Lecture 13 Introduction to Trace Elements

Wednesday, March 9, 2005

Chapter 9: Trace Elements

Note magnitude of major element changes

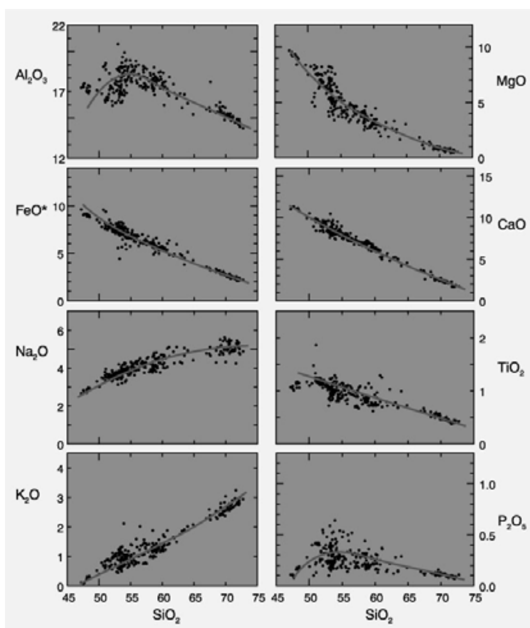


Figure 8-2. Harker variation diagram for 310 analyzed volcanic rocks from Crater Lake (Mt. Mazama), Oregon Cascades. Data compiled by Rick Conrey (personal communication). From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Chapter 9: Trace Elements

Now note magnitude of trace element changes

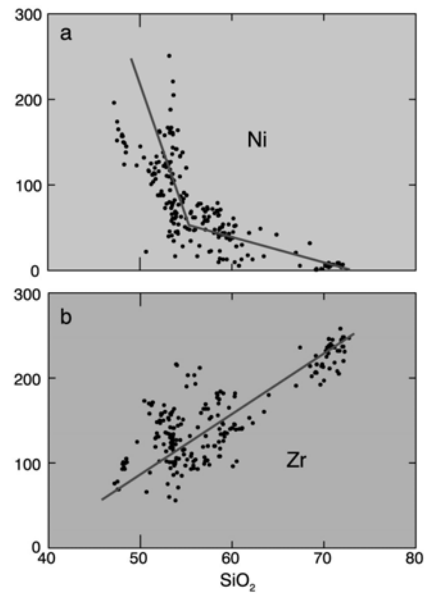


Figure 9-1. Harker Diagram for Crater Lake. From data compiled by Rick Conrey. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

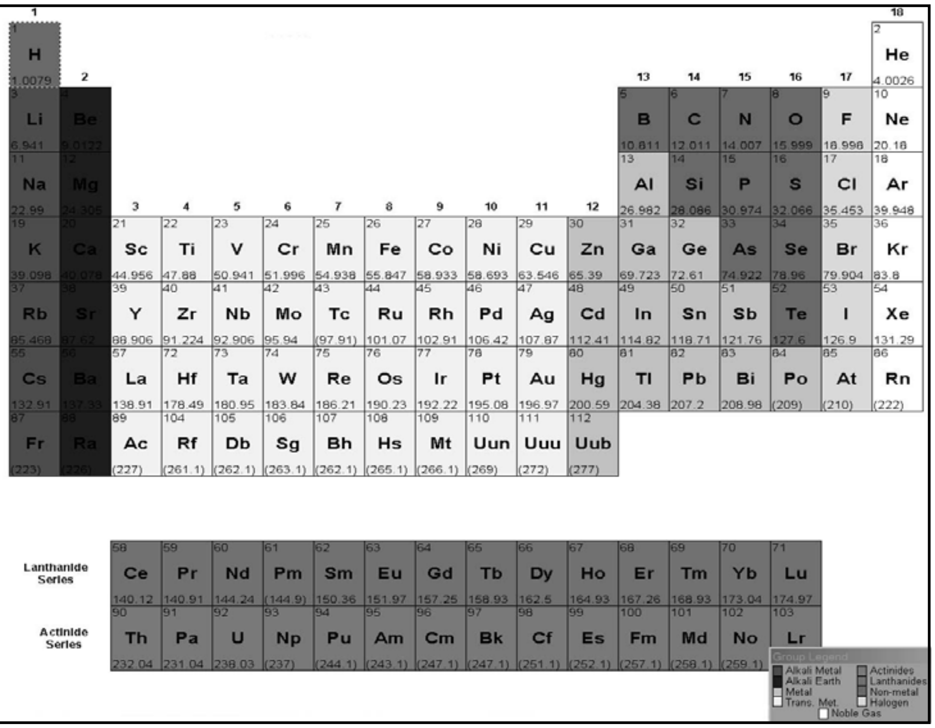
Element Distribution

Goldschmidt's rules (simplistic, but useful)

1. 2 ions with the same valence and radius should exchange easily and enter a solid solution in amounts equal to their overall proportions

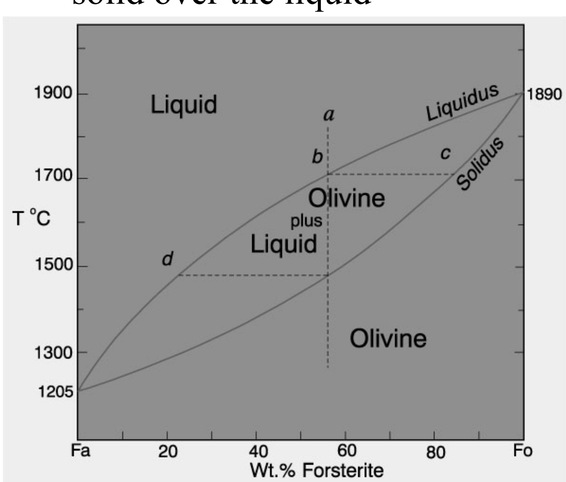
How do Rb and Ni behave?

	Ionic radius (angstroms)
K^+	1.33
Rb^+	1.47
Mg^{++}	0.66
Ni^{++}	0.69



Goldschmidt's rules

2. If 2 ions have a similar radius and the same valence: the smaller ion is preferentially incorporated into the solid over the liquid



	Ionic radius
Mg^{++}	0.66
Fe^{++}	0.74

Fig. 6-10. Isobaric T-X phase diagram at atmospheric pressure After Bowen and Shairer (1932), Amer. J. Sci. 5th Ser., **24**, 177-213. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

3. If 2 ions have a similar radius, but different valence: the ion with the higher charge is preferentially incorporated into the solid over the liquid

	ionic radius
K^{+}	1.33
Ba^{++}	1.35
Y^{+++}	0.90
U^{++++}	0.94

Chemical Fractionation

- The uneven distribution of an ion between two competing (equilibrium) phases

Phases can be liquids or crystals

The distribution of an element *i* between a melt and a crystal

$$K_D = \frac{X_i^{crystal}}{X_i^{melt}}$$

Where X_i is the mol fraction of element *i* in the solid or liquid phase

K_D is the distribution or partition coefficient

- For dilute solutions we can substitute D for K_D:

$$D = \frac{C_S}{C_L}$$

Where C_S = the concentration of some element in the crystal phase and C_L in the melt phase

- incompatible elements are concentrated in the melt

$(K_D \text{ or } D) \ll 1$

- compatible elements are concentrated in the solid

$K_D \text{ or } D \gg 1$

- Incompatible elements commonly fall into two subgroups
  - Smaller, highly charged high field strength (HFS) elements (REE, Th, U, Ce, Pb^{4+}, Zr, Hf, Ti, Nb, Ta)
  - Low field strength large ion lithophile (LIL) elements (K, Rb, Cs, Ba, Pb^{2+}, Sr, Eu^{2+}) are more mobile, particularly if a fluid phase is involved

Compatibility depends on minerals and melts involved.

Which are incompatible? Why?

Table 9-1. Partition Coefficients (C_S/C_L) for Some Commonly Used Trace Elements in Basaltic and Andesitic Rocks

		Olivine	Opx	Cpx	Garnet	Plag	Amph	Magnetite
Rb		0.010	0.022	0.031	0.042	0.071	0.29	
Sr		0.014	0.040	0.060	0.012	1.830	0.46	
Ba		0.010	0.013	0.026	0.023	0.23	0.42	
Ni		*14*	5	7	0.955	*0.01*	6.8	29
Cr		0.70	10	34	1.345	*0.01*	2.00	7.4
La	Rare Earth Elements	0.007	*0.03*	0.056	0.001	0.148	0.544	2
Ce	Rare Earth Elements	0.006	0.02	0.092	0.007	0.082	0.843	2
Nd	Rare Earth Elements	0.006	0.03	0.230	0.026	0.055	1.340	2
Sm	Rare Earth Elements	0.007	0.05	0.445	0.102	0.039	1.804	1
Eu	Rare Earth Elements	0.007	0.05	0.474	0.243	0.1/1.5*	1.557	1
Dy	Rare Earth Elements	0.013	0.15	0.582	1.940	0.023	2.024	1
Er	Rare Earth Elements	0.026	0.23	0.583	4.700	0.020	1.740	1.5
Yb	Rare Earth Elements	0.049	0.34	0.542	6.167	0.023	1.642	1.4
Lu		0.045	0.42	0.506	6.950	0.019	1.563	

Data from Rollinson (1993). * Eu^{3+}/Eu^{2+} *Italics* are estimated

- For a rock, determine the bulk distribution coefficient D for an element by calculating the contribution for each mineral

eq. 9-4: $\bar{D}_i = \Sigma W_A D_{i_A}$

W_A = weight % of mineral A in the rock

D_{i_A} = partition coefficient of element i in mineral A

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Example: hypothetical garnet lherzolite = 60% olivine, 25% orthopyroxene, 10% clinopyroxene, and 5% garnet (all by *weight*), using the data in Table 9-1, is:

$$\overline{D}_{Er} = (0.6 \cdot 0.026) + (0.25 \cdot 0.23) + (0.10 \cdot 0.583) + (0.05 \cdot 4.7) = 0.366$$

- Trace elements strongly partitioned into a single mineral
- Ni - olivine in Table 9-1 = 14

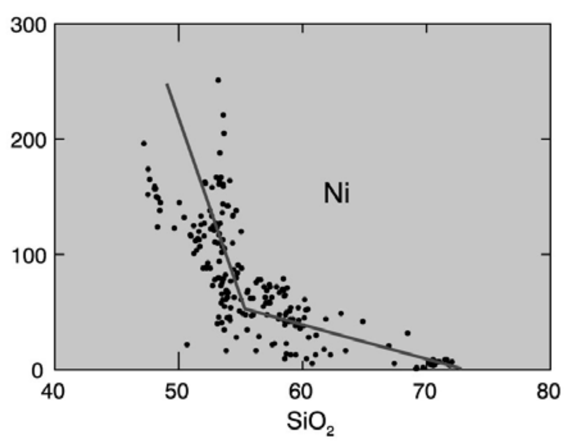

Figure 9-1a. Ni Harker Diagram for Crater Lake. From data compiled by Rick Conrey. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

- Incompatible trace elements concentrate → liquid
- Reflect the proportion of liquid at a given state of crystallization or melting

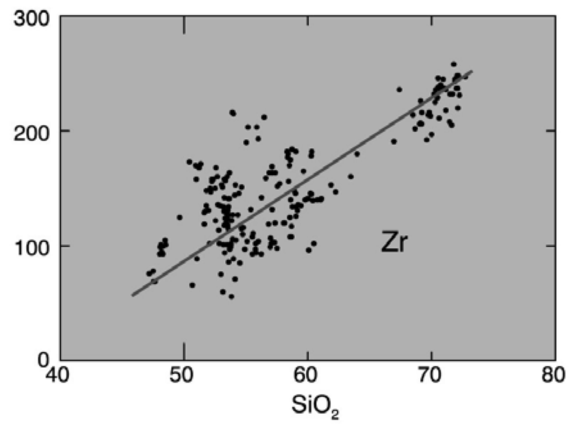

Figure 9-1b. Zr Harker Diagram for Crater Lake. From data compiled by Rick Conrey.
From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

- K/Rb often used → the importance of amphibole in a source rock
  - K & Rb behave very similarly, so K/Rb should be ~ constant
  - If amphibole, almost all K and Rb reside in it
  - Amphibole has a D of about 1.0 for K and 0.3 for Rb

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- Sr and Ba (also incompatible elements)
  - ▲ Sr is excluded from most common minerals except plagioclase
  - ▲ Ba similarly excluded except in alkali feldspar

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Compatible example:

- Ni strongly fractionated → olivine > pyroxene
- Cr and Sc → pyroxenes » olivine
- Ni/Cr or Ni/Sc can distinguish the effects of olivine and augite in a partial melt or a suite of rocks produced by fractional crystallization

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