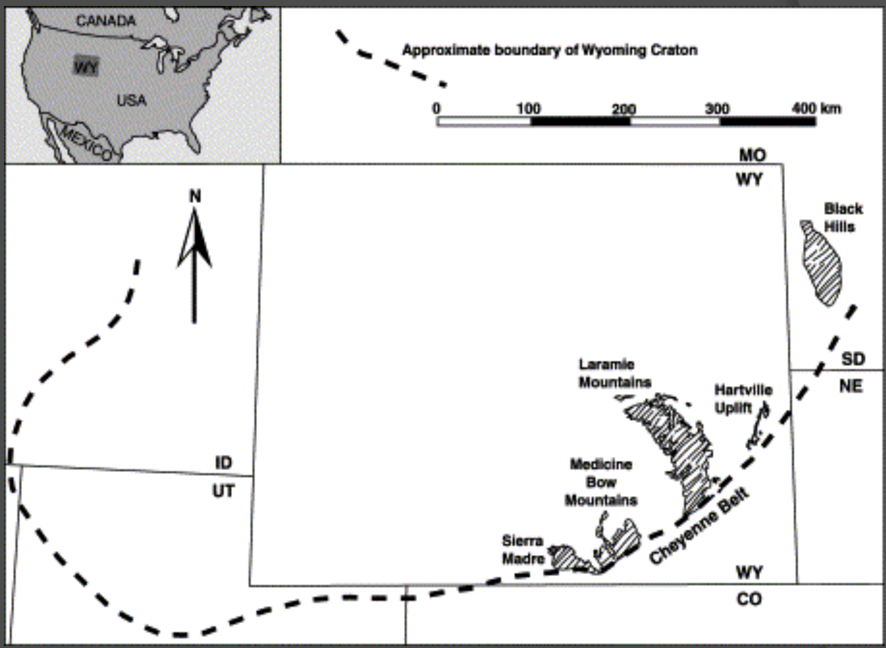

Figure 1. Map of the approximate boundary of the Archean Wyoming craton. The Black Hills are located on the eastern edge of the craton. (Bekker and Eriksson, 2003)

Geologic Background of the Black Hills, South Dakota

- Black hills represent a domal uplift, elongated in the north-northwest direction (Lufkin et al., 2009).
- The Black Hills were uplifted during the Laramide orogeny which occurred 75-35 Ma (Bird, 1998).
- The core of the Black Hills is comprised of igneous and metamorphic Precambrian rocks which are flanked by Paleozoic and Mesozoic sedimentary rocks (Norton and Redden, 1990).

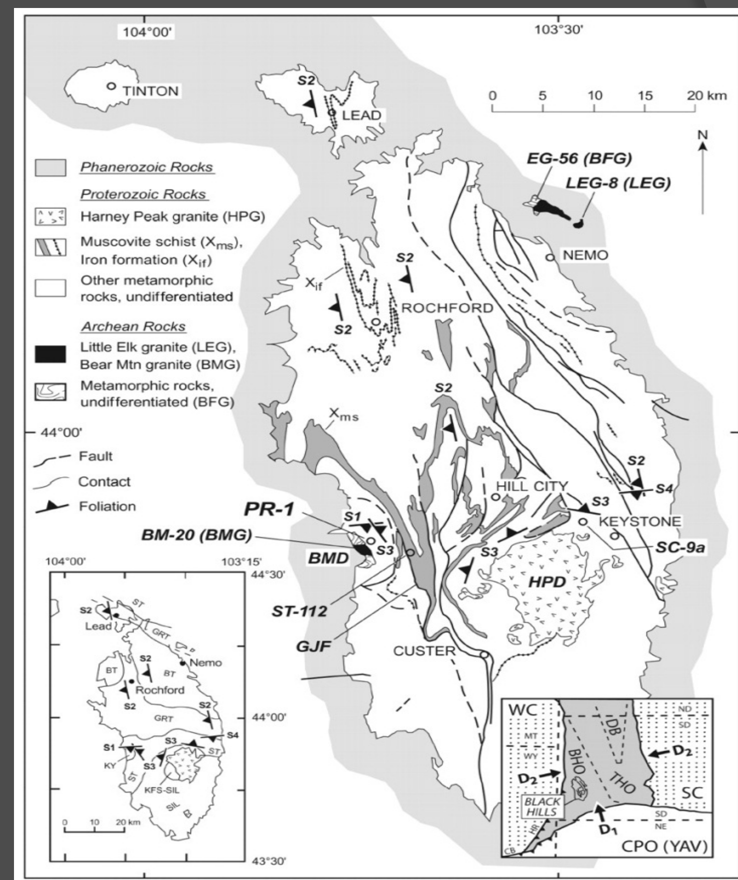

Figure 2. Geologic map of the Black Hills, South Dakota. (ammin.geoscienceworld.org)

Metamorphic Zones of the Black Hills, South Dakota

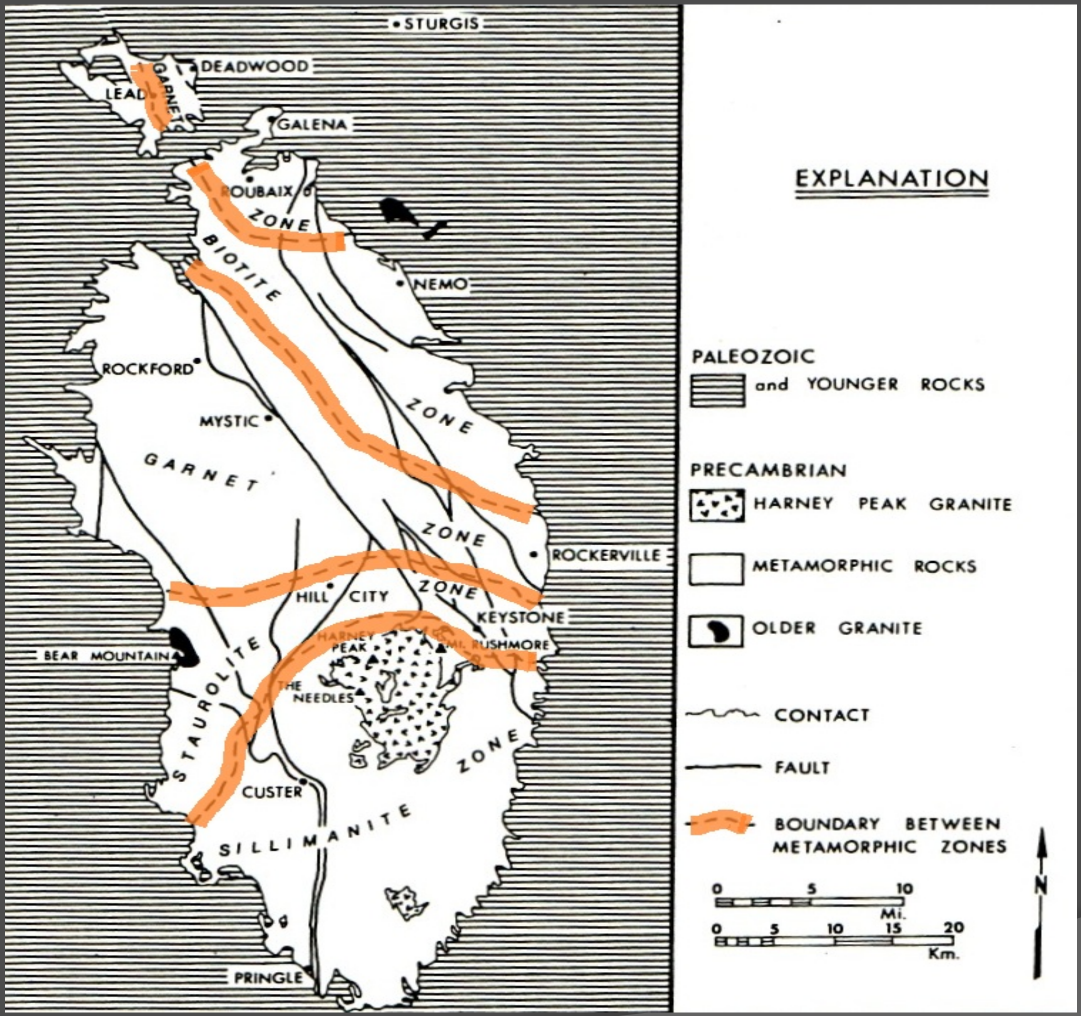

Figure 3. Metamorphic zones of the Black Hills. Boundaries between metamorphic zones are dashed lines highlighted in orange. Notice the increasing metamorphic grade in the southern portion from garnet to staurolite, and staurolite to sillimanite. In the northern portion, zones of metamorphism are alternating from garnet to biotite and back to garnet. (Figure modified from Redden, 1975)

Methods

- Petrographic Microscopy
- Scanning Electron Microscopy (SEM)
- Chemical Analyses
- Mathematical applications of geothermometry

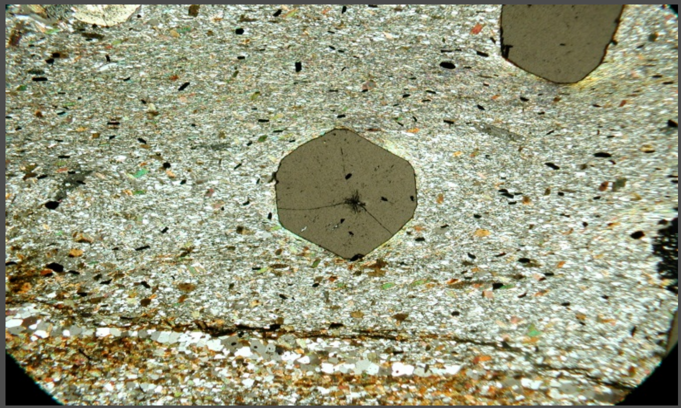

Figure 4. Thin section of garnet schist from Keystone, SD. Image in cross polarized light

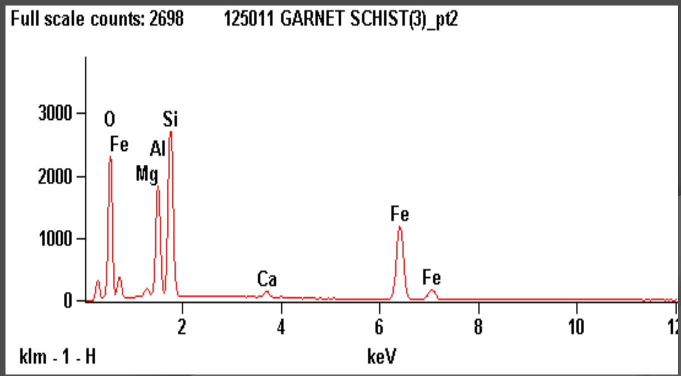

Figure 5. Image of SEM analysis of garnet schist using 20kV accelerating voltage

Petrographic Analyses

<u>Mode Approximation</u>

Muscovite:	~30%
Biotite:	~25%
Quartz:	~20%
Garnet:	~15%
Graphite:	~10%

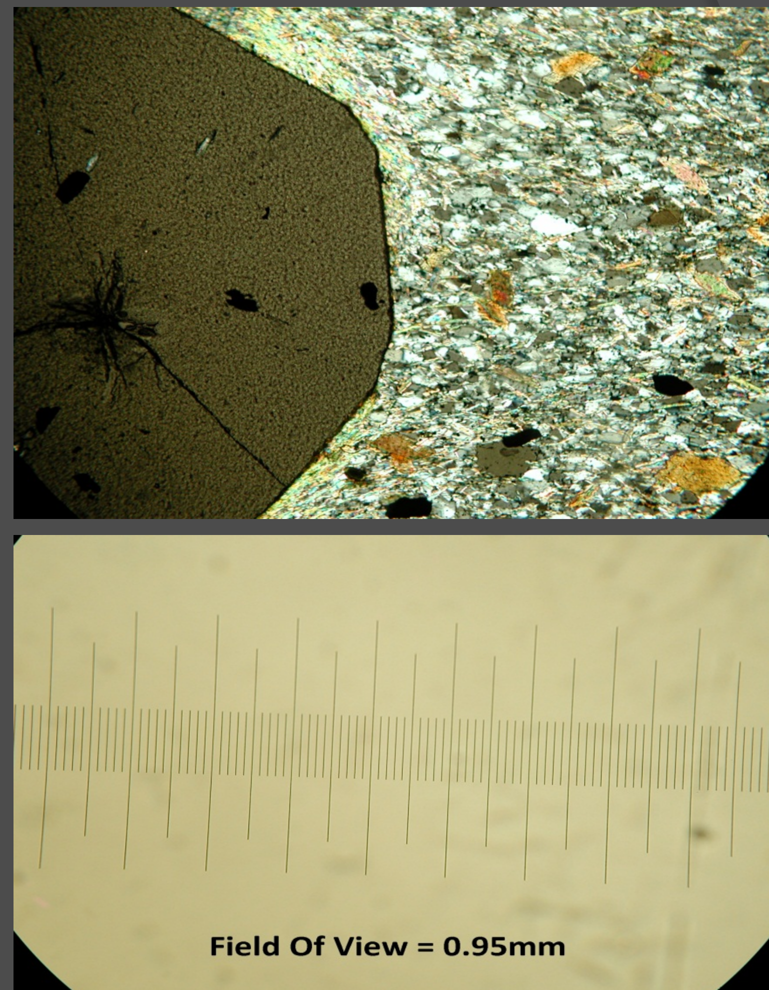

Figure 6. Image of garnet schist in cross polarized light with scale for reference

Scanning Electron Microscopy (SEM) Analyses

- The SEM scans a beam of electrons across a sample which interact with the atoms at or near the surface of the sample and produce numerous signals that are reflected back to different detectors and measured
- The type of signal measured for this experiment was back-scattered electrons (BSE)
- For this experiment it was necessary to choose a point in which the garnet and biotite were in contact with each other. In theory when the minerals are in contact, they crystallized at the same time and are in equilibrium. Although, there is no way to prove that this assumption is true.

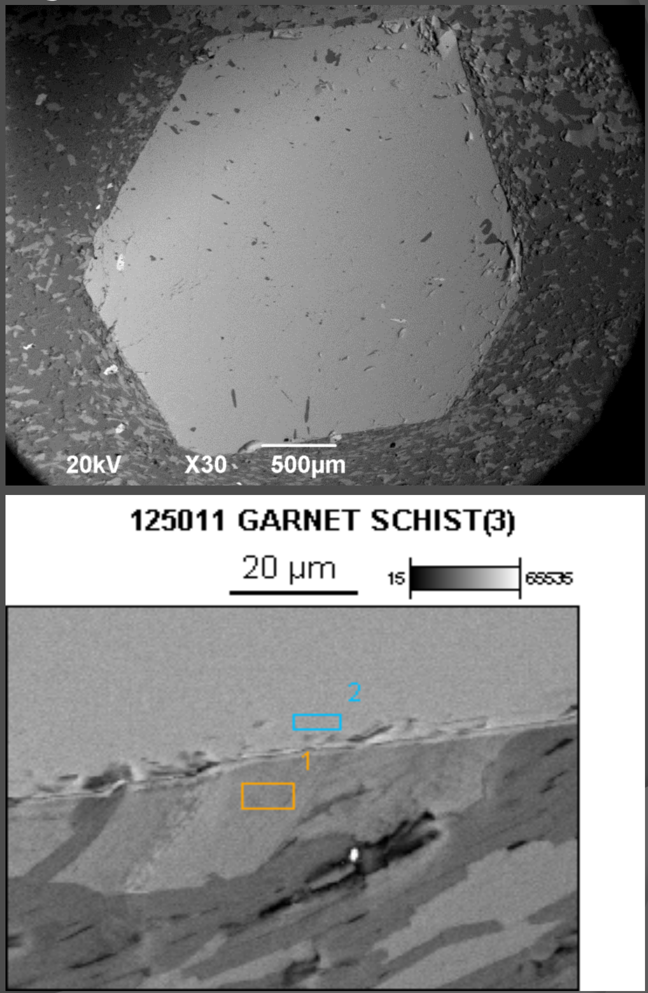

Figure 7. SEM images of garnet schist. Colored boxes represent chosen points for analysis

The Garnet-Biotite Exchange Geothermometer

- There are many useful geothermometers, but the garnet-biotite exchange is the most common
- Measuring the ratios of Magnesium and Iron in the garnet and biotite we can obtain a distribution value (Kd)
- $$Kd = \frac{\left(\frac{Mg}{Fe}\right)Garnet}{\left(\frac{Mg}{Fe}\right)Biotite}$$

$$T\left({}^{o}C\right) = \frac{52{,}090 + 2.494P\left(MPa\right)}{19.506 - 12.943\, ln\, K_D} - 27$$

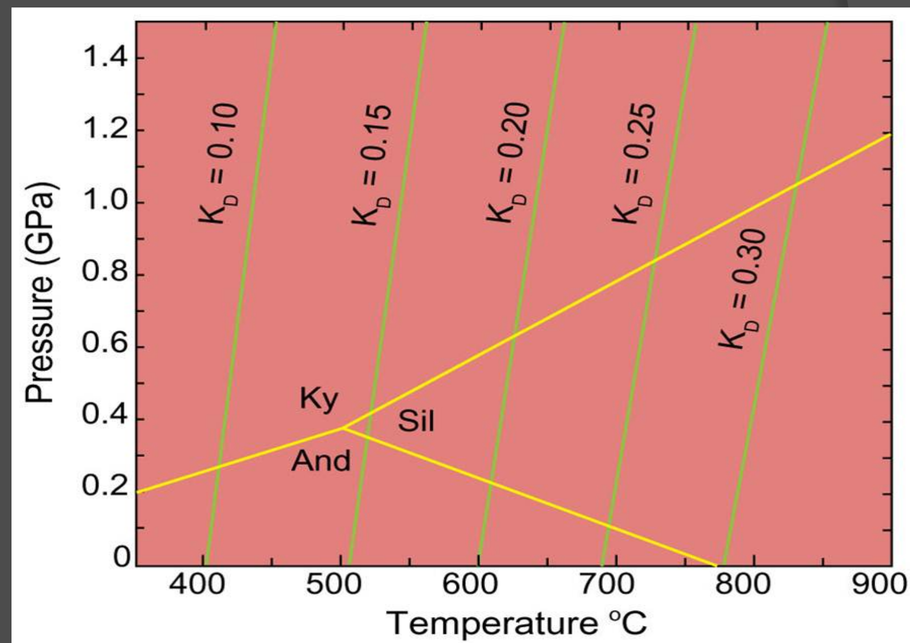

Figure 8. Pressure temperature diagram showing lines of constant Kd. (Winter, 2010)

Results

Garnet 3 - Point 2						
Oxide	**Weight %**	**Molecular Weight**	**Molecular Proportion**	**Cations**	**Oxygens**	**Basis of 12 Oxygens**
MgO	0.55	40.3	0.013647643	0.013648	0.013648	0.112311607
Al_2O_3	10.76	101.96	0.105531581	0.211063	0.316595	1.736918484
SiO_2	17.04	60.08	0.283621838	0.283622	0.567244	2.334031232
CaO	0.86	56.08	0.015335235	0.015335	0.015335	0.126199444
Fe_2O_3	29.03	159.69	0.181789718	0.363579	0.545369	2.992032505
					1.45819	
		12/1.45819=	8.229377726			
Ideal Chemical Formula: $(Fe,Mg)_3Al_2Si_3O_{12}$			Analysis: $(Fe_{2.99}Mg_{0.11}Ca_{0.13})Al_{1.74}Si_{2.33}O_{12}$			
	Pyralspite		$Almandine_{2.99}Pyrope_{0.11}$			

Results

-
- Kd= $\dfrac{\left(\frac{Mg}{Fe}\right)Garnet}{\left(\frac{Mg}{Fe}\right)Biotite}$
- $Kd = (\frac{.1123}{2.992})/(\frac{.82796}{1.8958})$
- $Kd = 0.08594$

$$T\left({}^{o}C\right) = \frac{52{,}090 + 2.494P\left(MPa\right)}{19.506 - 12.943\,ln\,K_D} - 27$$

- Temperature (°C) at 1GPa =

((52090 + 2.494(1000*MPa*))/(19.506 – 24.943 *ln*Kd)) – 273

= 403.2 °C

Temperature (°C) at 2GPa =

= 434.1 °C

Sources of Error in Geothermobarometry

- 1. The assumption of mineral assemblages and compositions in equilibrium
- 2. Minerals can be chemically zoned and will lead to flawed results
- 3. Additional components can affect the ratio of other components in a mineral
- 4. Limitations of microscopy such as not being able to distinguish oxidation states (For example, Fe^{3+}/Fe^{2+})

Conclusion

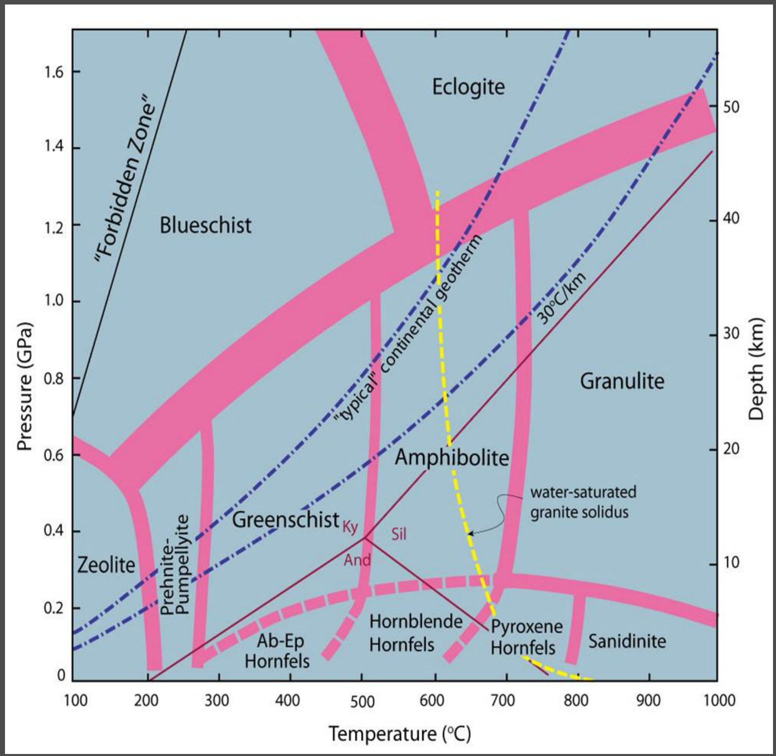

Figure 9. Temperature-Pressure diagram showing various limits of facies (Winter, 2010)

- Based upon T-P diagram, Pressures range from 0.6-2GPa
- At 0.6GPa, the calculated temperature of formation would be 390.87 °C
- This calculated range of temperatures between 391-434 °C fits well into the generally accepted values of Temperature

References Cited

- Bird, P., 1998, Kinematic History of the Laramide orogeny in latitudes 35-49 N, western United States: Tectonics, v. 17, p. 780-801.
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- Norton, J.J., and Redden, J.A., 1990, Relations of zoned pegmatites to other pegmatites, granite, and metamorphic rocks in the southern Black Hills, South Dakota: American Mineralogist, v. 75, p. 631-655.
- Winter, J.D., 2010, Principles of Igneous and Metamorphic Petrology, 2nd Edition: New Jersey, Pearson Prentice Hall, p. 458, 589-590, 598-599.