Instructor notes to accompany the Geothermobarometry exercise

Donna L. Whitney
University of Minnesota
Minneapolis, Minnesota 55455

Introduction

To do this exercise, students need to understand the concept of equilibrium and be able to identify major rock-forming minerals with a petrographic microscope. Knowledge of basic thermodynamics is helpful, but optional.

I use this exercise as a capstone that synthesizes many of the important concepts and skills that the students have learned after 6 (out of 7) weeks of lectures/labs/discussions of metamorphic petrology. At this point in the class, their experience with estimating P-T conditions consists of qualitative determinations: low/medium/high grade, metamorphic facies (metabasalts), and Barrovian zones (metapelites).

I think it is important to discuss *why* petrologists and others need to know metamorphic conditions better than can be determined with qualitative methods (low-medium-high, facies, zones etc.). This can be done by looking at a P-T diagram with facies delineated, or petrogenetic grids for end member equilibria (Fe vs. Mg) and discussing their limitations. Possible points to mention include:

- Some of these designations are not very sensitive to pressure, and pressure is an important variable to determine because it relates to depth (and therefore tectonic environment/processes).

- Temperature can perhaps be determined better than pressure by qualitative methods, but in some cases not well enough to assess gradients in temperature or to evaluate whether conditions were sufficient for melting (or some other petrologic process of interest).

Other notes regarding this exercise:

- The focus is on metamorphic rocks, but the exercise can be modified for igneous rocks.
- This is a time-intensive exercise and requires more than one lab session, complemented by class discussions.
- The "best" samples for this exercise are metasedimentary rocks (metashales/metapelites) containing garnets with interesting inclusions, but garnet amphibolites can also be used.
- The exercise can be done with a small number of samples (1-2) or can be extended to include samples recording a range of P-T conditions (e.g., a Barrovian sequence).
- The exercise is written as if all students are working on the same samples, but a more exciting approach is if different students or small groups of students work on different samples (perhaps from the same metamorphic terrain).
- Supplementary materials can also be included; e.g., garnet zoning maps and profiles, if this topic has been discussed; or field maps/photos.

- There are many different ways to do the actual calculations: using software that can be downloaded or run on the web (TWQ, Spear et al. program, PERPLEX, Thermocalc) or using simplified equations. This exercise contains various modules for the actual P-T calculations.

Comments on PART 1

To make the exercise more interesting at the beginning – before the students spend much time looking at the thin section(s) – slides/photos of the sample locality/terrain can be shown so that the students get a feel for where the sample is from and possibly become more interested in it, knowing that it is from a 'real' place and not just a random rock in a box in the lab. Maps can also be provided (preferably ones without metamorphic grade information) so that students can have the type of information that a metamorphic researcher would typically have available: e.g., proximity and relationship to plutons and structures, types of structures, the range of rock types in the terrain etc.

Some possible approaches to the step of determining which thermometers/barometers can be applied are:

- Students can figure this out entirely from class material/reading/discussion.
- Students can examine a P-T diagram (schematic or 'real') and figure out which equilibria have steep slopes and which have nearly horizontal slopes. This is the option described in the exercise.
- Students can run a program (e.g. TWQ) and answer the question from the equilibria/slopes produced.

Additional information can be included here or in Part 3 regarding garnet and/or plagioclase zoning. For example, X-ray maps and linescans of garnet can be provided. In the Shuswap Complex example included in the exercise, minerals are mostly homogeneous (a thin retrograde rim zone around garnet has been omitted from the compositional information in the Table). Text/questions that can be included at this step are:

- Are any of the solid solution phases likely to be zoned? (that is, have different compositions in one part of the crystal compared to another). For some minerals (plagioclase, tourmaline, some amphiboles), you can see zoning in thin section views by a change in color (plane light) or extinction/interference colors (under crossed polars). For other minerals (garnet), zoning is not typically seen in thin section and you need additional data to determine if zoning is present.
    - IF any of the solid solution minerals of interest are zoned – for example, if the core of a mineral has a different composition than the rim of the same mineral grain – which composition should be used in the calculation? (the core or rim?)

Comments on PART 2

The exercise describes how to use Kohn & Spear's program for calculating temperatures and pressures, a method for using the TWQ software, and also simple P-T equations using equations. The degree to which the thermodynamics concepts and values underlying this part of the exercise is explained can vary from none to comprehensive.

For running TWQ, I have found that the steps of calculating mole fractions, editing a rock.cmp file, and getting the program to read the file and accept the solution models (even the defaults) is beset by numerous bugs that do not arise from simply calculating an end member phase diagram. I like using this software, but be prepared for some problems.

The sample mineral composition table provided includes weight % oxides only, but this can be supplemented with cation and/or mole fraction data if desired. If students already know how to calculate cations and have a spreadsheet or web-based method handy, the calculation of cations and mole fractions is easy (though may require some discussion for complex minerals like biotite). If this is a new exercise, it may not be worth it to spend the time in this already time-intensive exercise, and the cation or mole fraction data could be provided directly.

The results of the T and P calculations should produce medium-P (6-7 kbar) at T ~ 730-750 C for Sample X, and higher P and T for Sample Y (10 kbar, > 800 C). This high-T result may be real, as the metapelite sample Y is interlayered with sapphirine-corundum-spinel bearing rocks.

Comments on PART 3

For the samples that I use in this exercise, it is difficult to infer much of a path for the lower grade sample (X) other than knowing that it started and ended at the Earth's surface and passed through the calculated peak P-T conditions.

The higher temperature sample (Y) is more complex. Some samples have kyanite partially to completely replaced by sillimanite, and cordierite rims on garnet and kyanite. Some garnets have corona/sympectite structures. These textures and assemblages may indicate high-T decompression. Despite the complexities, students like this sample because it is interesting.