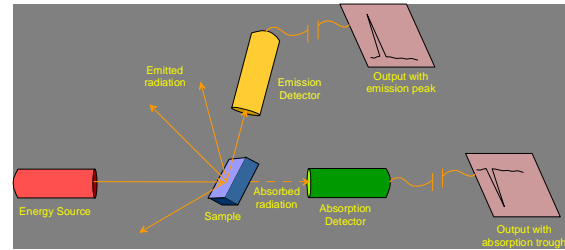


# Modern Spectroscopic Techniques

## Major Element Variation

Reading: Winter Chapter 8

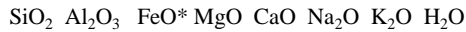


The geometry of typical spectroscopic instruments. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

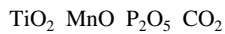
Element	Wt % Oxide	Atom %
O		60.8
Si	59.3	21.2
Al	15.3	6.4
Fe	7.5	2.2
Ca	6.9	2.6
Mg	4.5	2.4
Na	2.8	1.9

Abundance of the elements in the Earth's crust

Major elements: usually greater than 1%



Minor elements: usually 0.1 - 1%



Trace elements: usually < 0.1%  
everything else

## A typical rock analysis

Oxide	Wt. % Oxides to Atom % Conversion			
	Wt. %	Mol Wt.	Atom prop	Atom %
SiO <sub>2</sub>	49.20	60.09	0.82	12.25
TiO <sub>2</sub>	1.84	95.90	0.02	0.29
Al <sub>2</sub> O <sub>3</sub>	15.74	101.96	0.31	4.62
Fe <sub>2</sub> O <sub>3</sub>	3.79	159.70	0.05	0.71
FeO	7.13	71.85	0.10	1.48
MnO	0.20	70.94	0.00	0.04
MgO	6.73	40.31	0.17	2.50
CaO	9.47	56.08	0.17	2.53
Na <sub>2</sub> O	2.91	61.98	0.09	1.40
K <sub>2</sub> O	1.10	94.20	0.02	0.35
H <sub>2</sub> O*	0.95	18.02	0.11	1.58
(O)			4.83	72.26
Total	99.06		6.69	100.00

Must multiply by # of cations in oxide ↑

Table 8-3. Chemical analyses of some representative igneous rocks

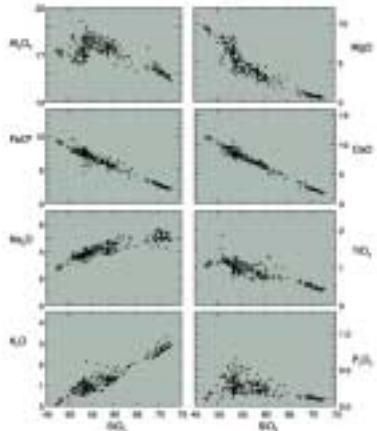
	Peridotite	Basalt	Andesite	Rhyolite	Phonolite
SiO <sub>2</sub>	42.26	49.20	57.94	72.82	56.19
TiO <sub>2</sub>	0.63	1.84	0.87	0.28	0.62
Al <sub>2</sub> O <sub>3</sub>	4.23	15.74	17.02	13.27	19.04
Fe <sub>2</sub> O <sub>3</sub>	3.61	3.79	3.27	1.48	2.79
FeO	6.58	7.13	4.04	1.11	2.03
MnO	0.41	0.20	0.14	0.06	0.17
MgO	31.24	6.73	3.33	0.39	1.07
CaO	5.05	9.47	6.79	1.14	2.72
Na <sub>2</sub> O	0.49	2.91	3.48	3.55	7.79
K <sub>2</sub> O	0.34	1.10	1.62	4.30	5.24
H <sub>2</sub> O+	3.91	0.95	0.83	1.10	1.57
Total	98.75	99.06	99.3	99.50	99.23

## CIPW Norm

- Mode is the volume % of minerals seen
- Norm is a calculated "idealized" mineralogy

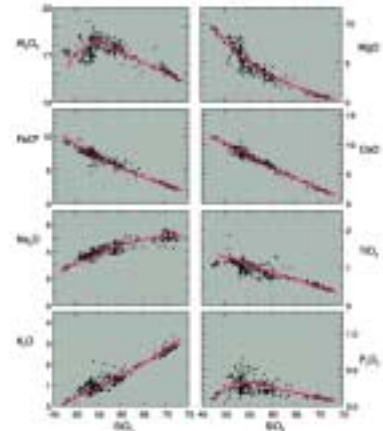
## Bivariate (x-y) diagrams

Harker variation diagram for 310 analyzed volcanic rocks from Crater Lake (Mt. Mazama), Oregon Cascades. Winter, 2002



## Bivariate (x-y) Diagrams

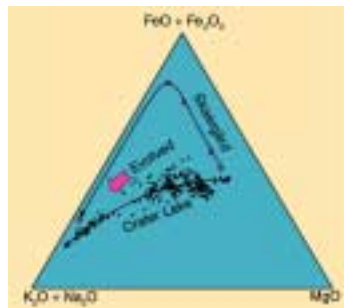
Harker variation diagram for 310 analyzed volcanic rocks from Crater Lake



## Ternary Variation Diagrams

AFM diagram (alkalis-FeO\*-MgO)

Crater Lake, OR



## Models of Magmatic Evolution

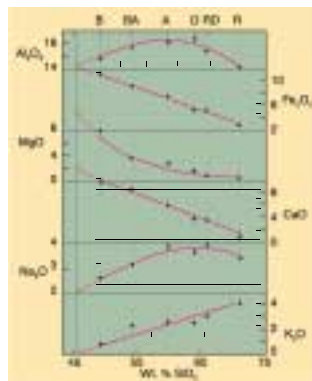
Table 8-5. Chemical analyses (wt. %) of a hypothetical set of related volcanics.

Oxide	B	BA	A	D	RD	R
SiO <sub>2</sub>	50.2	54.3	60.1	64.9	66.2	71.5
TiO <sub>2</sub>	1.1	0.8	0.7	0.6	0.5	0.3
Al <sub>2</sub> O <sub>3</sub>	14.9	15.7	16.1	16.4	15.3	14.1
Fe <sub>2</sub> O <sub>3</sub> *	10.4	9.2	6.9	5.1	5.1	2.8
MgO	7.4	3.7	2.8	1.7	0.9	0.5
CaO	10.0	8.2	5.9	3.6	3.5	1.1
Na <sub>2</sub> O	2.6	3.2	3.8	3.6	3.9	3.4
K <sub>2</sub> O	1.0	2.1	2.5	2.5	3.1	4.1
LOI	1.9	2.0	1.8	1.6	1.2	1.4
Total	99.5	99.2	100.6	100.0	99.7	99.2

B = basalt, BA = basaltic andesite, A = andesite, D = dacite, RD = rhyo-dacite, R = rhyolite. Data from Ragland (1989)

## Harker Diagram

- Smooth trends
- Model with 3 assumptions:
  - Rocks are related by FX
  - Trends = liquid line of descent
  - The basalt is the parent magma from which the others are derived



## Stacked Variation Diagrams

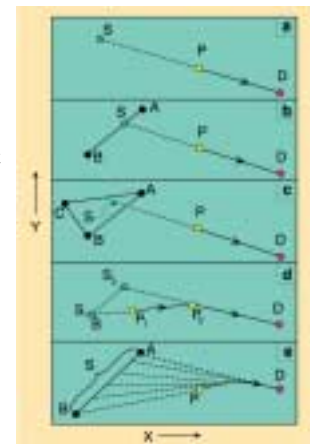
Hypothetical components

X and Y (either weight or mol %)

P = parent, D = daughter,

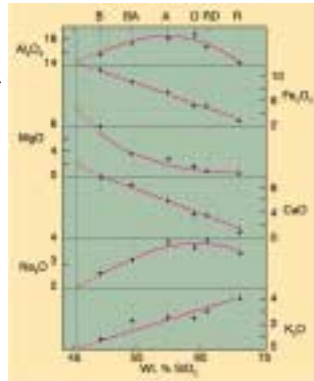
S = solid extract

A, B, C = possible extracted solid phases.



- Extrapolate BA → B and further to low SiO<sub>2</sub>
- K<sub>2</sub>O is first element to → (at SiO<sub>2</sub> = 46.5 red line)

Thus the blue line → the concentration of all other oxides

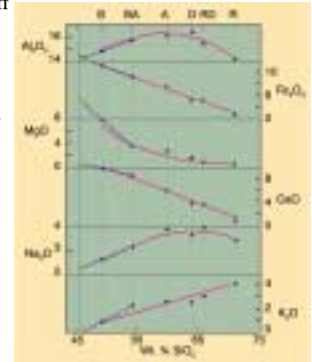


Extrapolate the other curves back  
BA → B → blue line and read off  
X of mineral extract

Results:

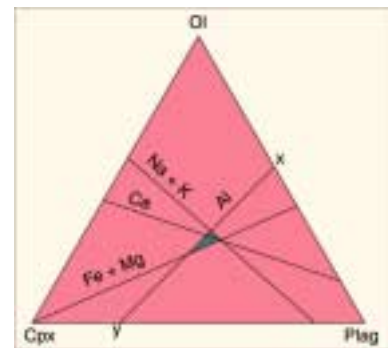
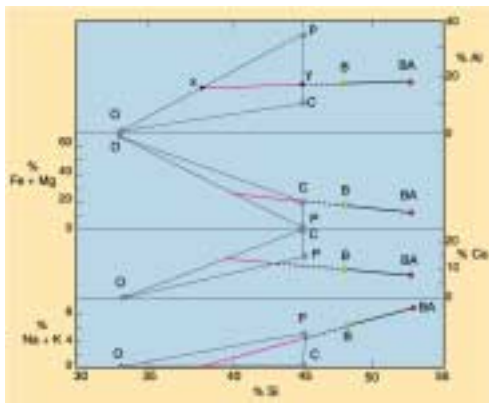
Remove plagioclase, olivine,  
pyroxene and Fe-Ti oxide

Oxide	Wt%	Cation Norm	
SiO <sub>2</sub>	46.5	ab	18.3
TiO <sub>2</sub>	1.4	an	30.1
Al <sub>2</sub> O <sub>3</sub>	14.2	di	23.2
Fe <sub>2</sub> O <sub>3</sub> <sup>+</sup>	11.5	hy	4.7
MgO	10.8	ol	19.3
CaO	11.5	mt	1.7
Na <sub>2</sub> O	2.1	il	2.7
K <sub>2</sub> O	0		
Total	98.1		100



Then repeat for each increment BA → A etc.

Variation diagram on a cation basis for the fractional crystallization of olivine, augite, and plagioclase to form BA from B



Equilateral triangle showing the solution to the bulk mineral extract (shaded area) best fitting the criteria for the variation diagrams

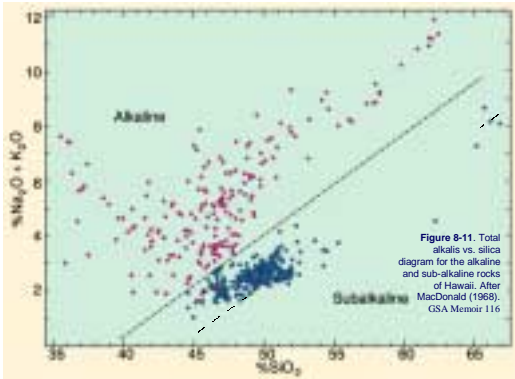
## Magma Series

Can chemistry be used to distinguish families of magma types?

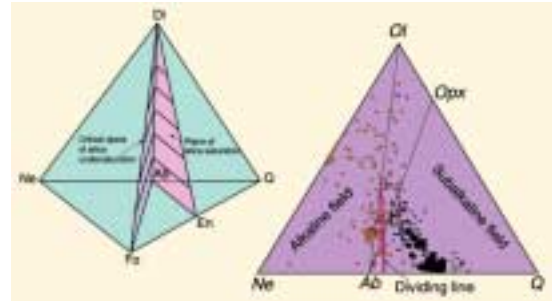
Early on it was recognized that some chemical parameters were very useful in regard to distinguishing magmatic groups

- Total Alkalis (Na<sub>2</sub>O + K<sub>2</sub>O)
- Silica (SiO<sub>2</sub>) and silica saturation
- Alumina (Al<sub>2</sub>O<sub>3</sub>)

Alkali vs. Silica diagram for Hawaiian volcanics:  
Seems to be two distinct groupings: alkaline and subalkaline



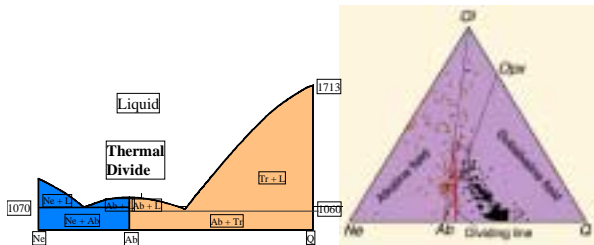
**The Basalt Tetrahedron and the Ne-Ol-Q base**  
Alkaline and subalkaline fields are distinct



Left: the basalt tetrahedron (after Yoder and Tilley, 1962). J. Pet., 3, 342-532. Right: the base of the basalt tetrahedron using cation normative minerals, with the compositions of subalkaline rocks (black) and alkaline rocks (gray) from , projected from Cpx. After Irvine and Baragar (1971). Can. J. Earth Sci., 8, 523-548.

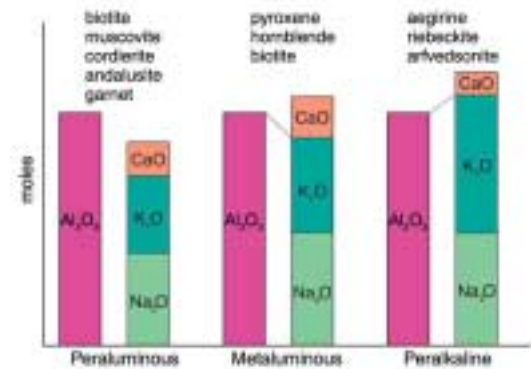
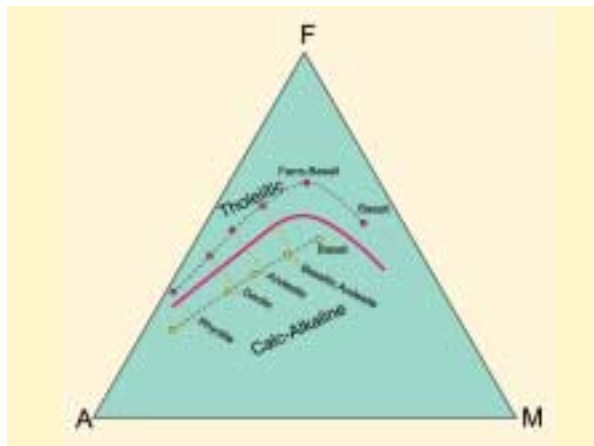
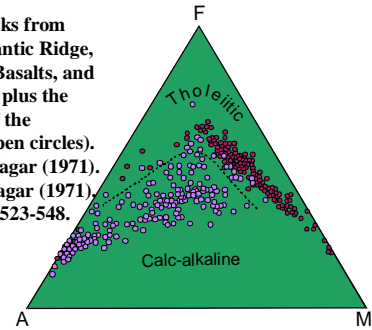
Thermal divide separates the silica-saturated (subalkaline) from the silica-undersaturated (alkaline) fields at low pressure

Cannot cross this divide by FX, so can't derive one series from the other (at least via low-P FX)



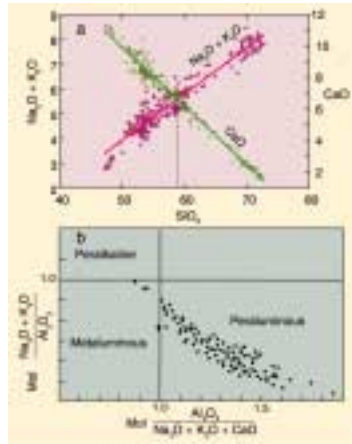
**AFM diagram can further subdivide the subalkaline magma series into a tholeiitic and a calc-alkaline series**

Selected tholeiitic rocks from Iceland, the Mid-Atlantic Ridge, the Columbia River Basalts, and Hawaii (solid circles) plus the calc-alkaline rocks of the Cascade volcanics (open circles). From Irving and Baragar (1971). After Irvine and Baragar (1971). Can. J. Earth Sci., 8, 523-548.

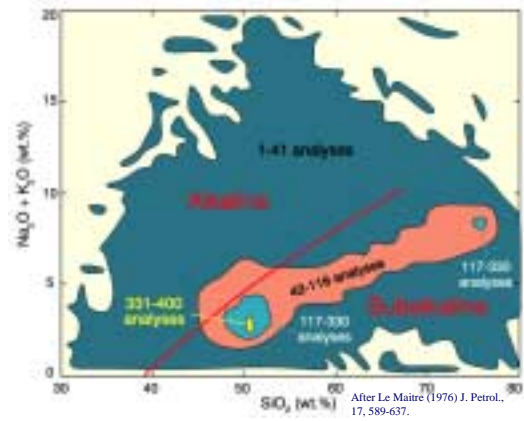


Alumina saturation classes based on the molar proportions of Al<sub>2</sub>O<sub>3</sub>/(CaO+Na<sub>2</sub>O+K<sub>2</sub>O) ("A/CNK") after Shand (1927). Common non-quartz-to-feldspathic minerals for each type are included. After Clarke (1992). Granitoid Rocks. Chapman Hall.

a. Plot of CaO (green) and (Na<sub>2</sub>O + K<sub>2</sub>O) (red) vs. SiO<sub>2</sub> for the Crater Lake data. Peacock (1931) “alkali-lime index” (dashed line).



b. Alumina saturation indices (Shand, 1927) with analyses of the peraluminous granitic rocks from the Achala Batholith, Argentina (Lira and Kirschbaum, 1990).



After Le Maitre (1976) J. Petrol., 17, 589-637.

**A world-wide survey suggests that there may be important differences between the three series**

Characteristic Series	Plate Margin		Within Plate	
	Convergent	Divergent	Oceanic	Continental
Alkaline	yes		yes	yes
Tholeiitic	yes	yes	yes	yes
Calc-alkaline	yes			

After Wilson (1989)