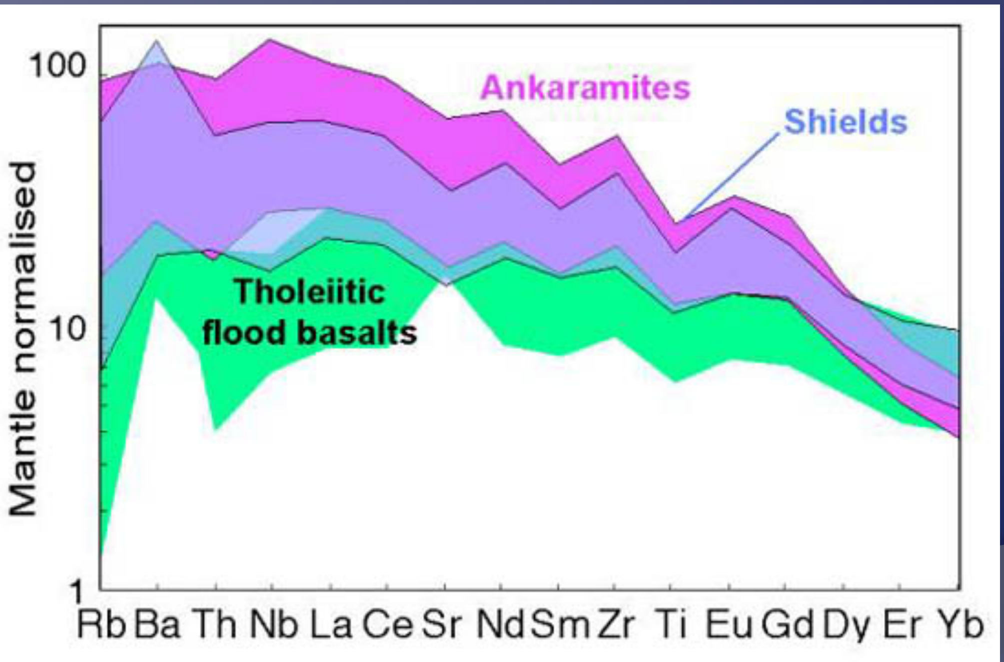
Sarah Lambart - 2016

LECTURES 14-15: TRACE ELEMENTS



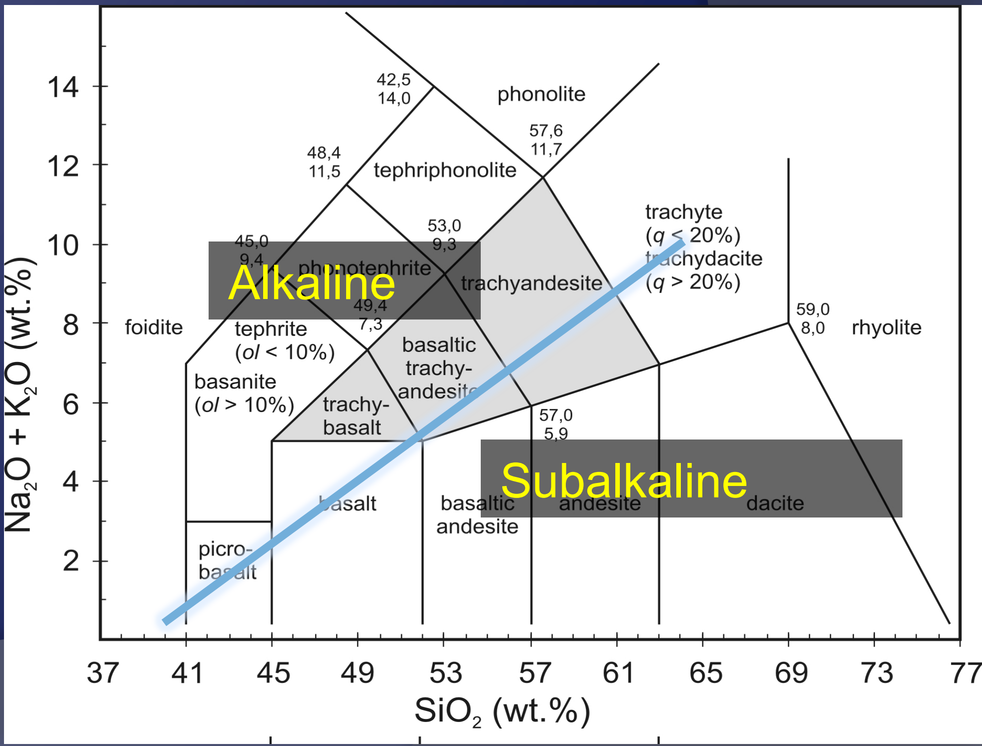
Recap Lecture 14

- 3 important magmatic series:

Tholeiitic → MOR

Calco-alkaline → subduction

alkaline → intraplate



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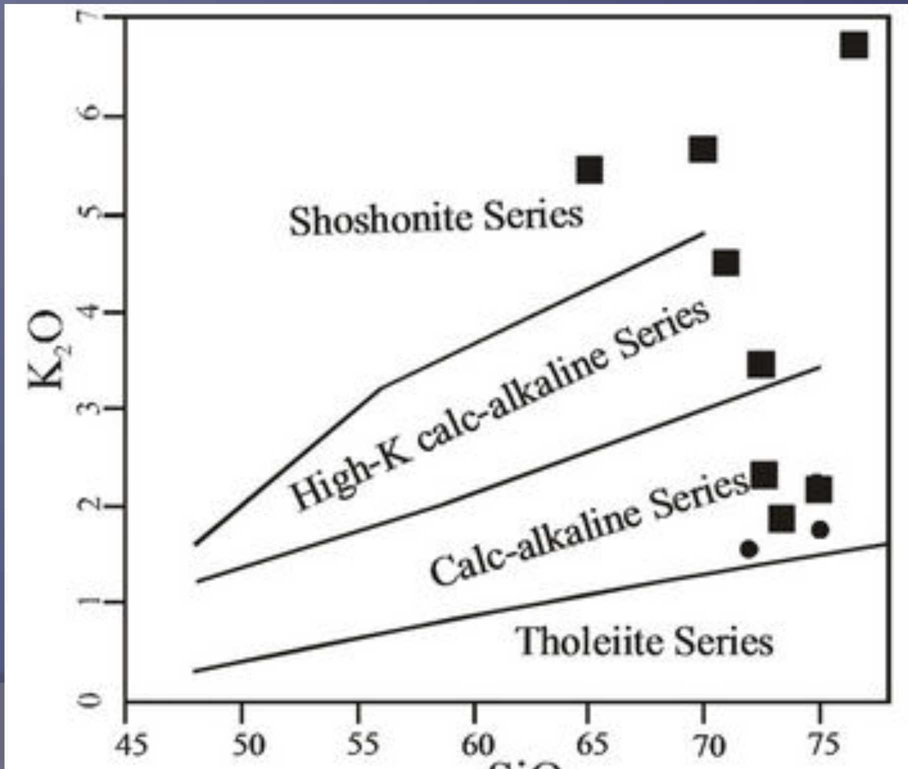
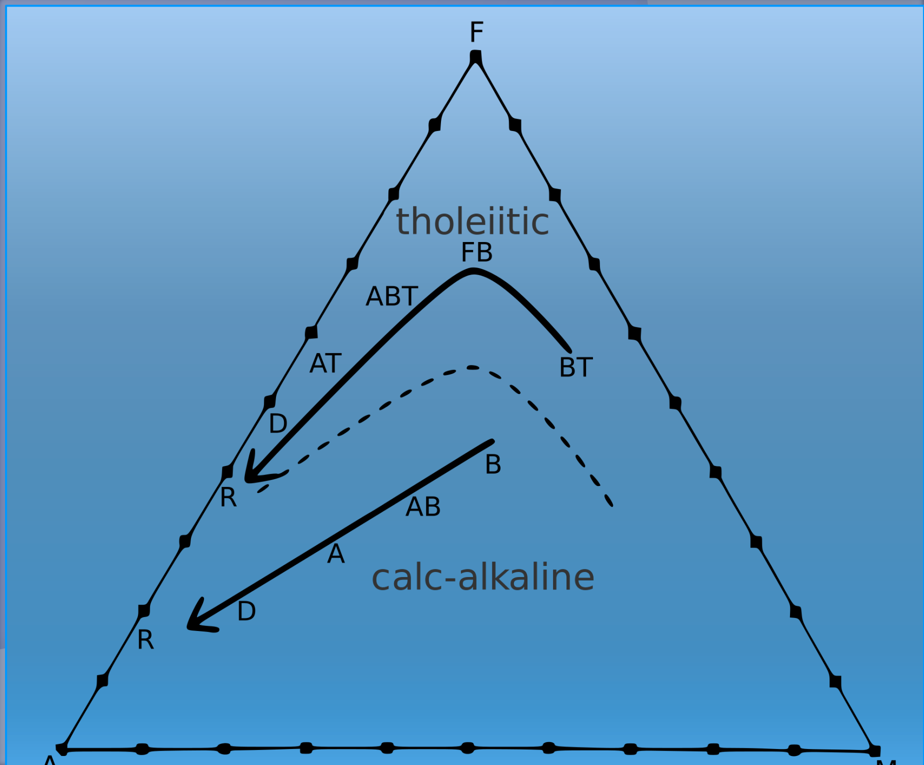
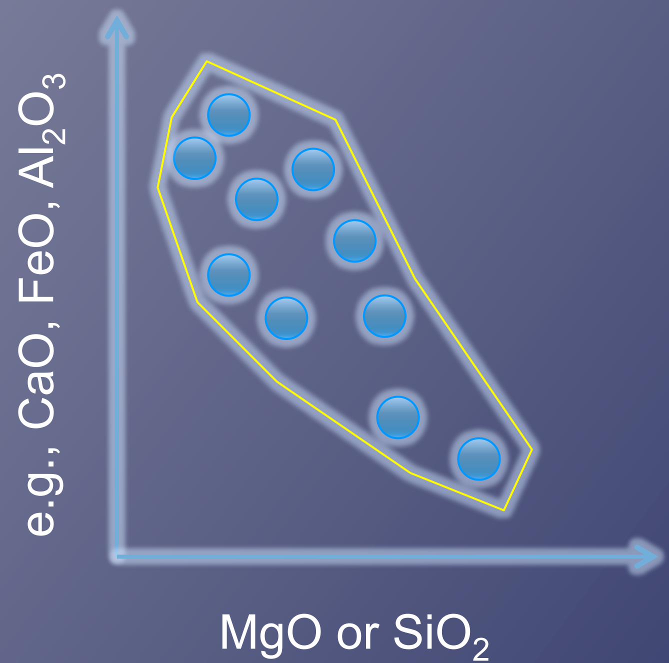
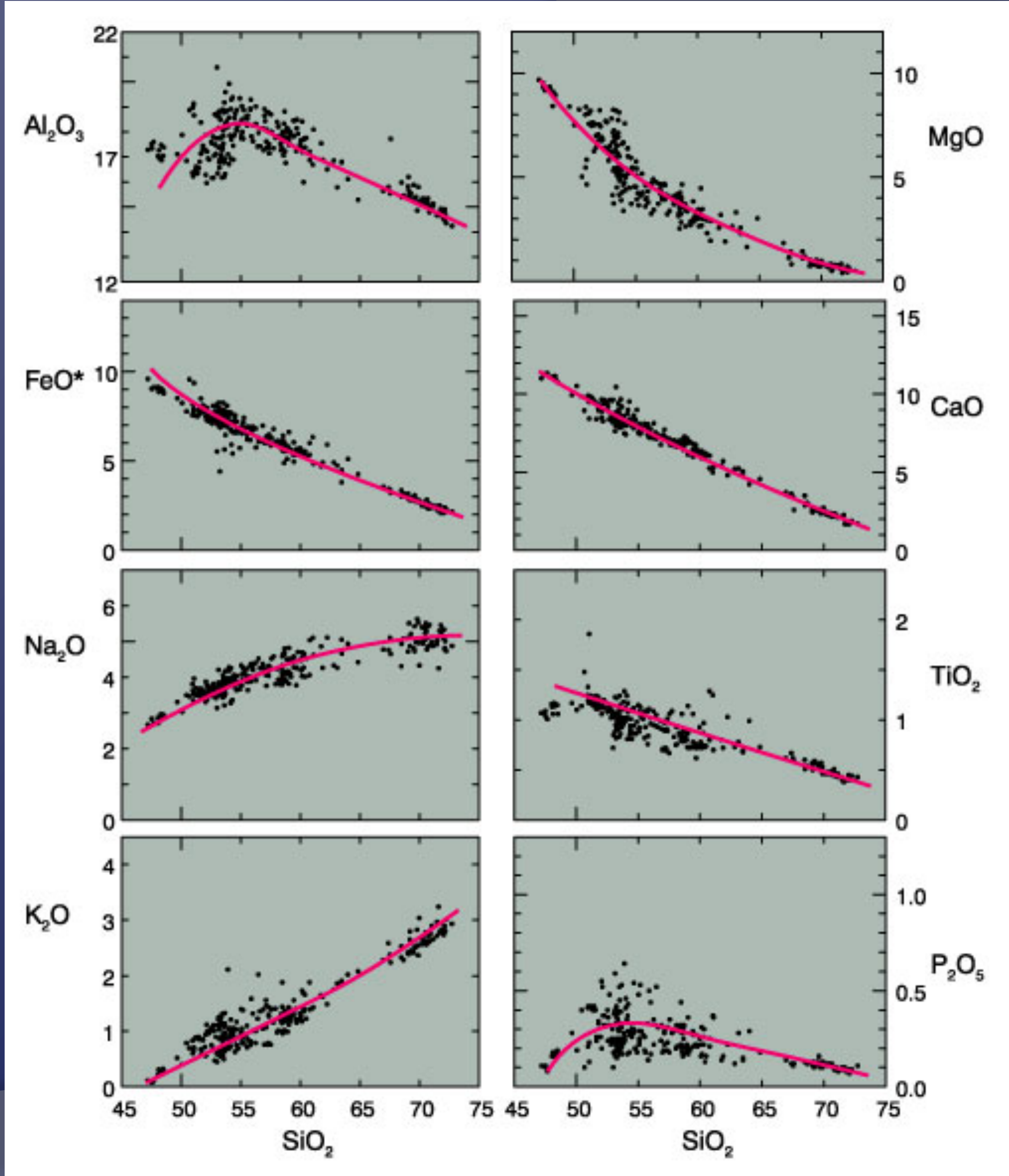


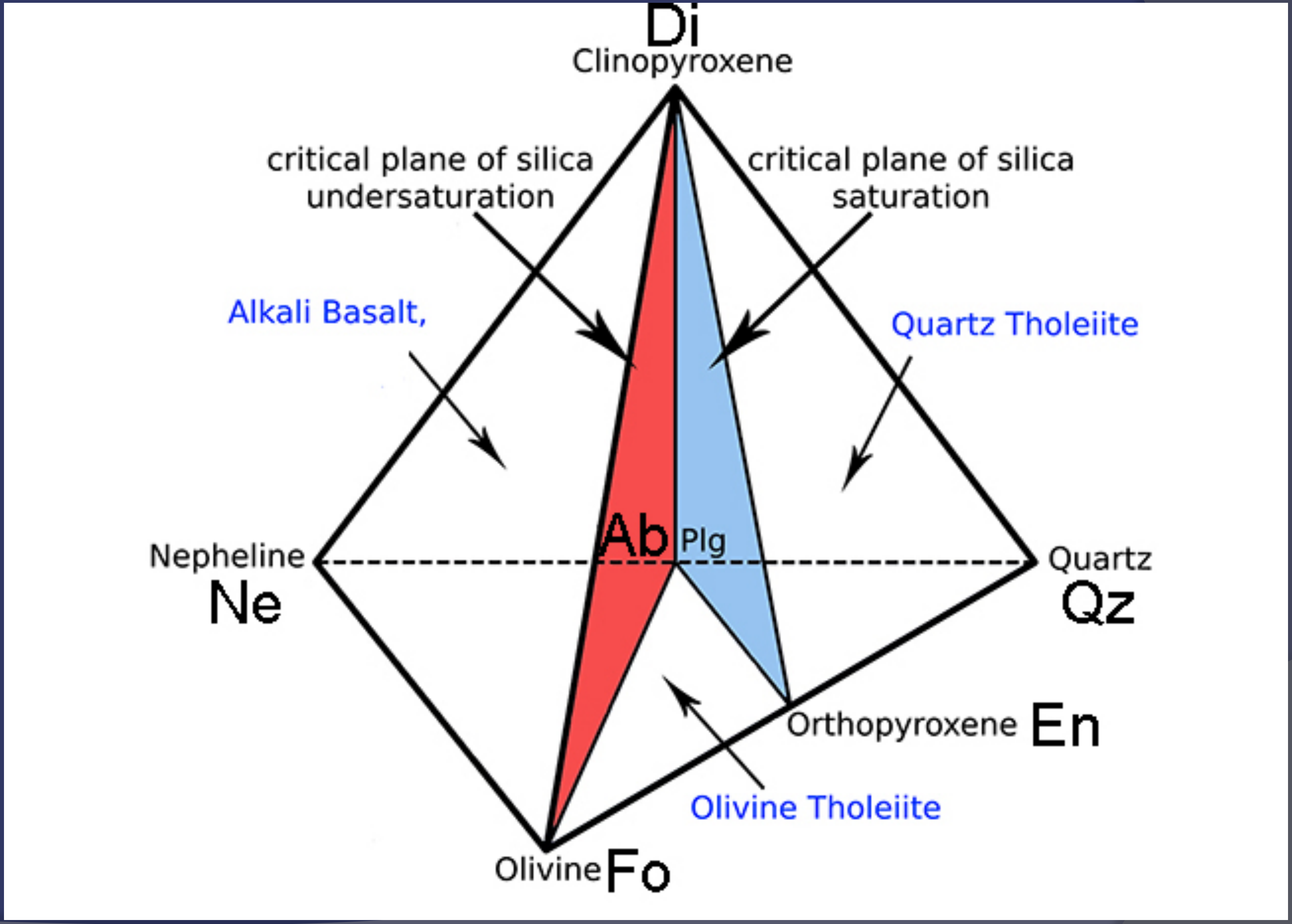


Major elements: Harker diagrams





Basalt Tetrahedron



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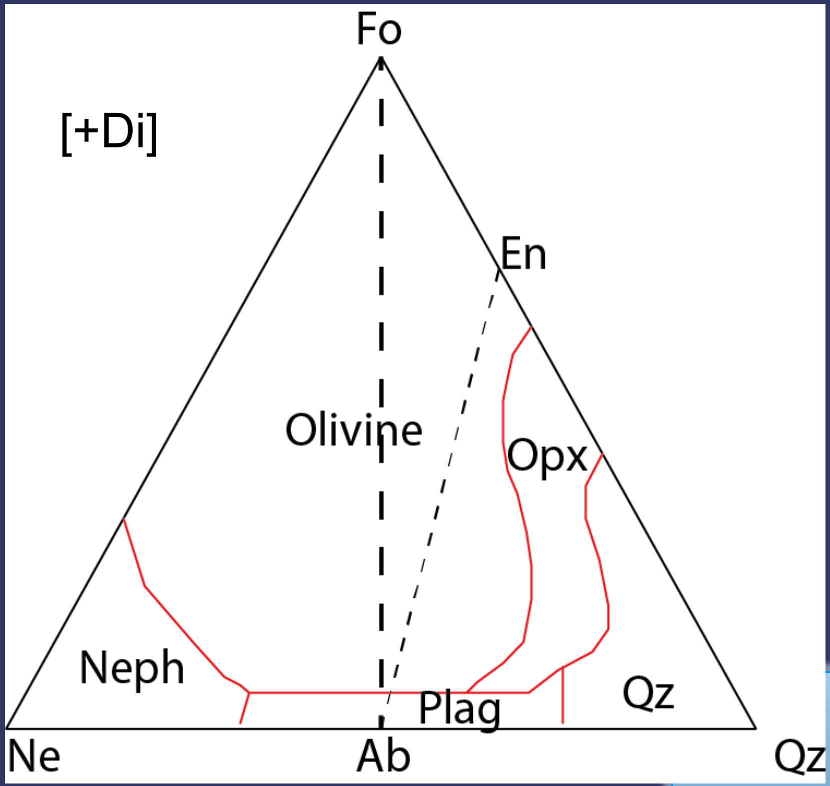
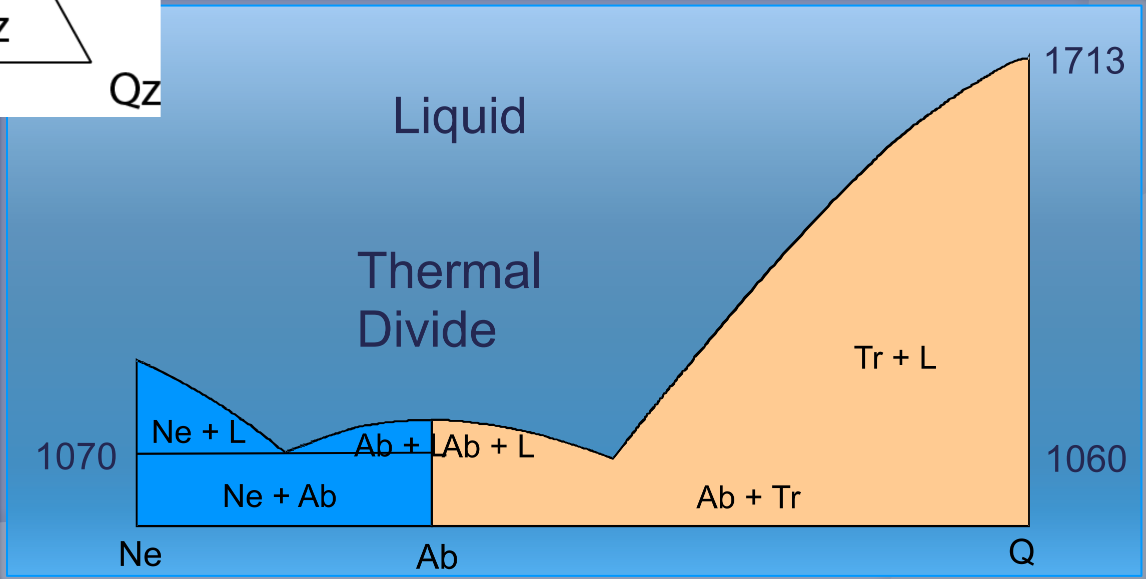




Trace elements

- What is trace elements?
  - Less than 1% in the bulk composition
  - Are not stoichiometric components in the phase
  - Do not affect chemical of physical properties of the system
  - Obey Henry's law: the activity of an element in a system is proportional to it's concentration

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.0079																	2 **He** 4.0026
2	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
3	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
4	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
5	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
6	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)
7	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)						

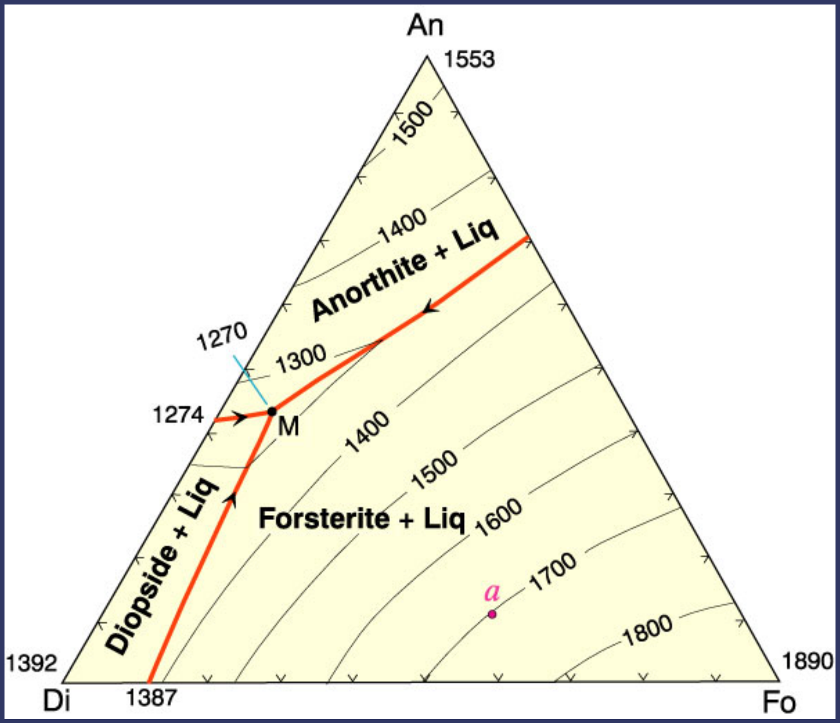
Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (144.9)	62 **Sm** 150.36	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.5	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	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**

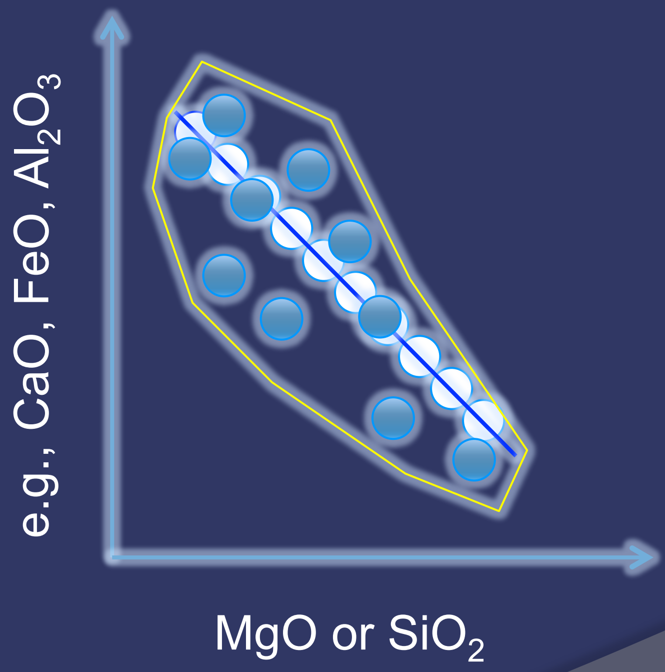
Group Legend

Alkali Metal	Actinides
Alkali Earth	Lanthanides
Metal	Non-metal
Trans. Met.	Halogen
Noble Gas	

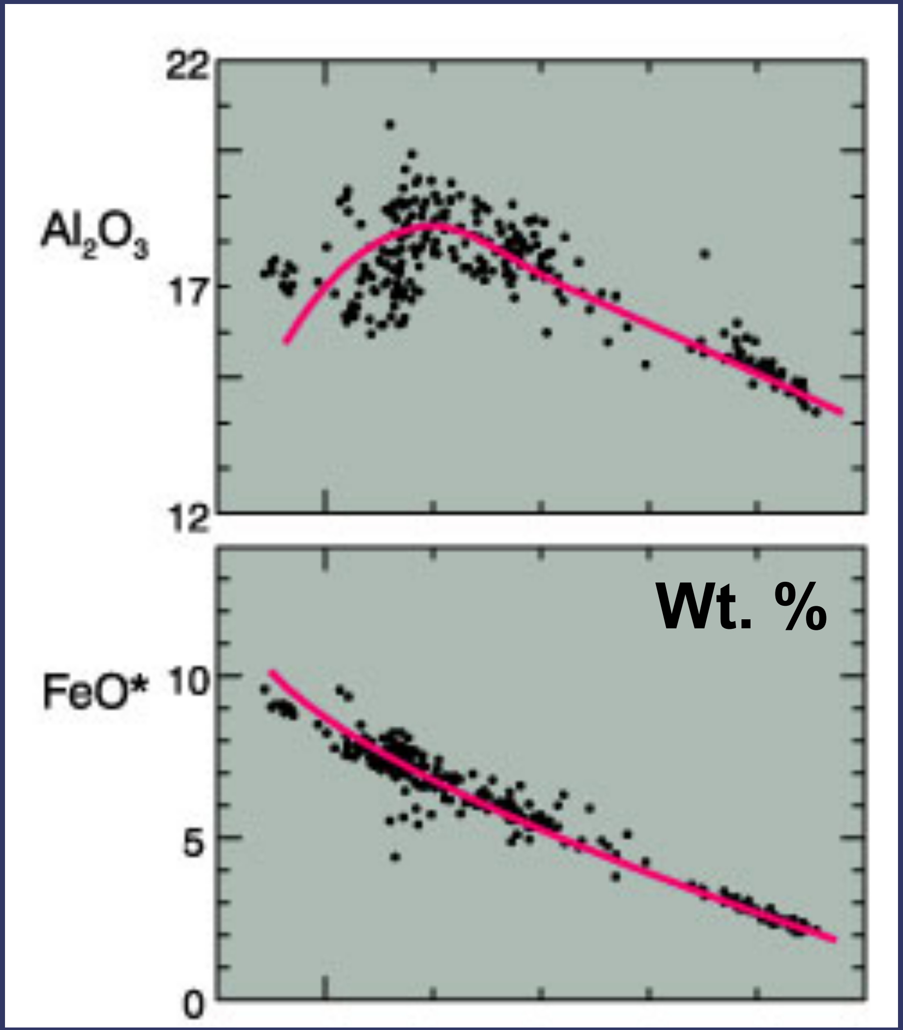
Trace elements

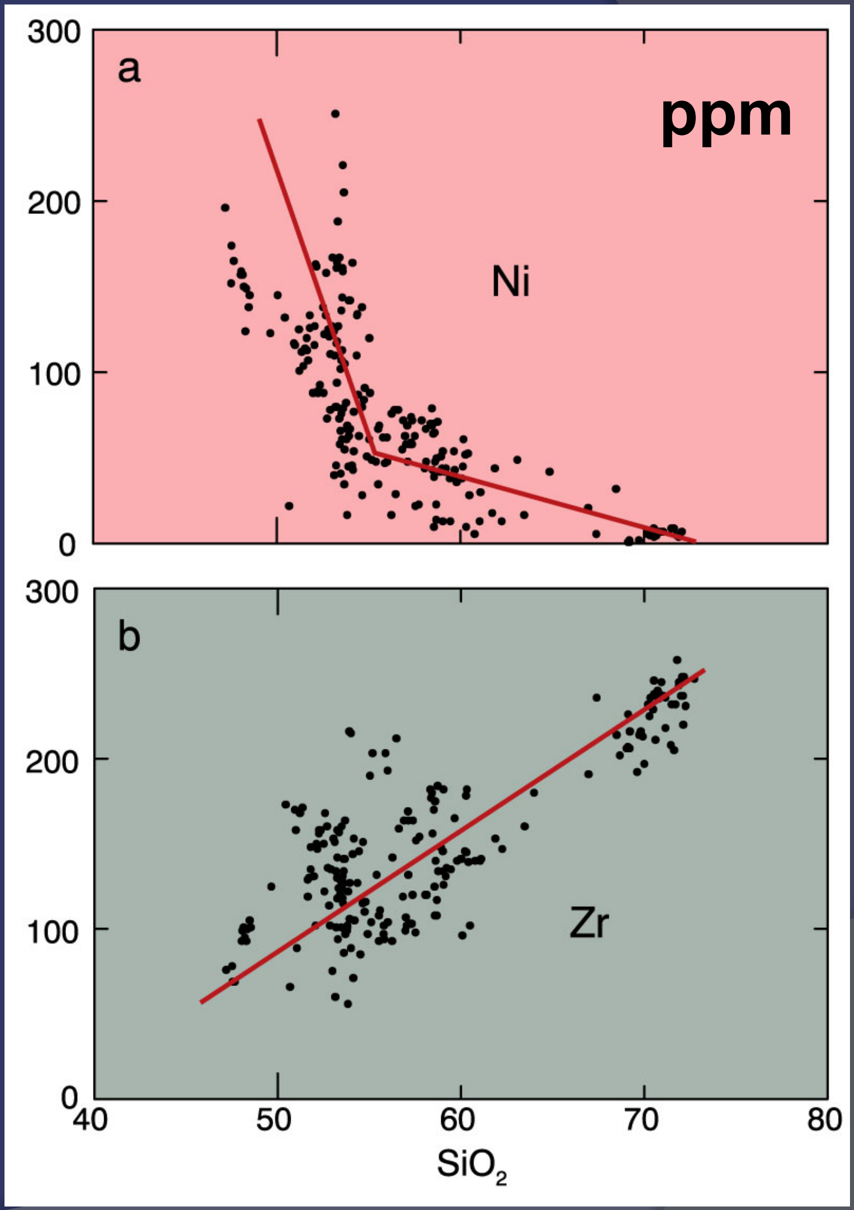
- Why do we care? They can be used as tracers of the source AND of the process.





Trace elements





Wt%: 10^{-2} vs. ppm: 10^{-6}

Element distribution

Goldschmidt's rules:
#1 - 2 ions with the same valence and **radius** should exchange easily and enter a solid solution in amounts equal to their overall proportions

Ex.: Sr vs Ca

	Olivine	Pyroxene	Plagioclase	Fract. Factor
SiO2	35%	52%	60%	≈2
MgO	45%	20%	0.20%	≈10
Sr	0.3 ppm	20 ppm	300 ppm	≈1000

Batch melting

C_0: Bulk composition
C_L: liquid composition
C_S: solid composition
F: melt fraction
Bulk D = C_S/C_L
$C_0 = F*C_L + (1-F)*C_S$
$C_0 = C_L(F+(1-F)D)$

$C_L/C_0 = 1/(F + D(1-F))$

Melting and crystallization processes

Batch melt: $C_L/C_0 = 1/(F + D(1-F))$
Instantaneous melt: $C_L/C_0 = (1/D)(1-F)^{((1/D)-1)}$

Fractional crystallization:

Liquid: $C_L/C_0 = F^{(D-1)}$
Instantaneous solid: $C_S/C_0 = DF^{(D-1)}$
Total solid: $C_{TS}/C_0 = (1-F)^{(D-1)}$

How to calculate “Bulk D”?
$D = \sum D_i X_i$

Example for Batch Melting

$C_L/C_0 = 1/(F + D(1-F))$

	Olivine	Opx	Cpx	Plg	Bulk D
Mode	60	25	13	2	
D^{Rb}	0.00018	0.0006	0.001	0.03	0.000988
D^{Ni}	20	11	6	0.1	14.7516

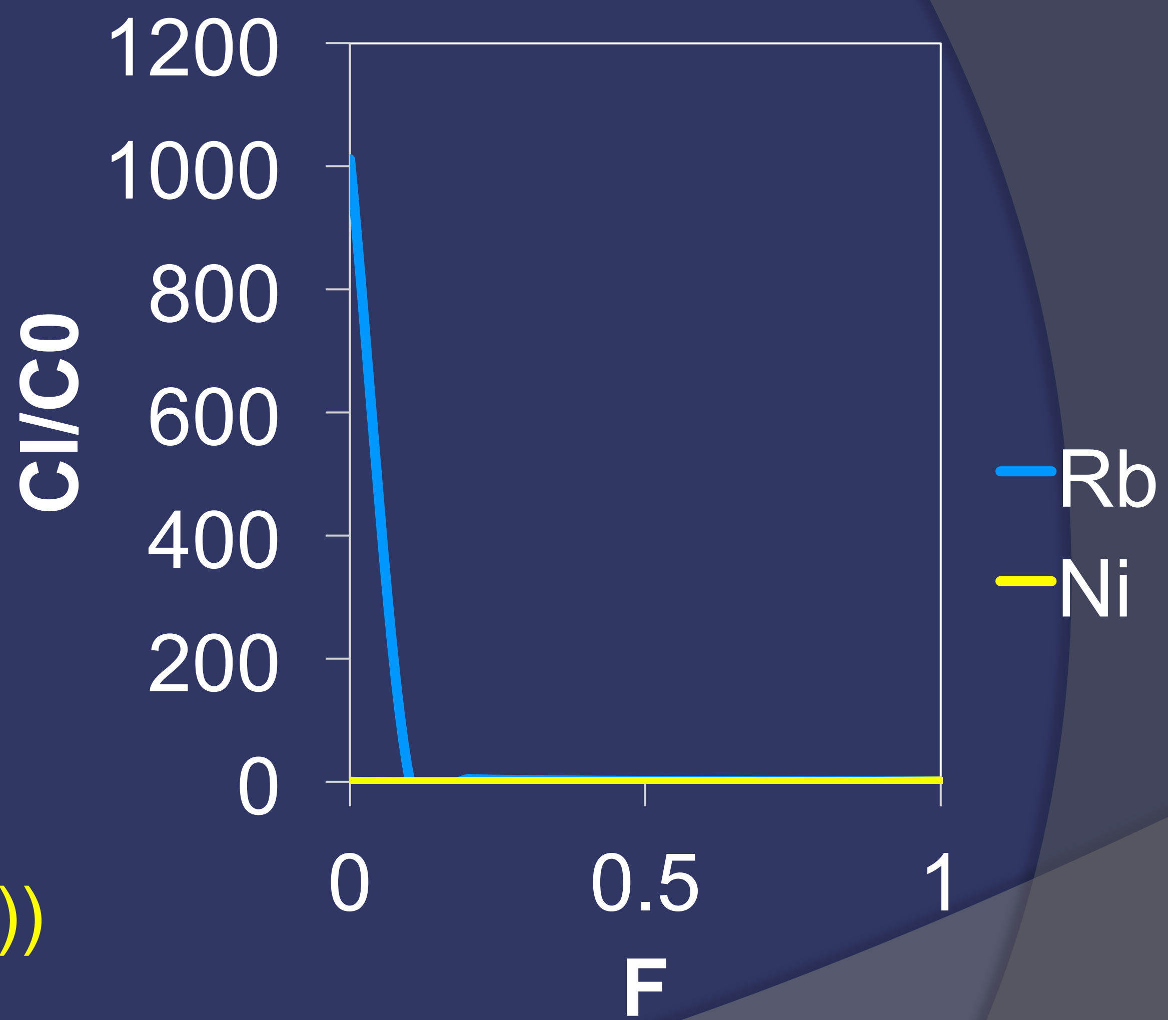
$D = \sum D_i X_i$

$D^{Rb} = 0.6D^{Rb}_{ol} + 0.25D^{Rb}_{opx} + 0.13D^{Rb}_{cpx} + 0.03D^{Rb}plg$

Example for Batch Melting

F	CL/C0(Rb)	CL/C0 (Ni)
0	1012.15	0.07
0.1	9.91	0.07
0.2	4.98	0.08
0.3	3.33	0.09
0.4	2.50	0.11
0.5	2.00	0.13
0.6	1.67	0.15
0.7	1.43	0.20
0.8	1.25	0.27
0.9	1.11	0.42
1	1.00	1.00

$C_L/C_0 = 1/(F + D(1-F))$



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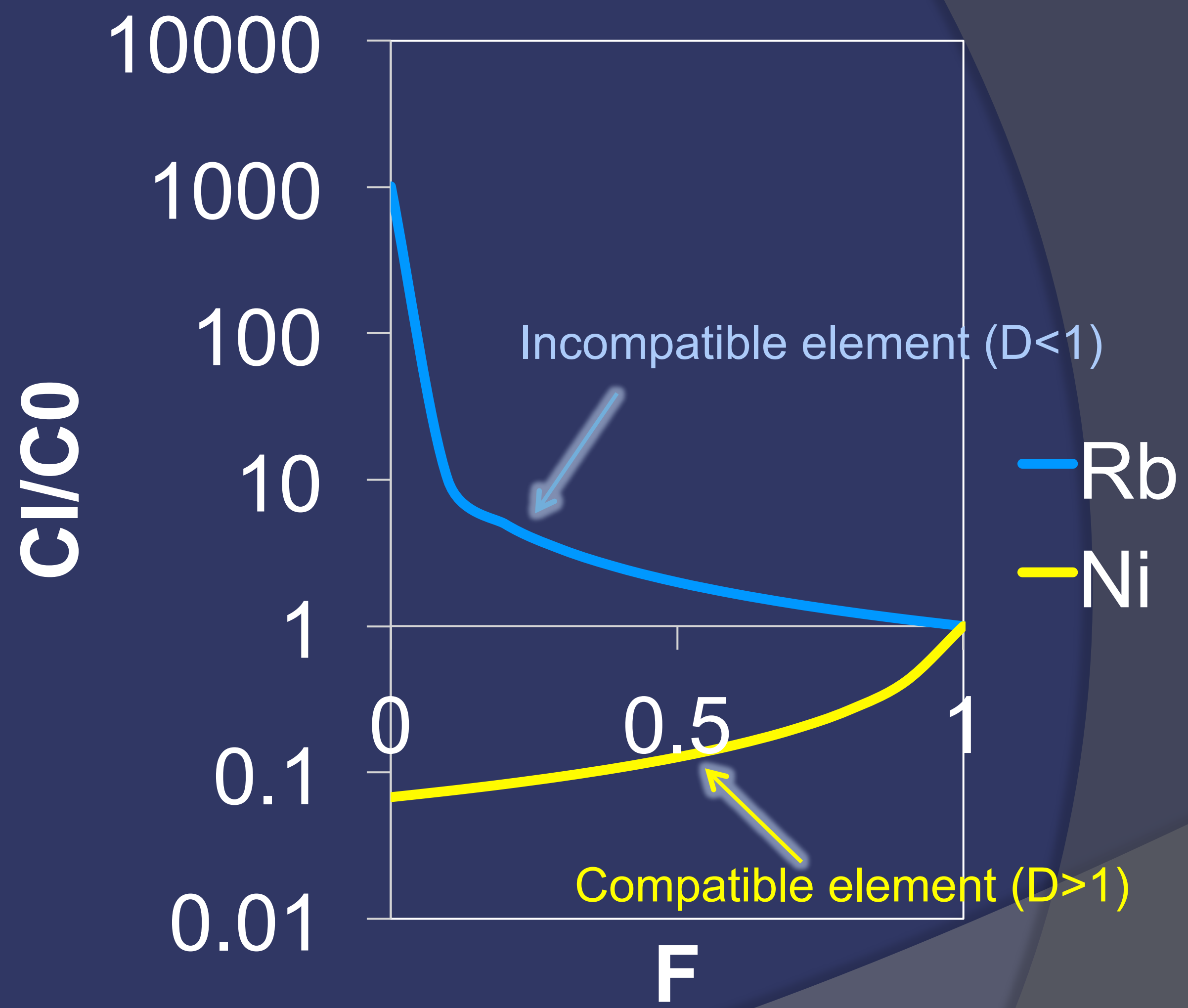

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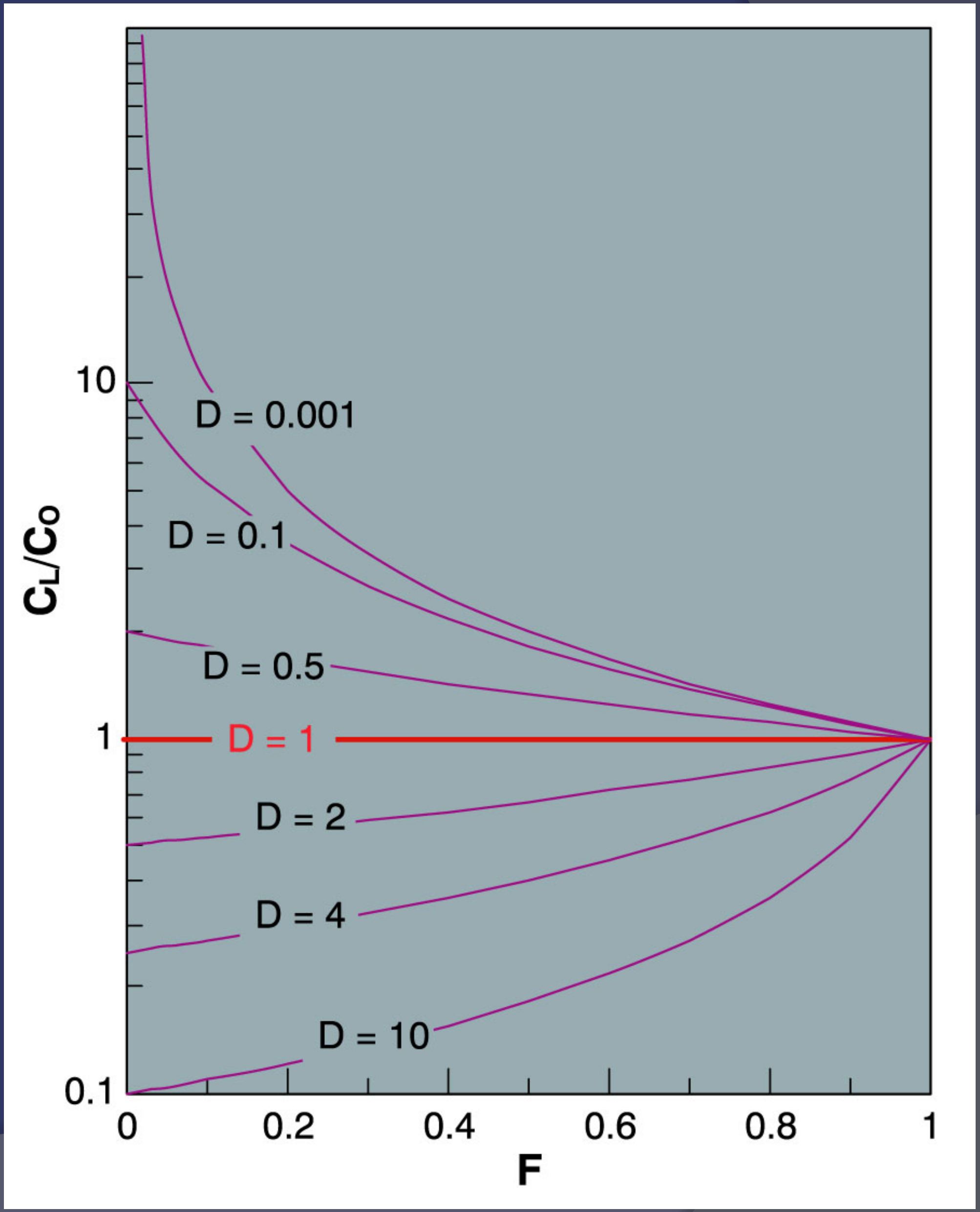
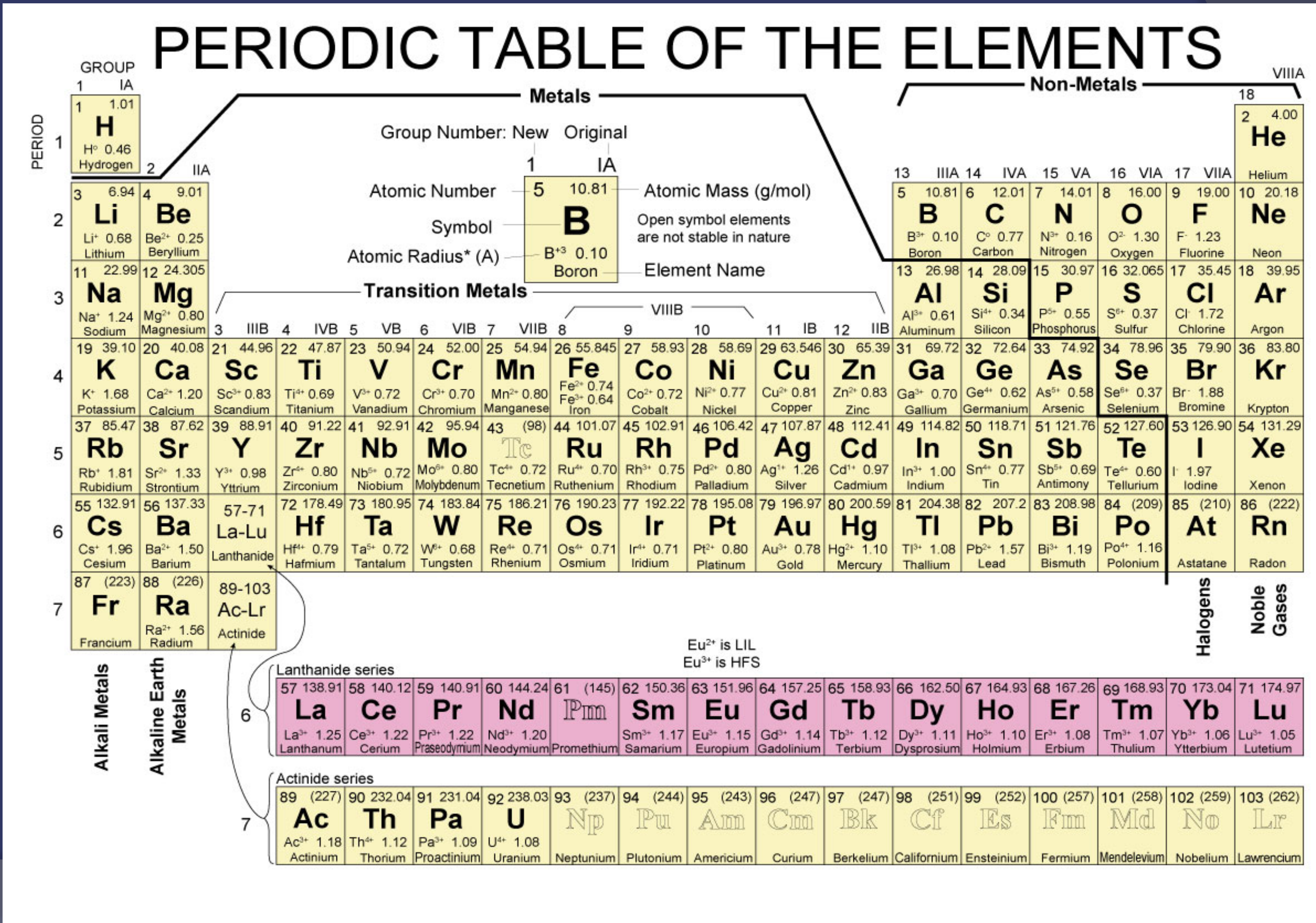


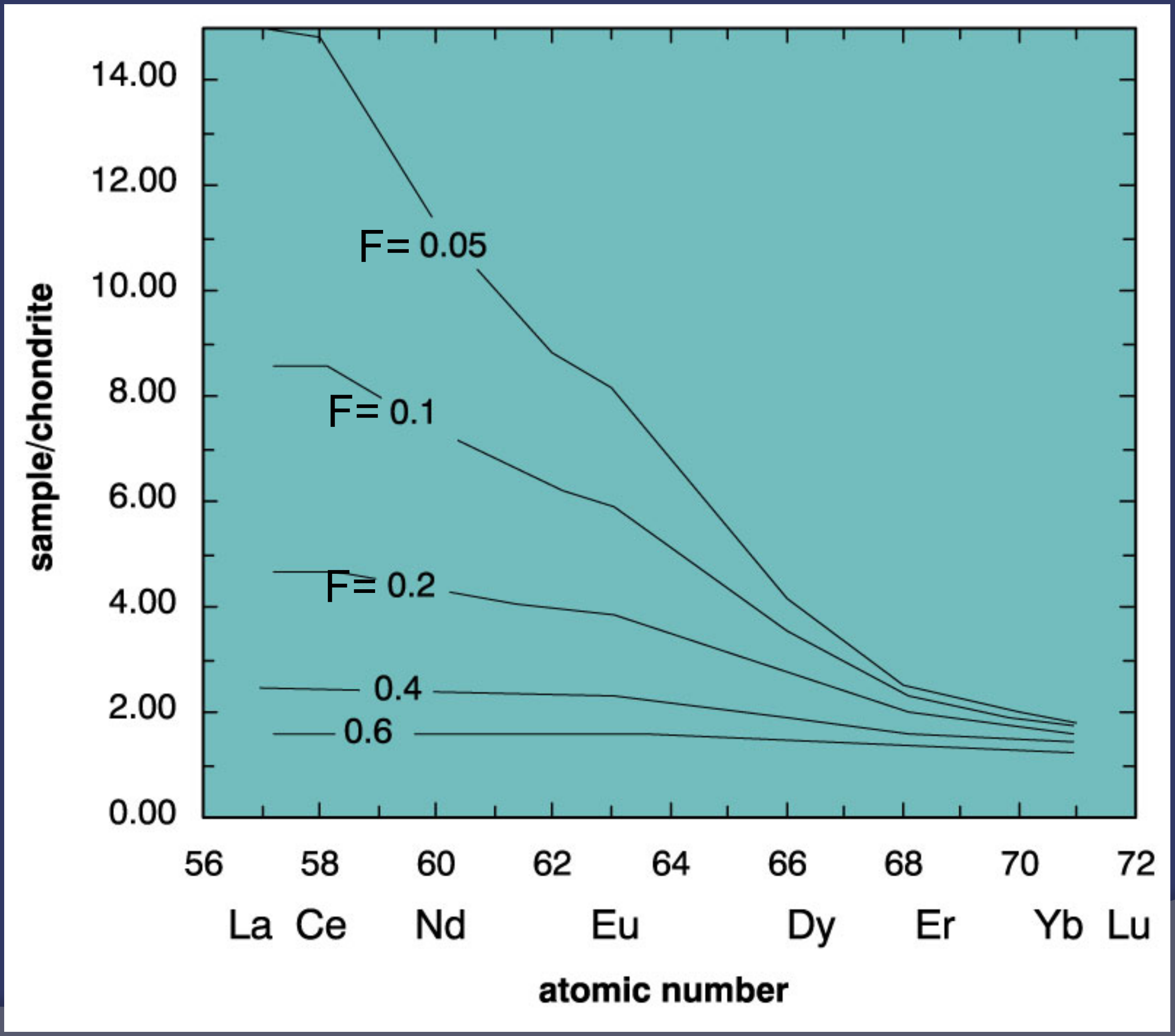
Fig. 9.2 in Winters

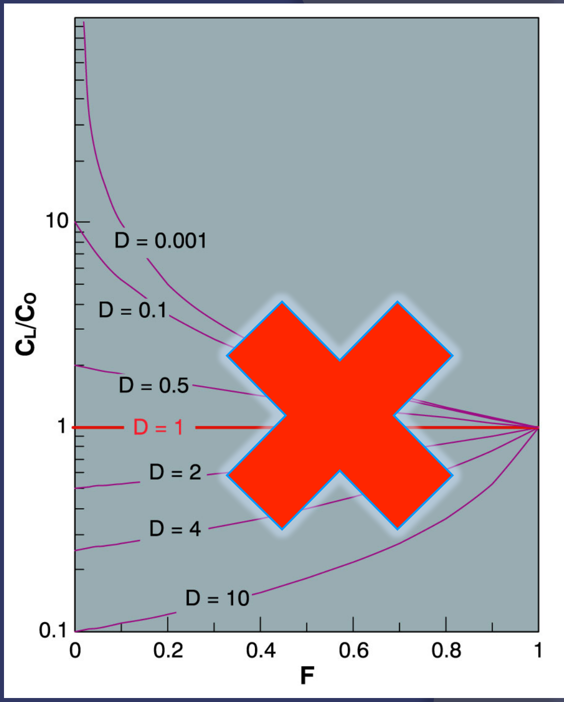
Rare Earth Elements (REE)



Rare Earth Elements (REE)

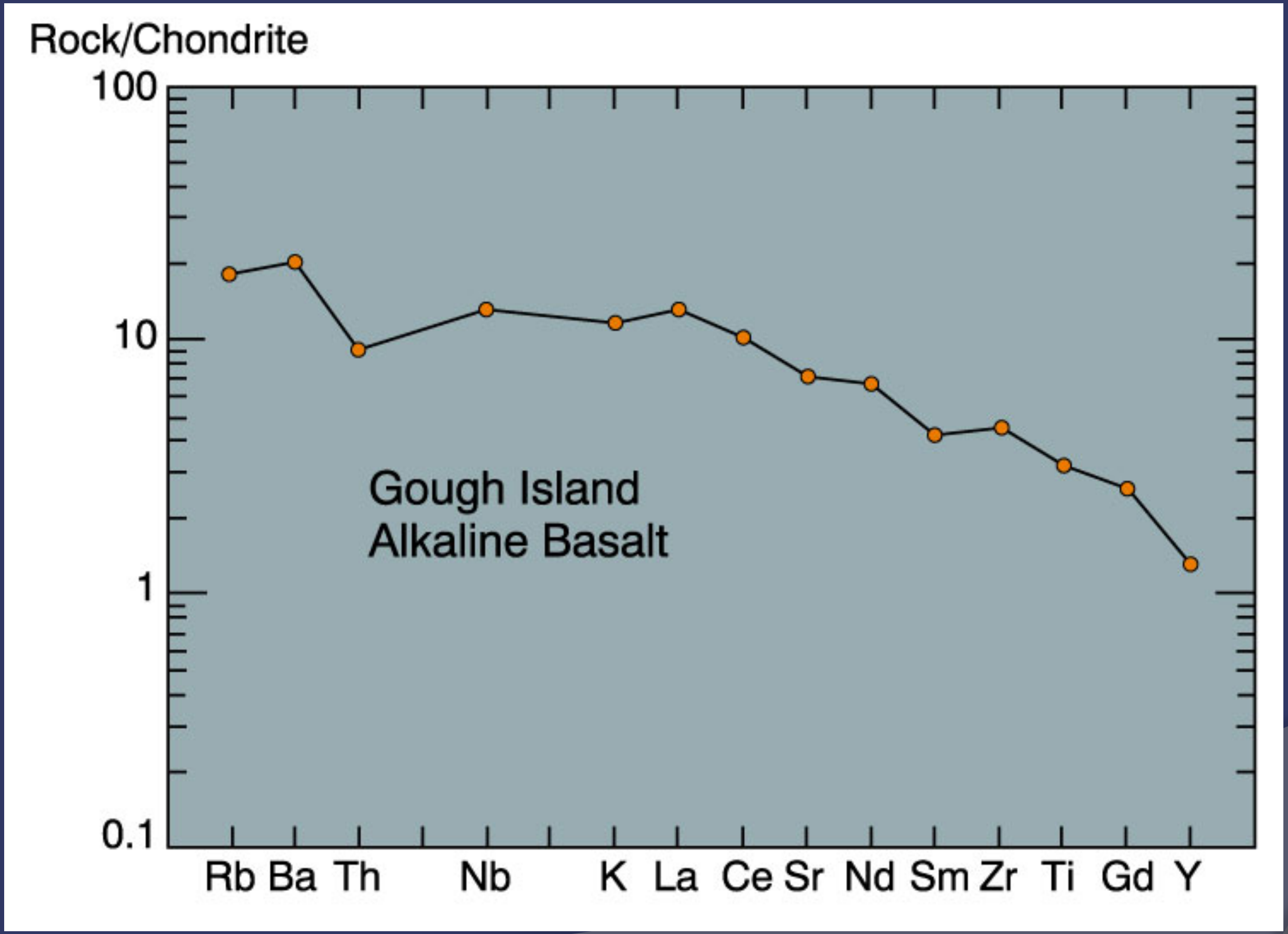
Fig. 9.4 in Winters



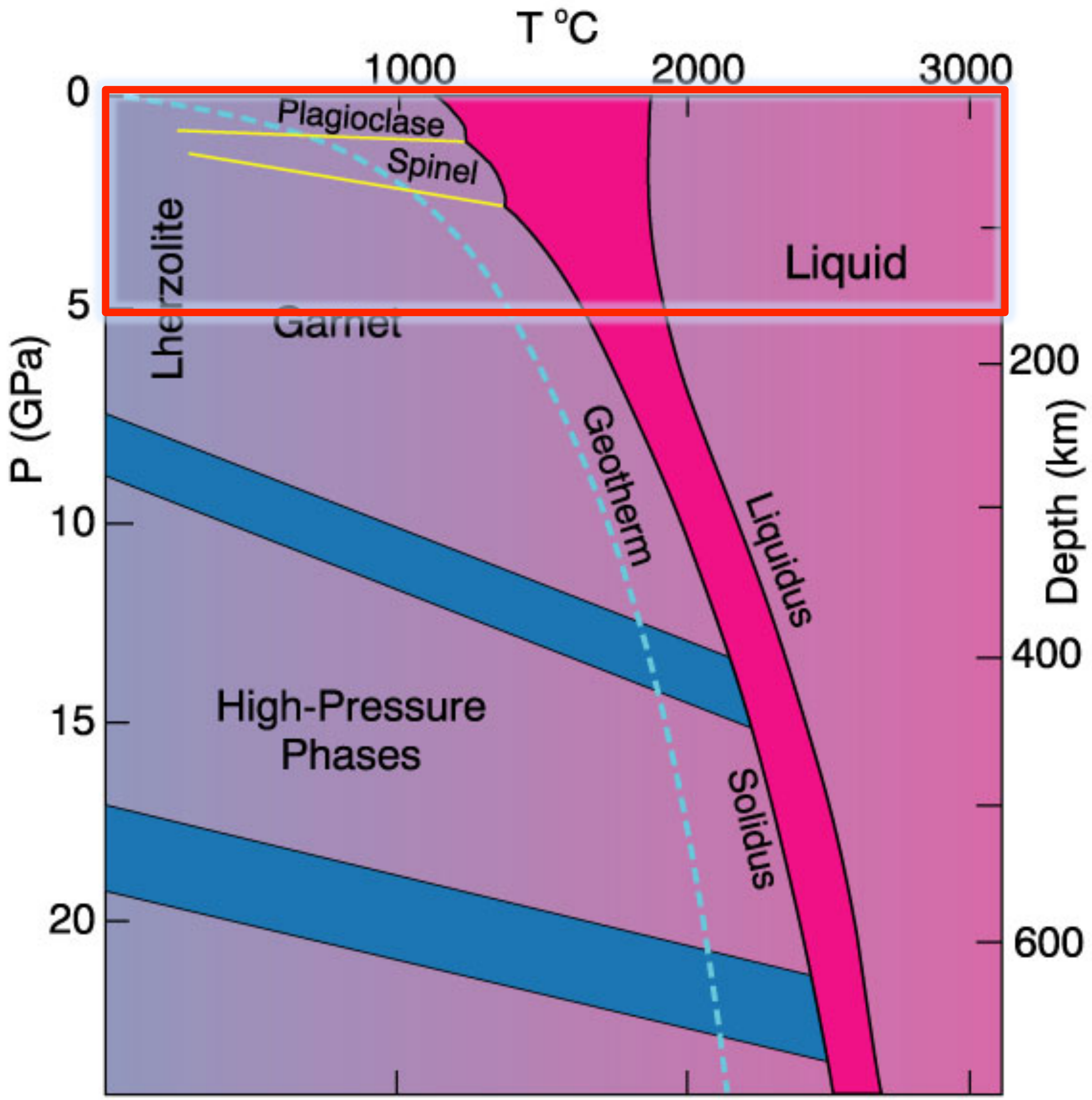


Spider diagram (multielement)

Fig. 9.6 in Winters



Application to igneous processes

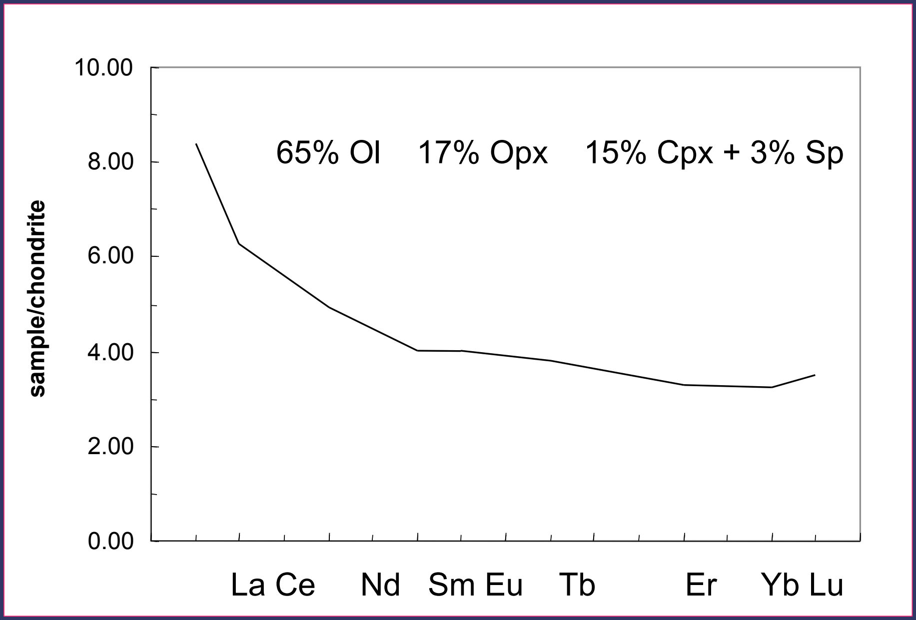


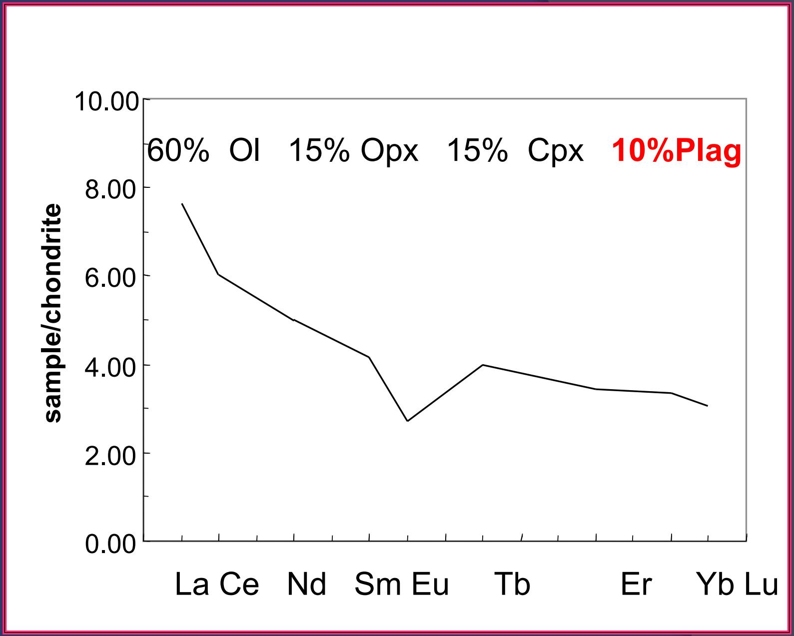
Identification of the source rock

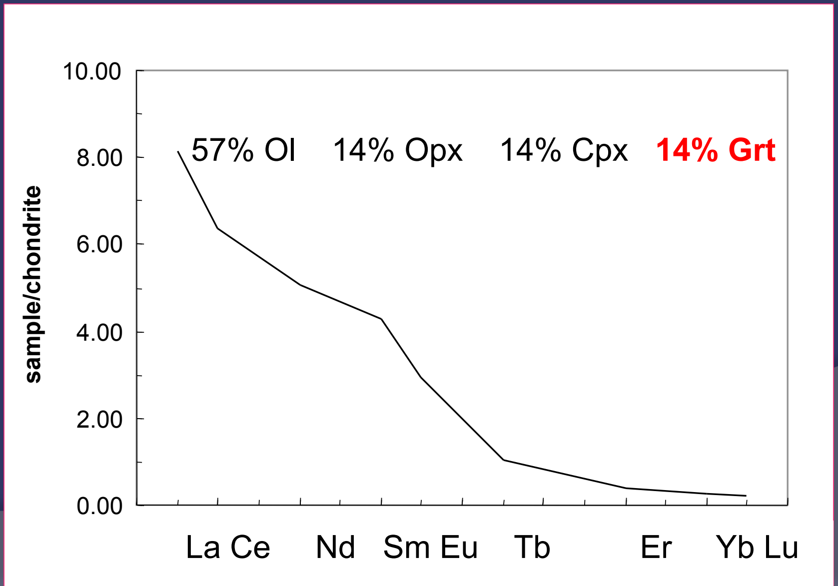
Plagioclase: Eu (MREE) is strongly compatible
$D_{Eu}^{plg} = 1.5$

Garnet: HREE are compatible
$D_{Yb}^{gt} = 11.5$

Identification of the source rock



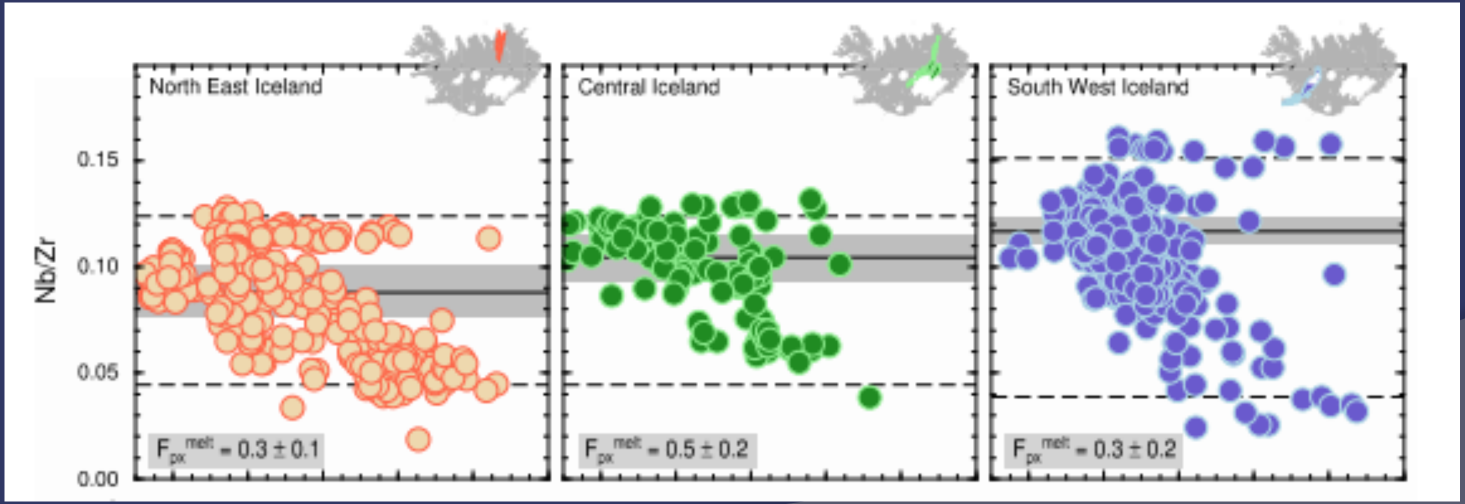




Identification of the source rock

$C_L/C_0 = 1/(F + D(1-F))$

- $D = 1 \Leftrightarrow C_0 = C_L$
- Assuming $D = 0 \quad \Leftrightarrow C_0 = F * C_L$
- Ratio of 2 elements with similar D: C_{L1}/C_{L2}
  $\Leftrightarrow$ Ratio in source



Shorttle et al., 2014, EPSL 395

NEXT TIME

Isotopes

TO READ:

Chapters 9

FIGURE PRESENTATION