Announcements

- Reading: p.167-179 (tough stuff)
- Focus on Rb-Sr system (p.172-175)
- Homework issues after lecture

Partition coefficients

- For dilute solutions:

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

Where C_S = the concentration of some element in the solid phase

C_L = the concentration of the element in the liquid phase

- incompatible elements are concentrated in the melt

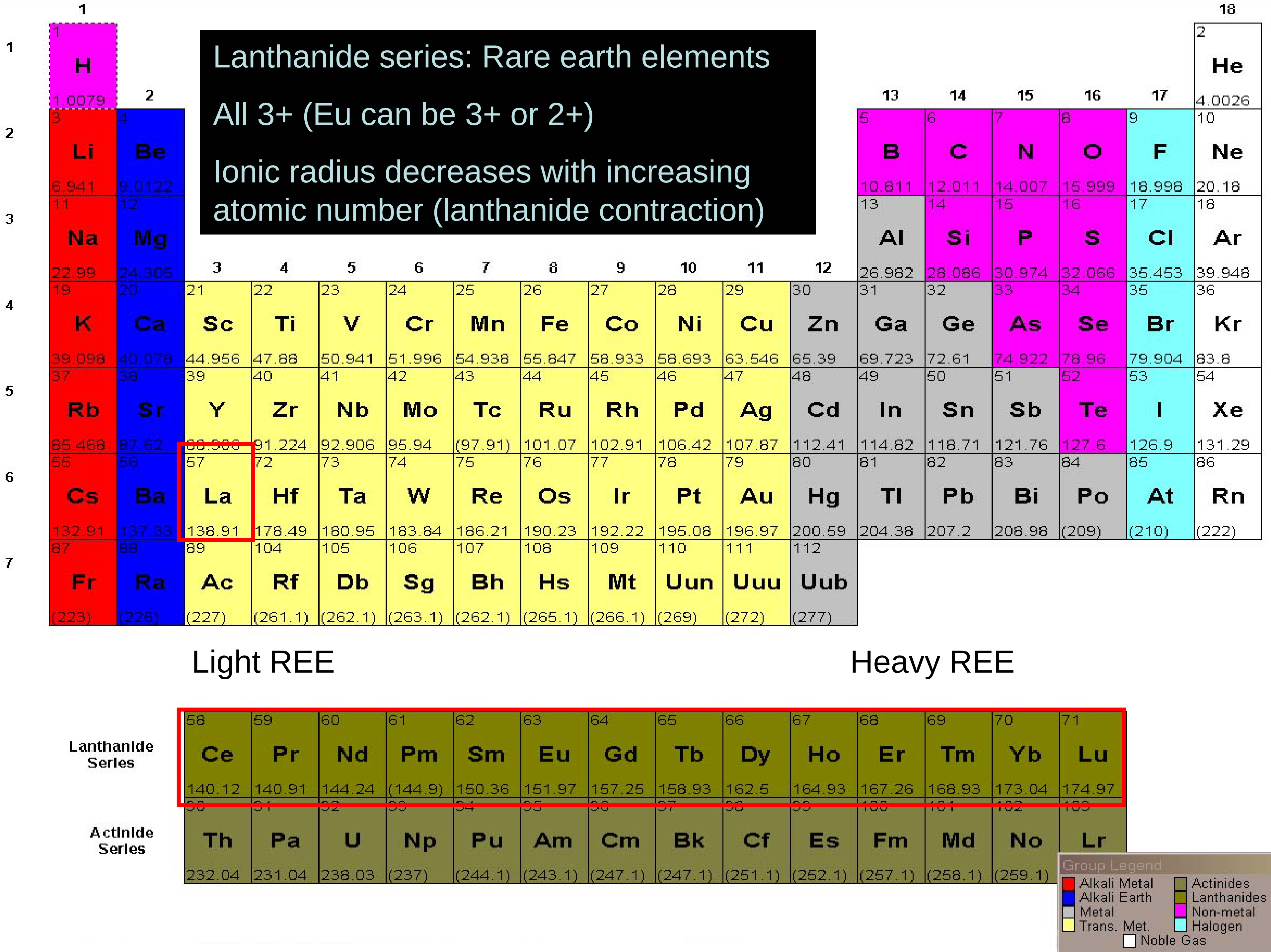
$(K_D \text{ or } D) \ll 1$

- compatible elements are concentrated in the solid

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

Incompatible elements commonly divided 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



Lanthanide series: Rare earth elements
All 3+ (Eu can be 3+ or 2+)
Ionic radius decreases with increasing atomic number (lanthanide contraction)
Light REE
Heavy REE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
1 H 1.0079
2 He 4.0026
3 Li 6.941
4 Be 9.0122
5 B 10.811
6 C 12.011
7 N 14.007
8 O 15.999
9 F 18.998
10 Ne 20.18
11 Na 22.99
12 Mg 24.305
13 Al 26.982
14 Si 28.086
15 P 30.974
16 S 32.066
17 Cl 35.453
18 Ar 39.948
19 K 39.098
20 Ca 40.078
21 Sc 44.956
22 Ti 47.88
23 V 50.941
24 Cr 51.996
25 Mn 54.938
26 Fe 55.847
27 Co 58.933
28 Ni 58.693
29 Cu 63.546
30 Zn 65.39
31 Ga 69.723
32 Ge 72.61
33 As 74.922
34 Se 78.96
35 Br 79.904
36 Kr 83.8
37 Rb 85.468
38 Sr 87.62
39 Y 88.906
40 Zr 91.224
41 Nb 92.906
42 Mo 95.94
43 Tc (97.91)
44 Ru 101.07
45 Rh 102.91
46 Pd 106.42
47 Ag 107.87
48 Cd 112.41
49 In 114.82
50 Sn 118.71
51 Sb 121.76
52 Te 127.6
53 I 126.9
54 Xe 131.29
55 Cs 132.91
56 Ba 137.33
57 La 138.91
72 Hf 178.49
73 Ta 180.95
74 W 183.84
75 Re 186.21
76 Os 190.23
77 Ir 192.22
78 Pt 195.08
79 Au 196.97
80 Hg 200.59
81 Tl 204.38
82 Pb 207.2
83 Bi 208.98
84 Po (209)
85 At (210)
86 Rn (222)
87 Fr (223)
88 Ra (226)
89 Ac (227)
104 Rf (261.1)
105 Db (262.1)
106 Sg (263.1)
107 Bh (262.1)
108 Hs (265.1)
109 Mt (266.1)
110 Uun (269)
111 Uuu (272)
112 Uub (277)
Lanthanide Series
58 Ce 140.12
59 Pr 140.91
60 Nd 144.24
61 Pm (144.9)
62 Sm 150.36
63 Eu 151.97
64 Gd 157.25
65 Tb 158.93
66 Dy 162.5
67 Ho 164.93
68 Er 167.26
69 Tm 168.93
70 Yb 173.04
71 Lu 174.97
Actinide Series
90 Th 232.04
91 Pa 231.04
92 U 238.03
93 Np (237)
94 Pu (244.1)
95 Am (243.1)
96 Cm (247.1)
97 Bk (247.1)
98 Cf (251.1)
99 Es (252.1)
100 Fm (257.1)
101 Md (258.1)
102 No (259.1)
103 Lr
Group Legend
Alkali Metal
Alkali Earth
Metal
Trans. Met.
Actinides
Lanthanides
Non-metal
Halogen
Noble Gas

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

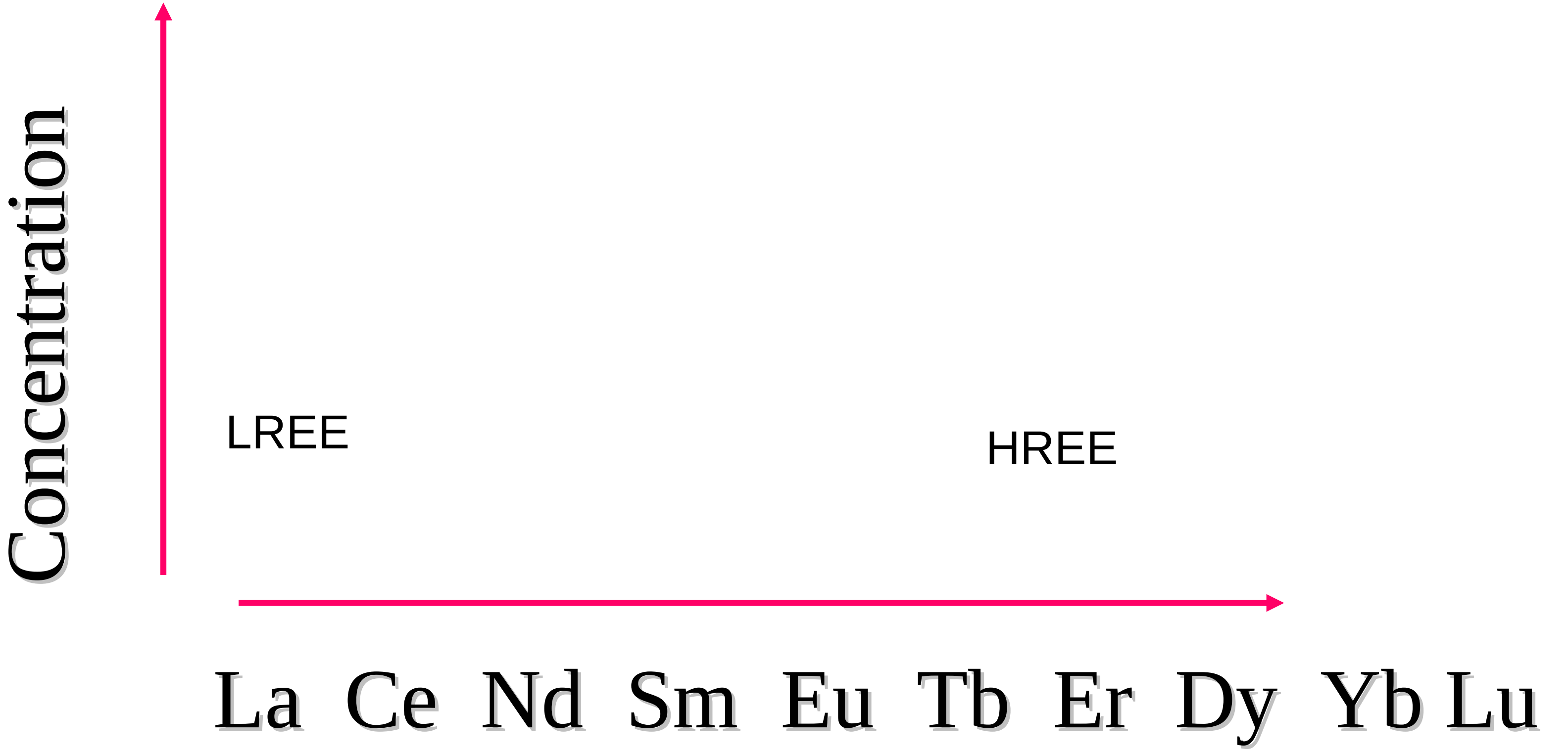
		Olivine	Opx	Cpx	Garnet	Plag	Amph	Magnetite
Rb		0.010	0.022	0.031	0.042	0.071	0.29	
Sr		0.014	0.040	0.060	0.012	1.830	0.46	
Ba		0.010	0.013	0.026	0.023	0.23	0.42	
Ni		*14*	5	*7*	0.955	*0.01*	6.8	29
Cr		0.70	10	34	1.345	*0.01*	2.00	7.4
La	Rare Earth Elements	0.007	*0.03*	0.056	0.001	0.148	0.544	2
Ce		0.006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

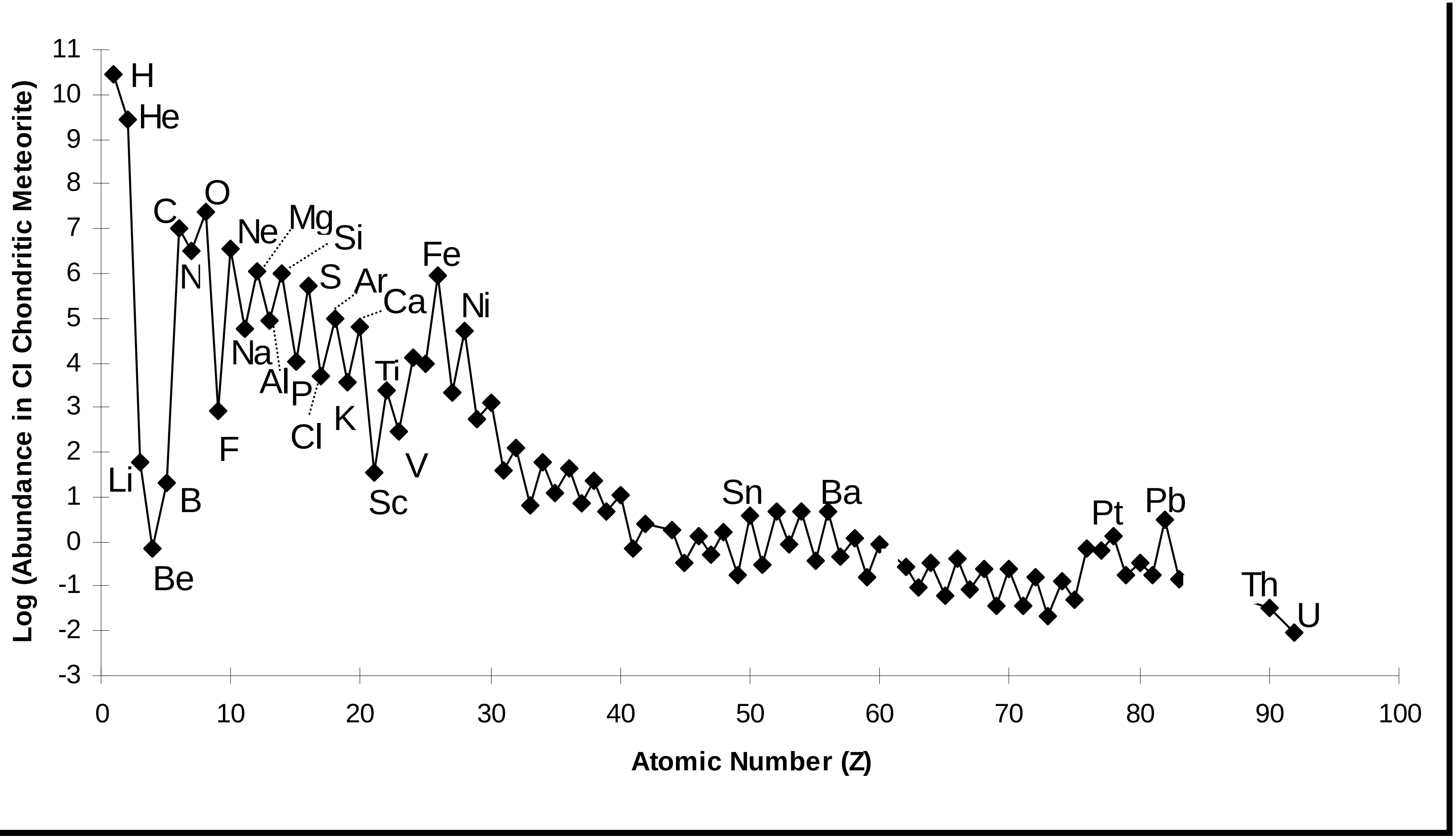
Data from Rollinson (1993). * Eu^{3+}/Eu^{2+} *Italics* are estimated

REEE Diagrams

Plots of concentration as the ordinate (y-axis) against increasing atomic number

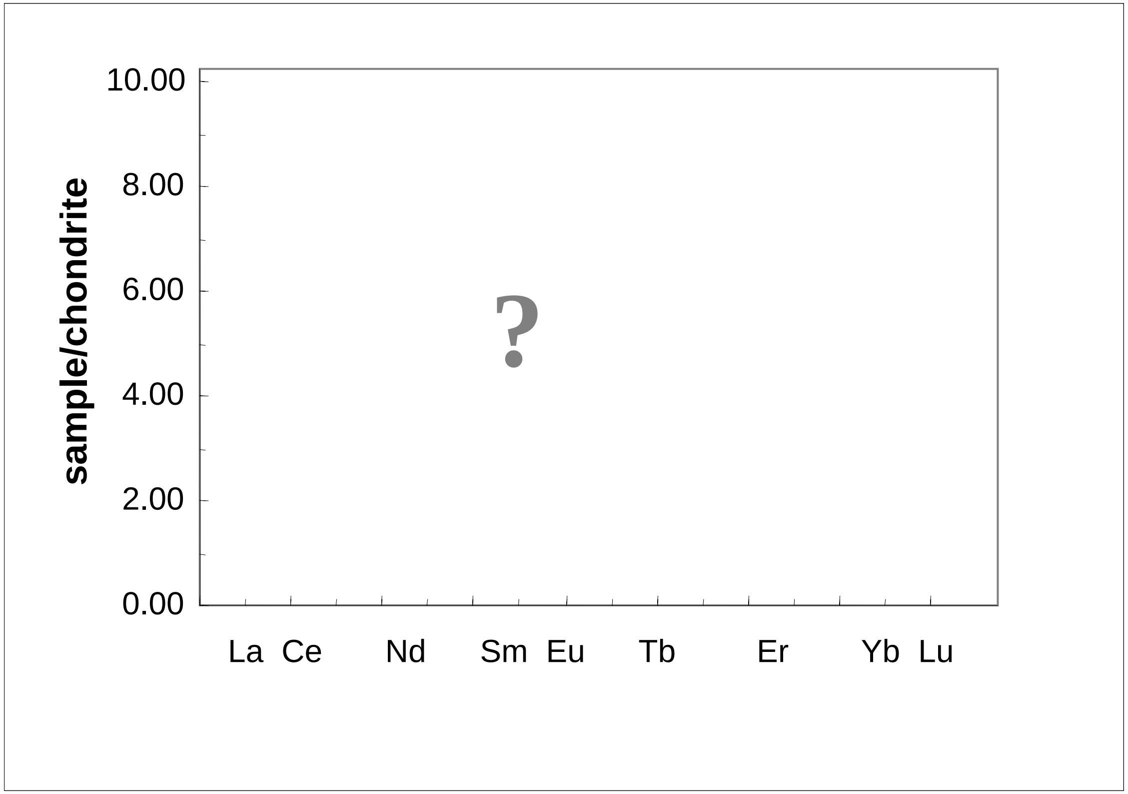
- Degree of compatibility increases from left to right across the diagram





– Eliminate Oddo-Harkins effect and make y-scale more functional by normalizing to a standard
  - estimates of primordial mantle REE
  - chondrite meteorite concentrations

What would an REE diagram look like for an analysis of a chondrite meteorite?



REE diagrams using batch melting model of a garnet lherzolite for various values of F:

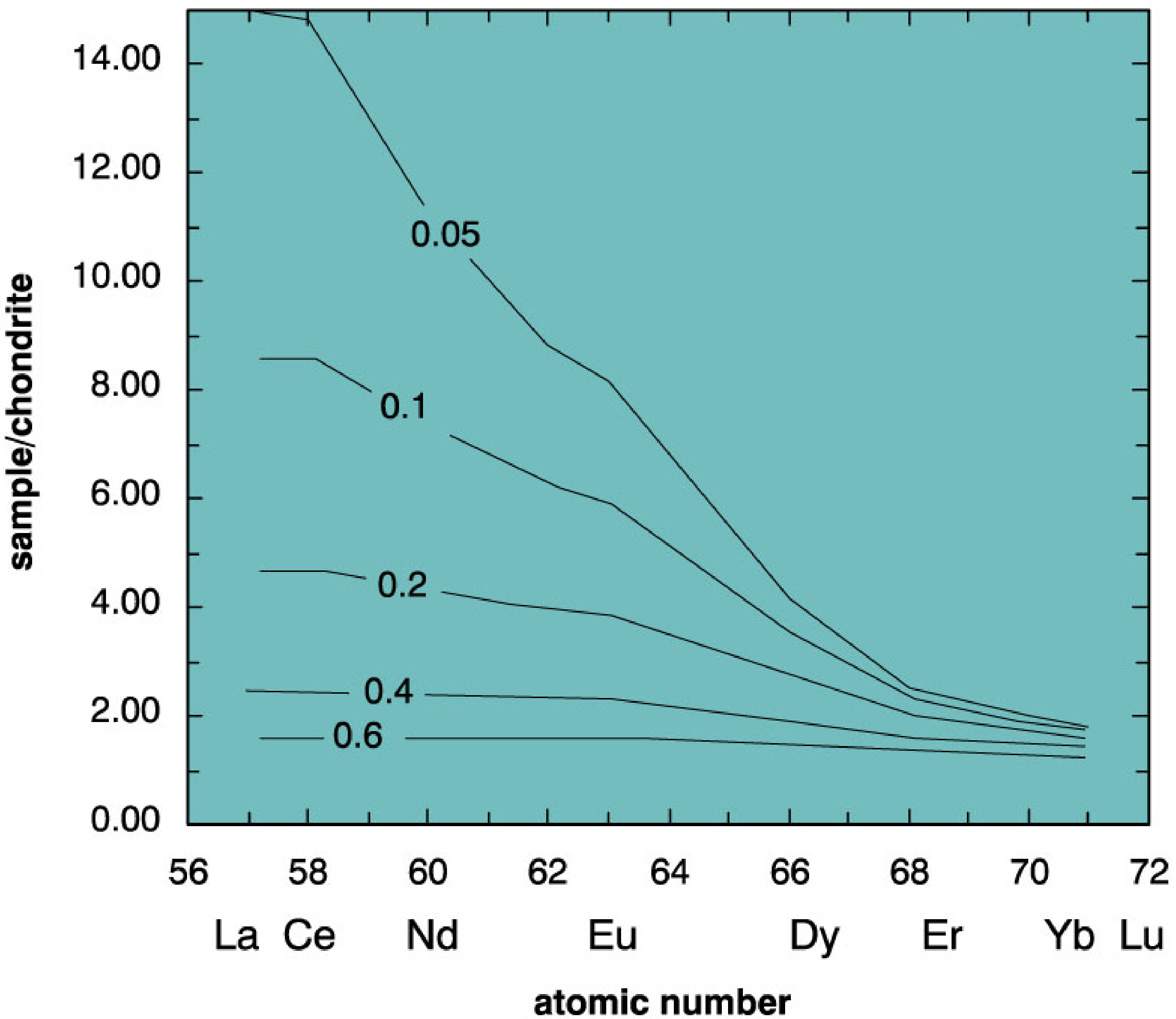


Figure 9-4. Rare Earth concentrations (normalized to chondrite) for melts produced at various values of F via melting of a hypothetical garnet lherzolite using the batch melting model (equation 9-5). From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Continental Arc Magmatism: South American Arc

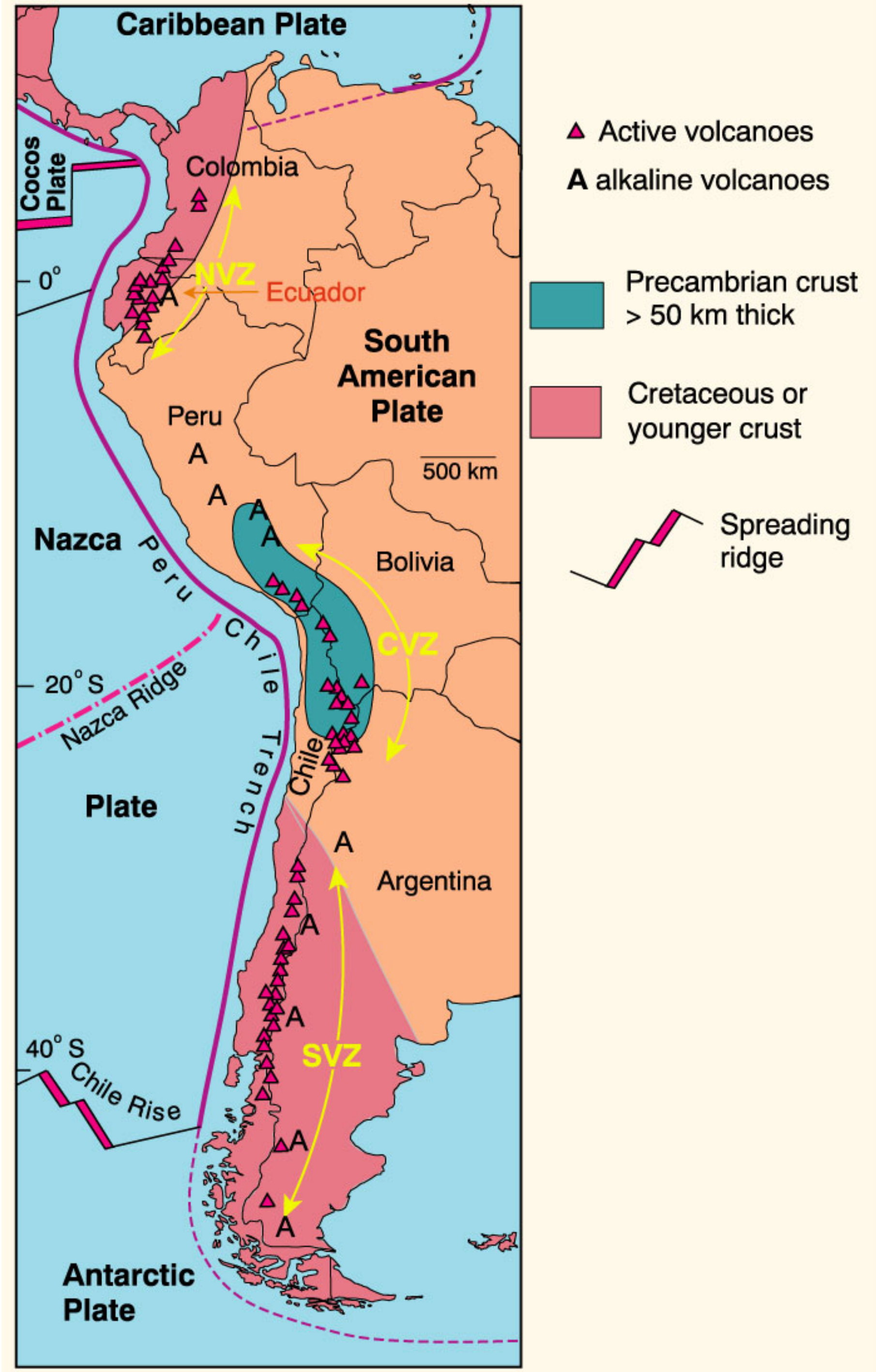


Figure 17-1. Map of western South America showing the plate tectonic framework, and the distribution of volcanics and crustal types. NVZ, CVZ, and SVZ are the northern, central, and southern volcanic zones. After Thorpe and Francis (1979) *Tectonophys.*, 57, 53-70; Thorpe *et al*. (1982) In R. S. Thorpe (ed.), (1982). *Andesites. Orogenic Andesites and Related Rocks*. John Wiley & Sons. New York, pp. 188-205; and Harmon *et al.* (1984) *J. Geol.* Soc. London, 141, 803-822. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

South American Arc

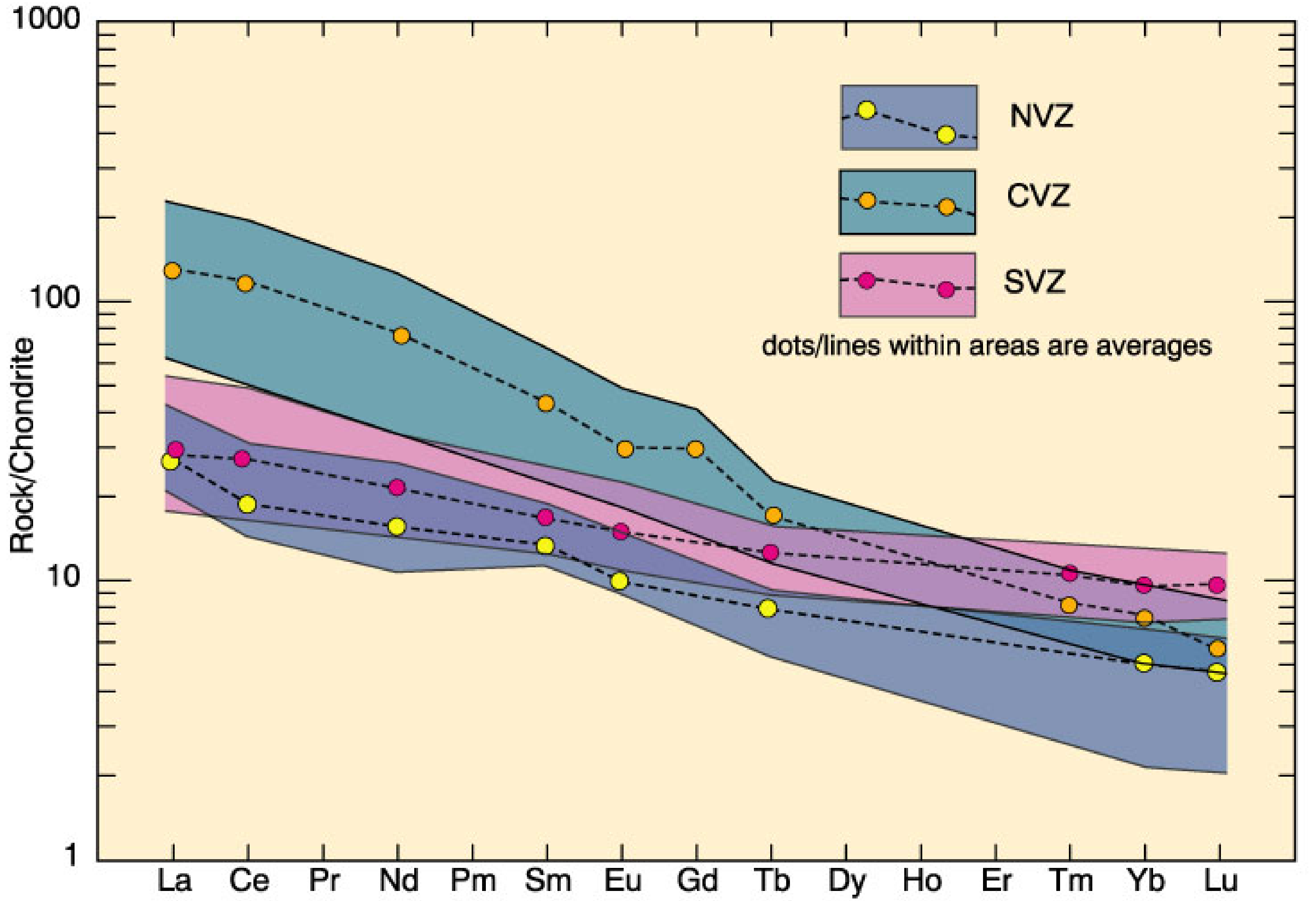


Figure 17-4. Chondrite-normalized REE diagram for selected Andean volcanics. NVZ (6 samples, average SiO_2 = 60.7, K_2O = 0.66, data from Thorpe *et al*. 1984; Geist, pers. comm.). CVZ (10 samples, ave. SiO_2 = 54.8, K_2O = 2.77, data from Deruelle, 1982; Davidson, pers. comm.; Thorpe *et al*., 1984). SVZ (49 samples, average SiO_2 = 52.1, K_2O = 1.07, data from Hickey *et al*. 1986; Deruelle, 1982; López-Escobar *et al*. 1981). Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Lunar rocks

- Model igneous processes with REE

- Europium anomaly when plagioclase is
  - a fractionating phenocryst

    or

  - a residual solid in source

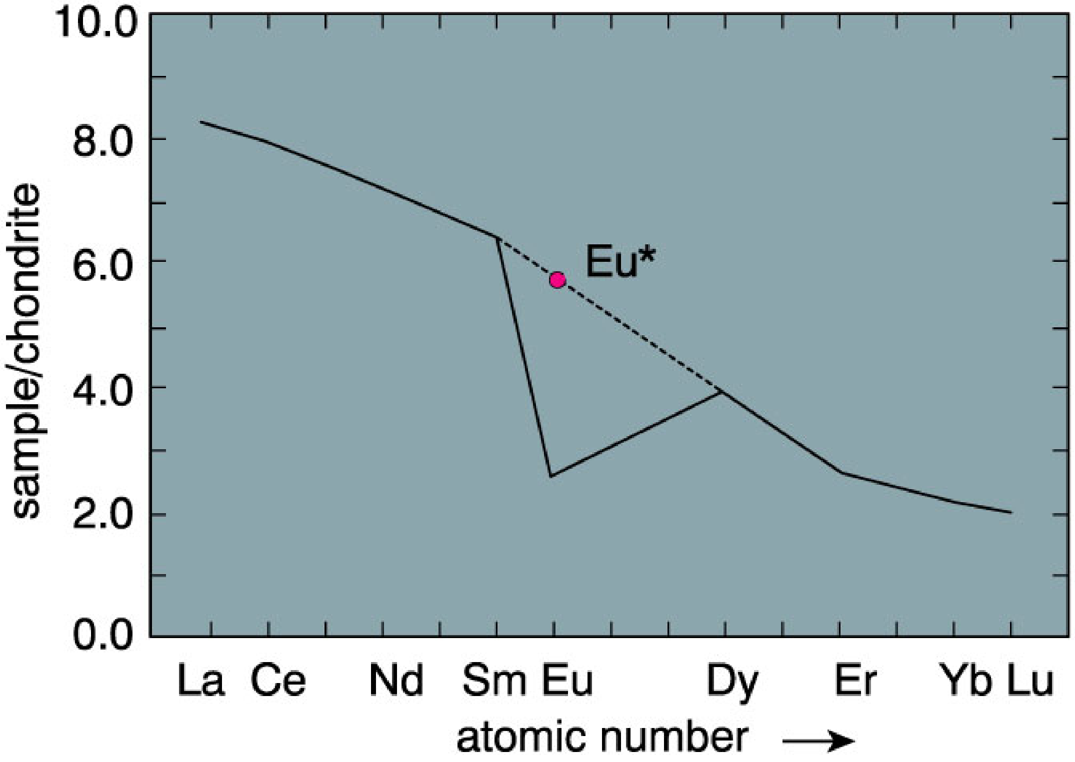


Figure 9-5. REE diagram for 10% batch melting of a hypothetical lherzolite with 20% plagioclase, resulting in a pronounced negative Europium anomaly. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Summary of important points

- Partition coefficients
- Rare earth elements (REE)
  - Normalization to chondritic values
  - Model melting or fractional crystallization in presence of certain minerals (garnet, plagioclase)