<u>Magma Modification in the central Sierra Nevada batholith</u>
<u>Petrology Lab</u>

The thin section samples are:

The petrography of the thin sections are recorded below:

Sample	BPC97-4	BPC97-5	EB97-1	EB97-2	RC97-1	NM97-1	LP97-1	GGG97-3	CC97-1	FP97-2
name	granite	grano-diorite	granite	quartz diorite	granite	grano-diorite	quartz monzonite	granite	grano-diorite	monzo-diorite
Modal Mineralogy										
Q	20%	12%	30%	2%	30%	35%	15%	30%	15%	2%
Pl	20%	30%	25%	20%	15%	20%	30%	15%	20%	35%
Ksp	20%	13%	15%		30%	15%	30%	25%	15%	15%
hb	4%	25%	10%	35%		10%	5%	10%	15%	20%
bt	15%	8%	10%	25%	5%	10%	10%	10%	15%	15%
musc			1%		5%					
opaques	4%	2%	3%	4%	3%	3%	5%	5%	5%	3%
sphene	5%	3%	3%	5%	2%	5%	3%	2%	5%	2%
zircon	2%	1%		1%	1%				1%	
apatite	2%	1%	1%	1%					2%	
garnet					1%					
Secondary minerals										
sericite	**4%**	**3%**	2%	3%	**4%**	2%	2%	3%	3%	5%
chlorite	2%	2%		4%	4%				4%	3%
epidote	2%									

Observed textures

Sample	BPC97-4	BPC97-5	EB97-1	EB97-2	RC97-1	NM97-1	LP97-1	GGG97-3	CC97-1	FP97-2
	myrmekite	qtz with hb rims	myrmekite	plagioclase rimmed by bt and hb	deformation twins	myrmekite	inter-growth	myrmekite	rapakivi	zoned plag
	ophitic	plag with hb rims	zoning	sphene assoc. with bt and hb	perthite	deforma-tion twins	perthite	zoned plagioclase	myrme-kite	plag with hb or bt rims
	zoning	myrmekite	perthite			perthite	myrmekite	ophitic	complex-ly zoned plag	qtz with hb or bt rims
	perthite	complex zoning in plag	sphene associated with bt			inclusions in bt	complex zoning in plag	inclusions	inclusions	rapakivi
	quartz with hb rims	opaques rimming sphene						perthite	ophitic	
	sphene rimmed with biotite								perthite	

YOUR ASSIGNMENT:

1. Make some observations about the spatial relationships of rock types.

   Students usually are capable of making the observation that diorites are almost always associated with high-silica granites. Sometimes they need some prodding with a few leading questions. They may also note that more mafic plutons outcrop on the west side than on the east side. They may also make the observation that there are more metasedimentary rocks exposed on the west side than on the east side (or at the very least that there are larger metasedimentary "pendants" on the west side). This observation may lead to some confusion when the write up comes along because there is less evidence for sediment on the west side than on the east side. However, the students usually can come to terms with these small discrepancies and I often tell them, "Back up your conclusions with data and you'll do fine."

   Record the petrography of each of these samples in your lab notebook. Be sure to include estimates of modal mineralogy, sketches and textural observations. These samples are loaded with textures such as rapakivi, complex zoning (in plagioclase), hornblende rims on quartz, and other rimmed minerals such as plagioclase, sphene, and oxides, etc. For information on how these textures form, see *Petrography to Petrogenesis* by M.J. Hibbard (1995). Also keep your eye out for other familiar textures such as perthite, myrmekite, ophitic textures, etc.

   By the time we reach this lab, students have seen all of these textures at least once. They have completed labs that have leading questions about these textures and are relatively adept at finding them in thin section and hand sample. The biggest difficulty I have at Oshkosh is getting them to remember that they have seen them before and to be willing to revisit previous lab exercises in their lab notebooks – for some reason, they are reluctant to look back in the semester (perhaps they feel they have finished that part of the course and need to move on). Nonetheless, before beginning this lab, the students need to have had a bit of petrographic experience.

   I have found Hibbard's *Petrography to Petrogenesis* (1995) to be extremely useful in this exercise as he does an excellent job of explaining how each of the textures mentioned above might be formed during mixing.

   This lab could also be used to introduce the concept of magma mixing since these thin sections and hand samples have such great examples. If this is desired, each of the thin sections should have some leading questions (it isn't necessarily intuitive for the students to come up with mixing).

> **For example, you might ask students to observe the relationship of quartz to hornblende in BPC97-5 (*hornblende rims quartz*). Could this relationship have formed under equilibrium conditions? Why or why not? What other (disequilibrium) processes might have generated this texture? Examine the plagioclase in this sample and describe the zoning. Is this type of zoning consistent with equilibrium or disequilibrium conditions? Explain.**

Each of the thin sections could have leading questions such as this – and could be related to one another by some other leading questions.

2. Calculate a CIPW norm for samples NM97-1, CC97-1, BPC97-5 and LP97-1, using the spreadsheet program provided. Compare the normative mineralogy to the modal mineralogy. In your lab notebook, explain any discrepancies in a short paragraph.

	BPC97-5	*CC97-1*	*LP97-1*	*NM97-3*
Q	3.13	13.62	15.94	29.93
or	9.34	17.02	24.58	35.93
ab	25.72	27.59	33.34	25.72
an	23.95	22.15	13.48	4.42
di	15.53	3.25	0.00	0.00
hy	16.27	11.35	7.78	2.07
wo	0.00	0.00	0.00	0.00
ol	0.00	0.00	0.00	0.00
mt	1.68	1.16	0.87	0.26
hm	0.00	0.00	0.00	0.00
il	2.38	1.63	1.20	0.33
pr	0.00	0.00	0.00	0.00
cm	0.00	0.00	0.00	0.00
tn	0.00	0.00	0.00	0.00
pf	0.00	0.00	0.00	0.00
Z	0.00	0.00	0.00	0.00
ap	0.85	0.44	0.44	0.13
ru	0.00	0.00	0.00	0.00
C	0.00	0.00	0.30	0.48
ne	0.00	0.00	0.00	0.00
lc	0.00	0.00	0.00	0.00
kp	0.00	0.00	0.00	0.00
ac	0.00	0.00	0.00	0.00
ns	0.00	0.00	0.00	0.00
cs	0.00	0.00	0.00	0.00
fr	0.00	0.00	0.00	0.00
cc	0.00	0.00	0.00	0.00
TOTAL	98.86	98.22	97.93	99.27

	BPC97-5	*CC97-1*	*LP97-1*	*NM97-3*
QAPF				
Q	0.05	0.17	0.18	0.31
A	0.15	0.21	0.28	0.37
P	0.80	0.62	0.54	0.31
F				
Gabbro				
Pl	0.61	0.77	0.86	0.94
Px	0.39	0.23	0.14	0.06
Ol	0.00	0.00	0.00	0.00
Ultramafic				
Ol	0.00	0.00	0.00	0.00
Opx	0.51	0.78	1.00	1.00
Cpx	0.49	0.22	0.00	0.00

The main point of this particular exercise is to reiterate (they've thought about it in previous labs and in class) that there is a big difference between MODAL and NORMATIVE mineralogy. That the fact that there is water in these magmas changes the mineralogy and that the NORM does not take into account the presence of water!

3. Refer to your modal mineralogies and use the IUGS classification diamond (Streckheisen, 1974; figure 2-2 in your textbook) to name each rock. The names should be recorded in your lab notebook.

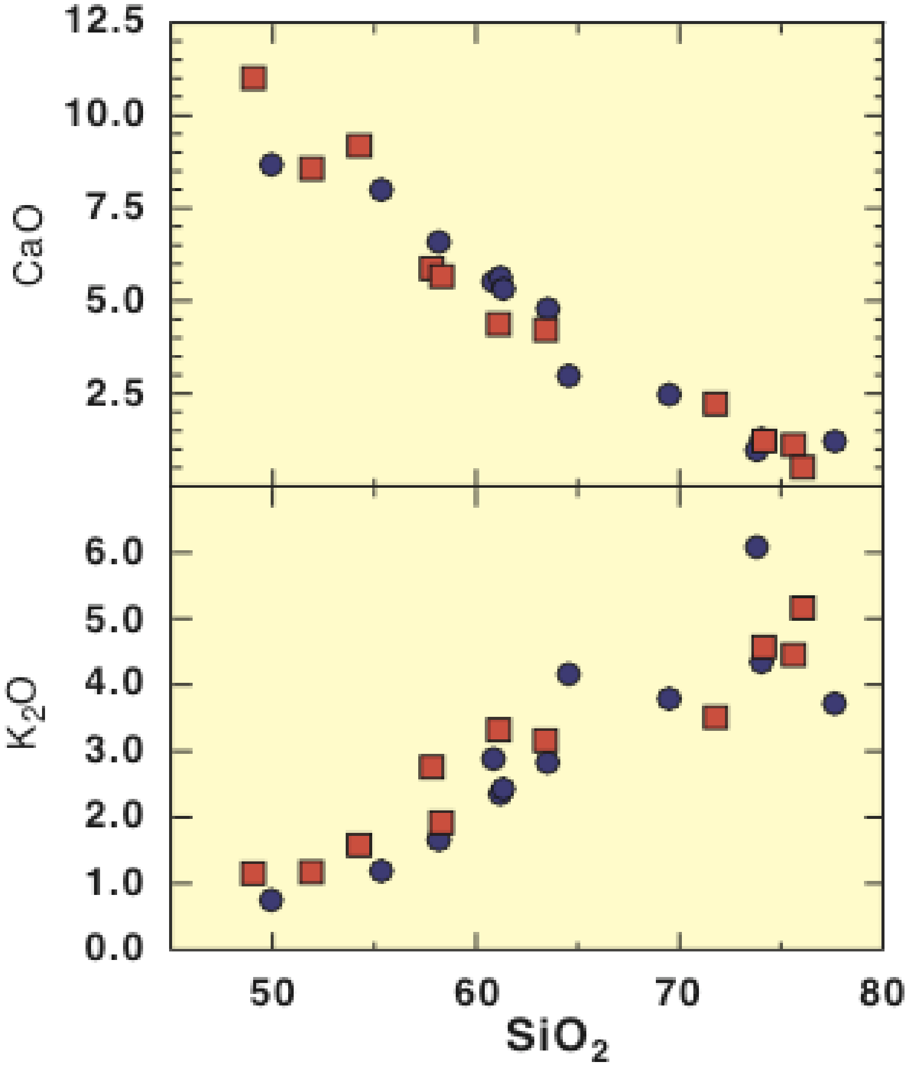
   See above table with modal mineralogies and names. Students will get different names depending on how they estimate modal mineralogies. This is a great teaching moment for talking about how we estimate…some students are really good at it whereas others don't really get it. I often use this example to talk about using a range of percentages and using things like hand samples to estimate modal mineralogy since hand sampels tend to be better representations of the "whole sample".

   I also often talk about naming the rock using norm at this time. To emphasize that they should all get the same name if they use the normative mineralogies. That drives home the need for normative mineralogies, too.

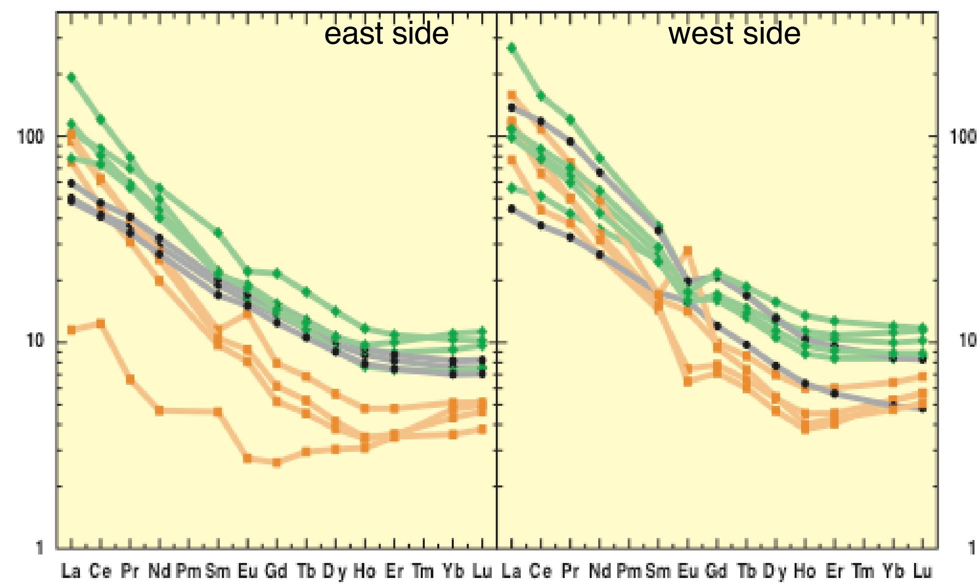
4. Several spreadsheets showing the chemical analyses for these rocks, including Sr and Nd isotope analyses [two tables with analyses from east and west side samples, and one table with REE values normalized to chondrite (Sun and McDonough, 1989)] are attached to this sheet. A table with values for a number of normalizing standards for both trace- and rare-earth elements as determined by Sun and McDonough (1989) is also attached. These tables will also be e-mailed to you (so that you don't have to spend a lot of time putting data into spreadsheet form). Use these data to generate some Harker diagrams, REE diagrams, spider diagrams and isotope diagrams to better understand the source(s) and processes that generated this batholith. Remember your hypothesis as you started this project - that OLD continental crust plays a role in the eastern part of the batholith but is absent in the west. Your chemical interpretation should be consistent with what you see in thin section (so connect the two things). Also make sure that you note similarities and differences between the east- and west-side suites.

   Most of the major elements for the central batholith give straight line trends for both the east and west sides (see below). Al_2O_3 is a little confusing (seems to have some fractionation at both high and low silica end) but a little ambiguity tends to make the students think. With a little conversation and some nudging (mostly trying to get them to have some confidence in themselves) they can come up with a number of possibilities and combined with other evidence they can bring a story together.

Most major elements mimic those of K2O and CaO seen in the plot below.

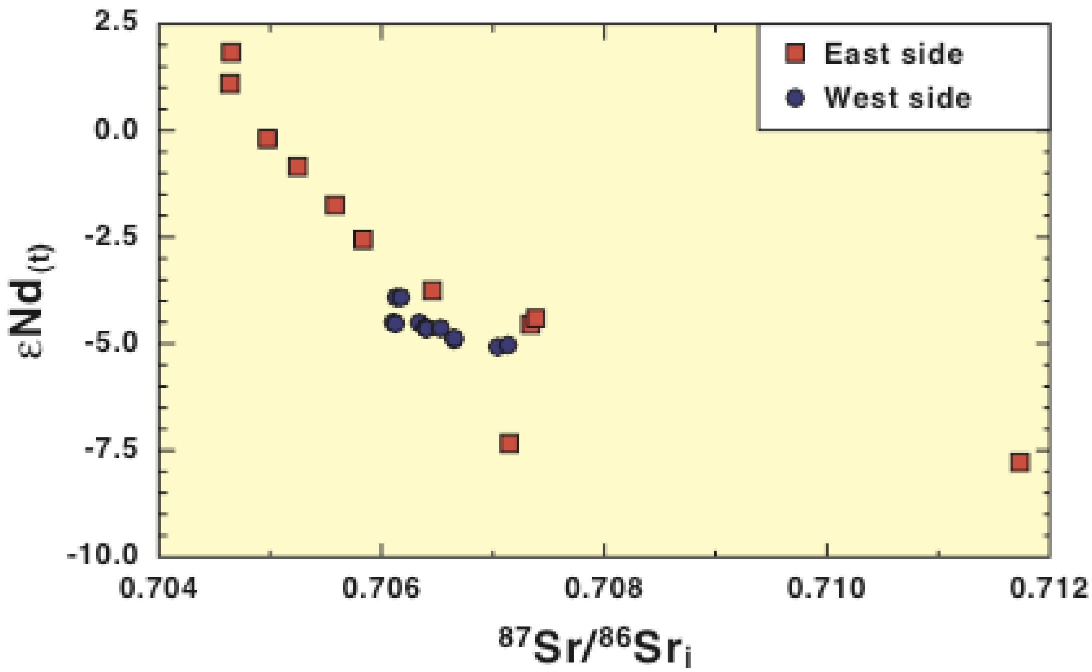


Trace element patterns are somewhat less straightforward – normalizing them to one another (as in Ba/Nb) makes them more interesting but most students are not ready to take that next step. I often do not ask the students to look at Harkers of the trace elements instead I have them plot REE diagrams (or spider diagrams). REE diagrams seem to suggest that each side has different processes acting.



The REE diagrams above suggest that rocks on the east side have undergone less fractionation than the west side rocks have. Also, the east side seems to have a number of different sources (perhaps continental crustal contamination?) whereas the west side plutons seem to be genetically related.

The isotopes also provide a coherent story about the differences between the two parts of the Sierra. The east side suite, plotted as initial Sr vs. □Nd(t), shows a distinct mixing curve. The west side suite on the other hand, plots as a nice cluster of data points. This suggests that continental crust is involved in the generation of plutons on the east side but less so on the west.



5. Type up a 3-5 page (maximum, double-spaced) report formulating a hypothesis regarding the source of the magmas and the origin of the variation in the suite of samples (what processes modified these magmas?). Include petrographic, chemical and isotopic data supporting your conclusions- you may wish attach diagrams as illustrations for chemical or isotopic trends.

   Students use the data above to come to conclusions about these rocks. I have accepted a number of different interpretations of the data.

   - **Some students interpret mixing as a major process for both sides – this is consistent with the data provided that they stipulate that the mixing members on the west side must be young crust as opposed to the east where there is OLD continental crust involved.**
   - **Some students interpret the east side as having mixed old crust with new dioritic magmas from the mantle and the west side generated by fractionation. This is also consistent with the data although it is**

difficult to explain the strictly straight line trends by fractionation alone.

- **Some students have tried to explain both sides by fractionation but it is much harder to justify with the isotopes! These students rarely get an exceptional grade.**

I require that students attach any plots or sketches that support their conclusions (these are not included in the 3-5 page limit). I grade them on their scientific merit and support of their arguments with evidence but also on writing skills such as organization and separation of observations (results) from interpretations. Some of the students have never written a paper that uses their own observations about rocks and so there is a wide range of grades on this paper.