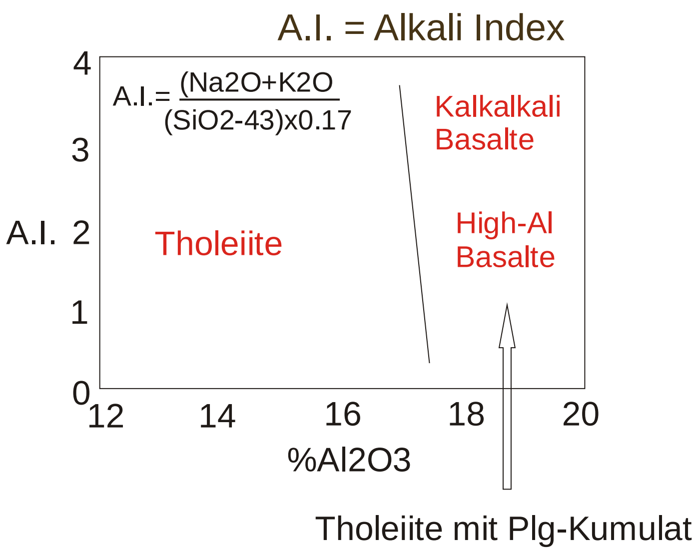
The major element chemistry of MORBs

A “typical” MORB is an olivine tholeiite with low K_2O (< 0.2%) and low TiO_2 (< 2.0%)



Glass samples are very important chemically, because they represent *liquid* compositions, whereas the chemistry of phyric samples can be modified by crystal accumulation

Average Analyses and CIPW Norms of MORBs (BVTP Table 1.2.5.2)

Oxide (wt%)	All	MAR	EPR	IOR
SiO_2	50.5	50.7	50.2	50.9
TiO_2	1.56	1.49	1.77	1.19
Al_2O_3	15.3	15.6	14.9	15.2
FeO*	10.5	9.85	11.3	10.3
MgO	7.47	7.69	7.10	7.69
CaO	11.5	11.4	11.4	11.8
Na_2O	2.62	2.66	2.66	2.32
K_2O	0.16	0.17	0.16	0.14
P_2O_5	0.13	0.12	0.14	0.10
Total	99.74	99.68	99.63	99.64
Norm				
q	0.94	0.76	0.93	1.60
or	0.95	1.0	0.95	0.83
ab	22.17	22.51	22.51	19.64
an	29.44	30.13	28.14	30.53
di	21.62	20.84	22.5	22.38
hy	17.19	17.32	16.53	18.62
ol	0.0	0.0	0.0	0.0
mt	4.44	4.34	4.74	3.90
il	2.96	2.83	3.36	2.26
ap	0.30	0.28	0.32	0.23

All: Ave of glasses from Atlantic, Pacific and Indian Ocean ridges.

MAR: Ave. of MAR glasses. EPR: Ave. of EPR glasses.

IOR: Ave. of Indian Ocean ridge glasses.

The major element chemistry of MORBs

Estimates of Bulk Silicate Earth Composition

	CI Chondrites	CI Chondritic Mantle	Hart & Zindler LOSIMAG	Ringwood Pyrolite	McDonough & Sun Pyrolite	Allegre et al. PRIMA
SiO_2	22.77	49.52	45.96	44.76	45.0	46.12
Al_2O_3	1.64	3.56	4.06	4.46	4.45	4.09
FeO	24.49	7.14	7.54	8.43	8.05	7.49
MgO	16.41	35.68	37.78	37.23	37.8	37.77
CaO	1.30	2.82	3.21	3.60	3.55	3.23
Na_2O	0.67	1.457	0.332	0.61	0.36	0.36
K_2O	0.067	0.146	0.032	0.029	0.029	0.034
Cr_2O_3	0.39	0.412	0.468	0.43	0.384	0.38
MnO	0.256	0.557	0.130	0.14	0.135	0.149
TiO_2	0.073	0.159	0.181	0.21	0.20	0.18
NiO	1.39	0.244	0.277	0.241	0.25	0.25
CoO	0.064	0.012	0.013	0.013	0.013	0.07
P_2O_5	0.274	0.018	0.019	0.015	0.021	
Sum	69.79	100.0	100.0			

The major element chemistry of MORBs

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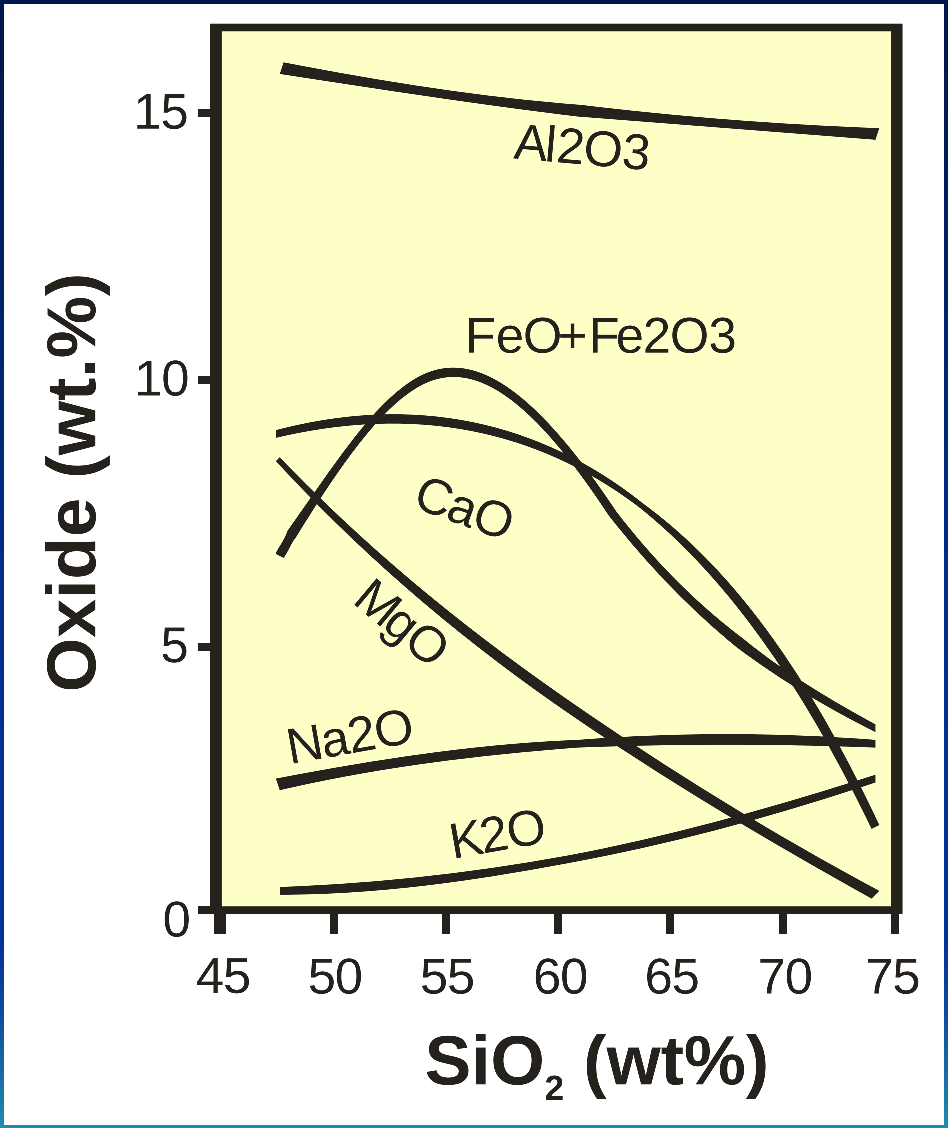
“Harker-type” variation diagrams for MORB



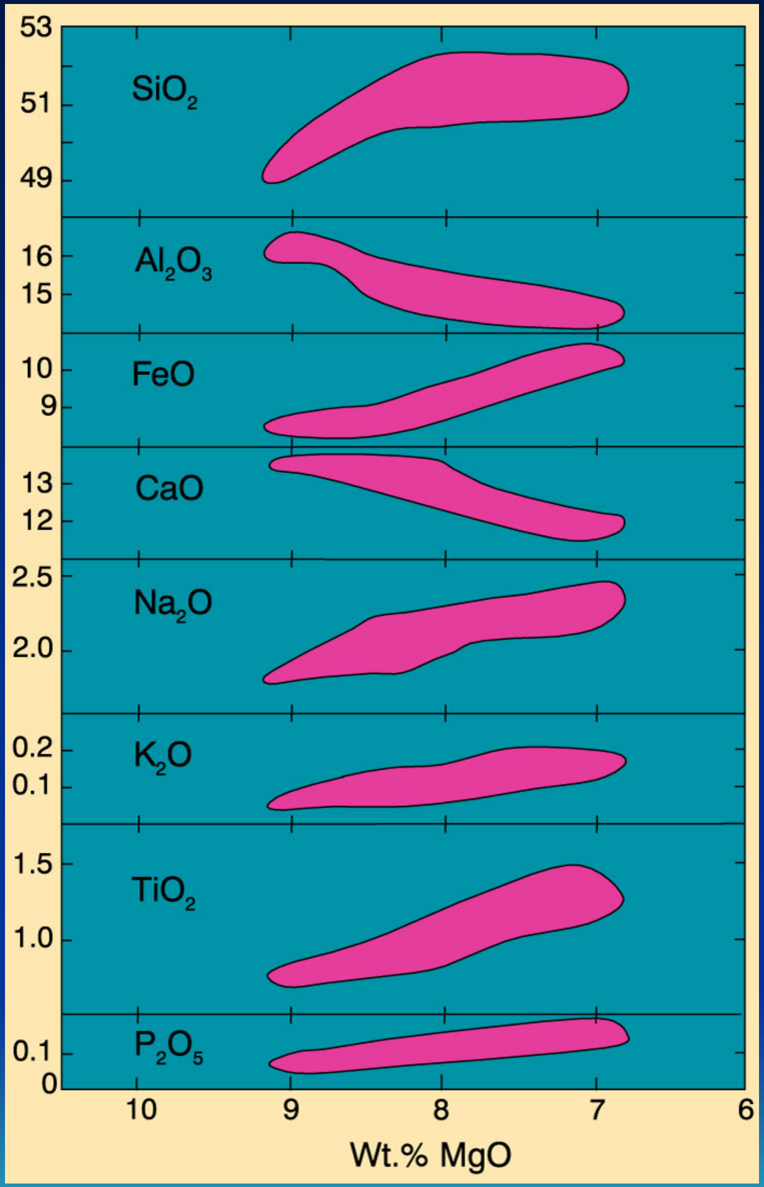
SiO_2 is a ~ poor fractionation index for MORB

"Fenner-type" variation diagrams for MORB

Decrease in MgO and relative increase in FeO $\rightarrow$ early differentiation trend of tholeiites

Patterns are compatible with crystal fractionation of the observed phenocryst phases

Separation of a calcic plagioclase can cause Al_2O_3 and CaO to decrease



Stakes et al. (1984)

Conclusions about MORBs, and the processes beneath mid-ocean ridges

MORBs are not the completely uniform magmas that they were once considered to be

They show chemical trends consistent with fractional crystallization of olivine, plagioclase, and clinopyroxene

MORBs cannot be primary magmas, but are derivative magmas resulting from fractional crystallization (~ 40-60%)

Background for trace element modeling

*Partial melting of Earth's mantle and crystal fractionation within a magma causes **fractionation** of trace elements.*

The amount of fractionation can be calculated for a given element if partition coefficients and mineral proportions of the residue/crystallizing assemblage are known and if an assumption is made about the style of melting (e.g., batch melting, fractional melting, etc.) and fractionation.

In this exercise we will assume that melting occurs by batch melting and the fractional crystallization is accomplished by Rayleigh crystal fractionation.

Terminology

- *trace element partitioning*
- *partition coefficient*
- *bulk partition coefficient*
- *batch melting*
- *crystal fractionation (=fractional crystallization)*
- *compatible, incompatible*
- *REE pattern*
- *differentiation*
- *fractionation*

Distribution coefficient

$$D = C_S / C_L$$

D = partition coefficient
C_S = concentration of the element in the solid (i.e. residuals)
C_L = concentration of the element in the liquid (i.e. melt)

Distribution Coefficients are determined:

1) Experimentally

2) Natural Systems (phenocryst/glass)

Compatible element: $D > 1$
Incompatible element: $D < 1$

Bulk partition coefficient

$$\bar{D}_i = \sum X_A D_i^A$$

$\bar{D}_i$ = bulk partition coefficient for element i

X_A = weight fraction of mineral A in the rock

D_i^A = partition coefficient for element i in mineral A

$X_{plag}=0.5$ $X_{cpx}=0.5$ $D^{plag/L}=4$ $D^{cpx/L}=0.2$

Bulk Partition Coefficient D

$$= \sum X \cdot D = 0.5 \times 4 + 0.5 \times 0.2 = 2 + 0.1 = 2.1$$

Batch melting modeling

Batch Melting is the melting process whereby the liquid remains in equilibrium with the residue until the liquid is removed.

$C_L/C_0 = 1/[D_S + F(1 - D_S]$ bzw. $$\frac{C_L}{C_o} = \frac{1}{\bar{D}*(1-F)+F}$$

$C_S/C_0 = D_S/[D_S + F(1 – D_S)]$

C_o = concentration of the element in the starting material (in the case of mantle melting, the concentration in the original mantle).
C_S = concentration of the element in the solid (i.e. residuals)
C_L = concentration of the element in the liquid (i.e. melt)
D_S = bulk partition coefficient for the residual mantle
F = weight fraction of melt produced [= melt/(melt + rock)]

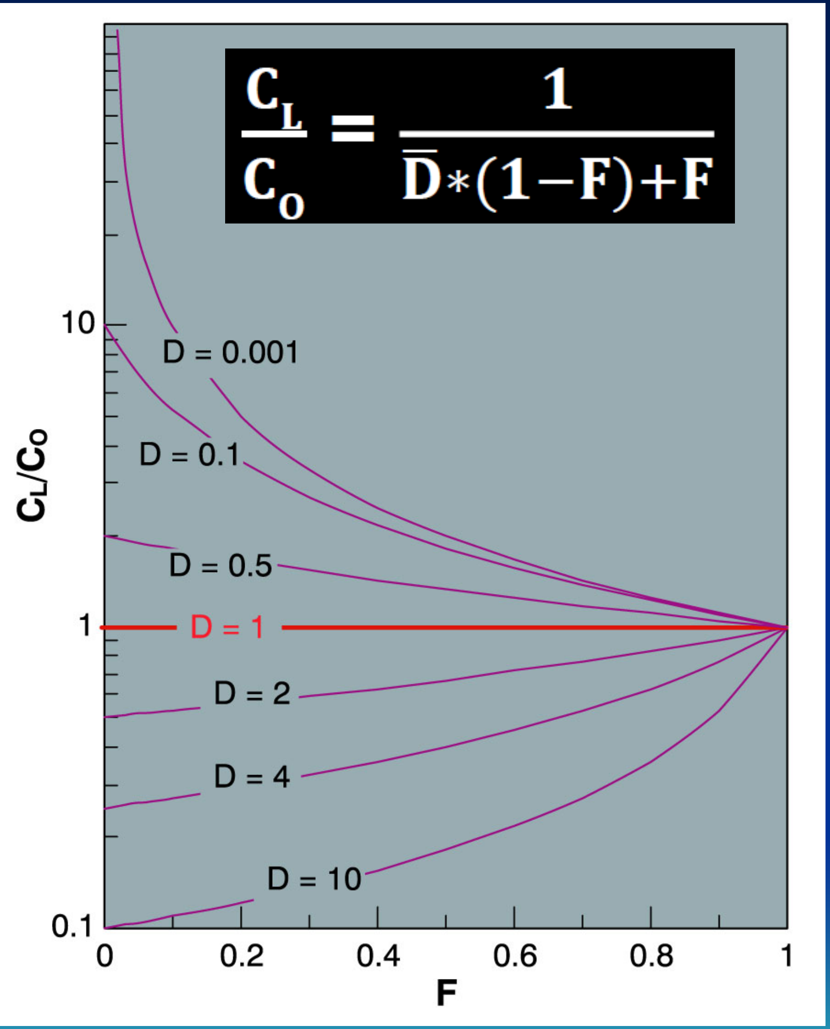
Batch melting modeling

Batch melting

At low degrees of melt incompatible elements are concentrated and compatible elements are diluted

For an incompatible element, enrichment is simply related to degree of melting

When F = 1
C_L/C_O = 1
i.e. total fusion

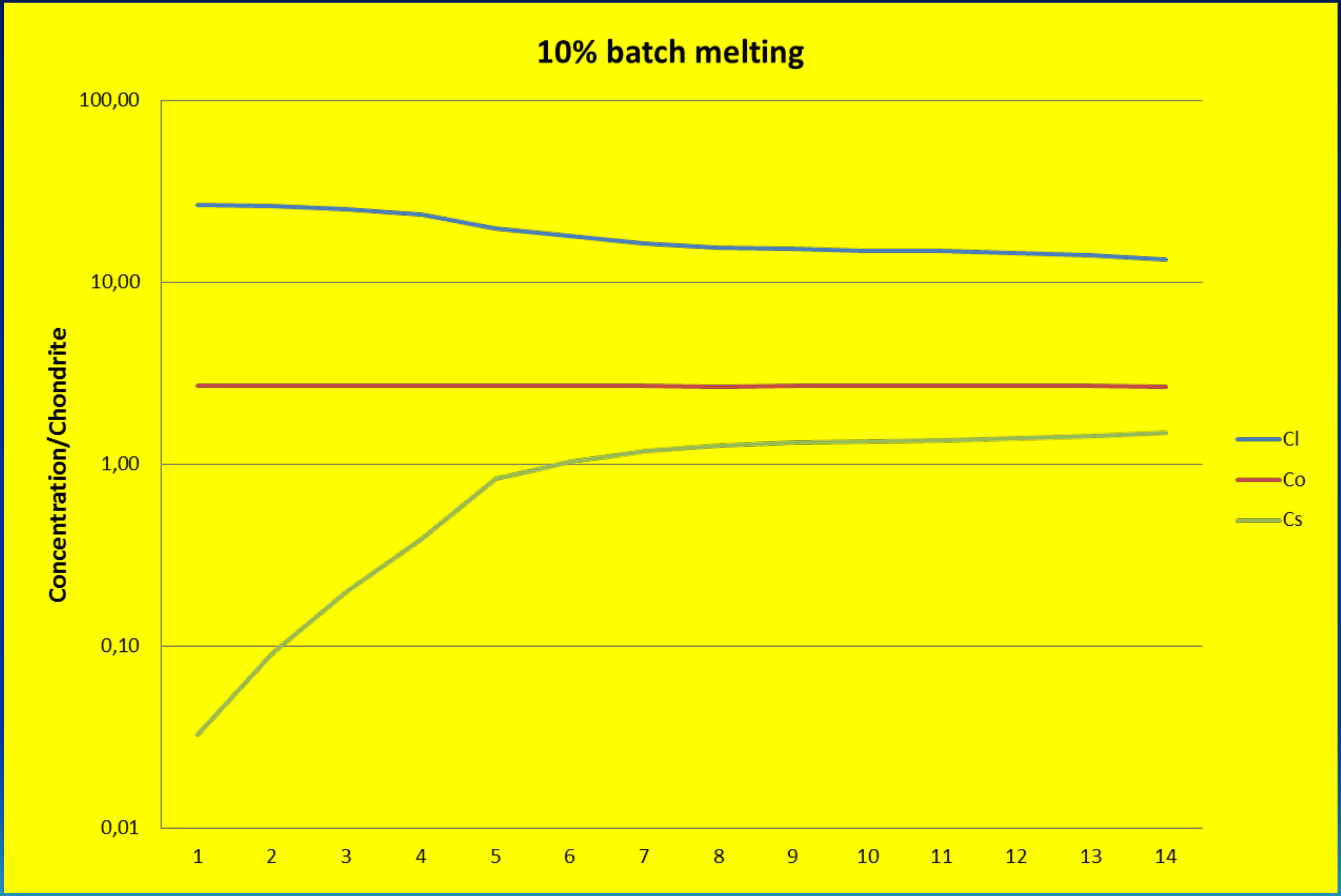


From Winter (2001) An Introduction to Igneous and Metamorphic Petrology

Data for batch melting modeling

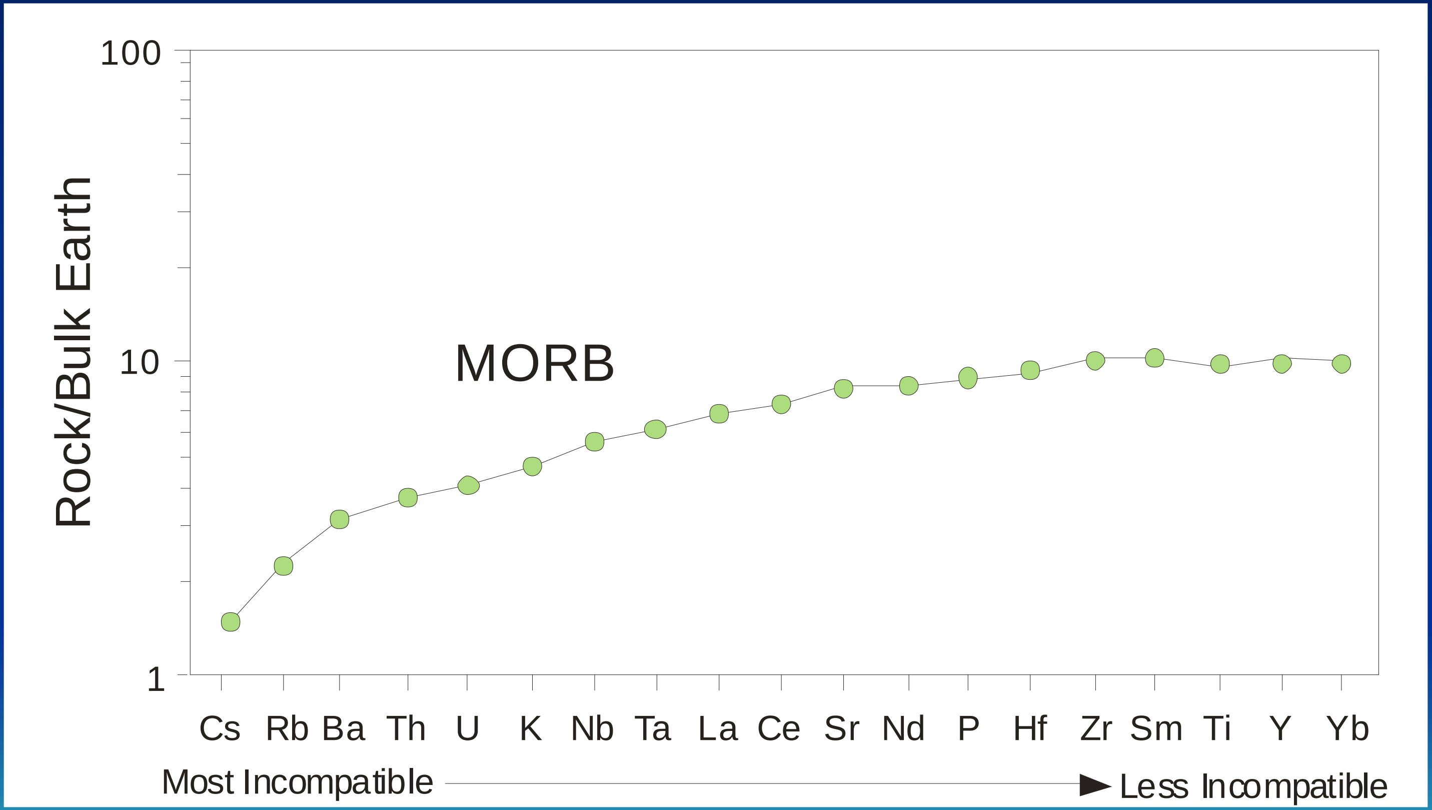
D-values	Cpx	Opx	Ol	Plag	Chondrite	Co
Residue Proportion	10%	20%	70%		ppm	ppm
La	0.01	0.00017	0.0001	0.217	0.237	0.640
Ce	0.03	0.00026	0.00015	0.166	0.613	1.655
Pr	0.07	0.0004	0.0002	0.152	0.0928	0.251
Nd	0.15	0.0006	0.00025	0.138	0.457	1.234
Pm						
Sm	0.4	0.00077	0.0003	0.124	0.148	0.400
Eu	0.55	0.001	0.00035	0.183	0.0563	0.152
Gd	0.7	0.0011	0.0004	0.095	0.199	0.537
Tb	0.8	0.0012	0.00045	0.0838	0.0361	0.097
Dy	0.85	0.0015	0.0005	0.0781	0.246	0.664
Ho	0.89	0.002	0.00055	0.0725	0.0546	0.147
Er	0.9	0.0025	0.0006	0.0669	0.16	0.432
Tm	0.95	0.003	0.00065	0.0613	0.0247	0.067
Yb	1	0.0035	0.0007	0.0556	0.161	0.435
Lu	1.1	0.004	0.00075	0.05	0.0246	0.066

Batch melting modeling



Trace Elements

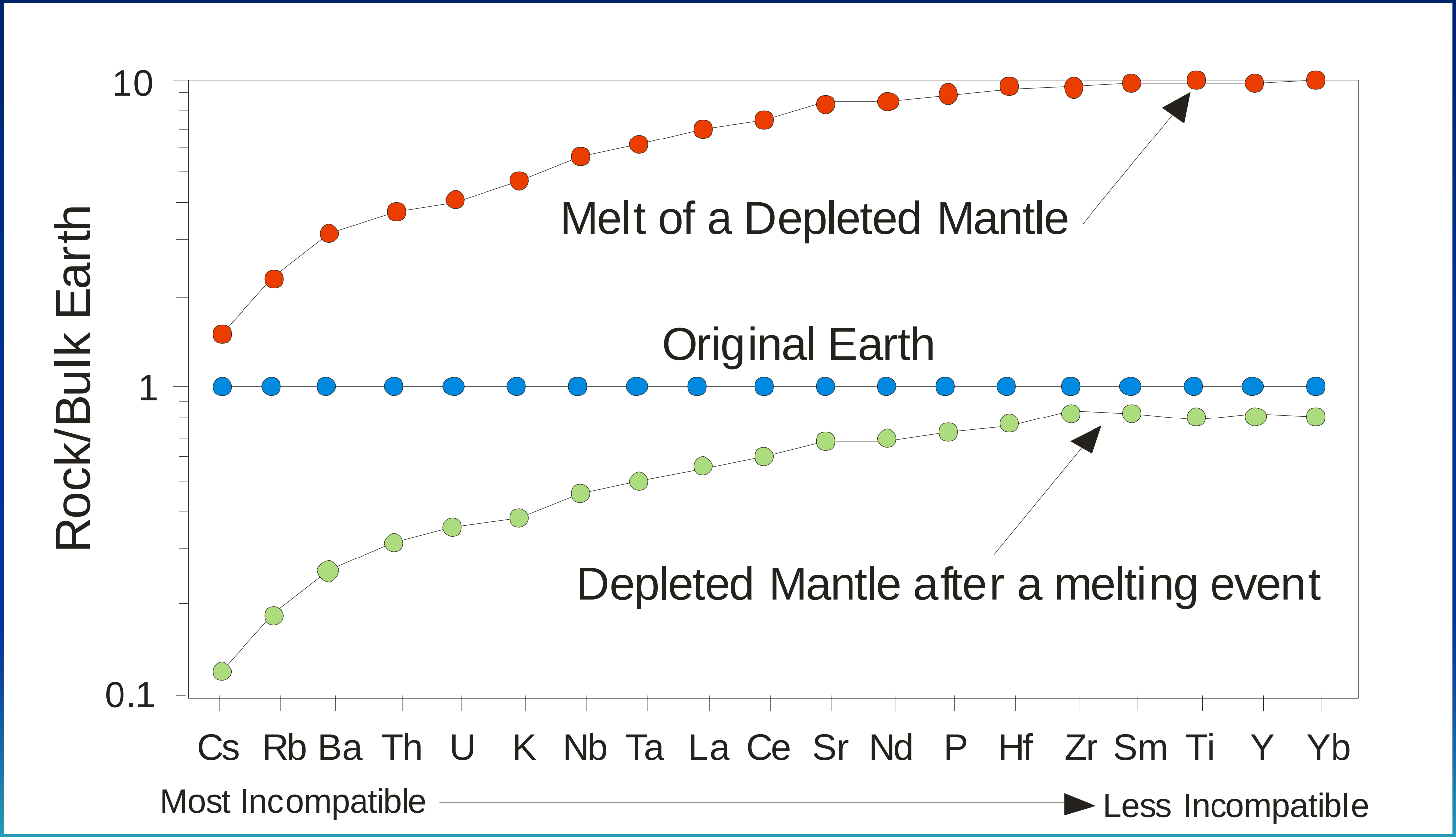
Multi element diagram for MORBs



Trace Elements

Petrogenesis of MORBs

Melting of the mantle:
Incompatible: K, Rb, Cs, Ta, Nb, U, Th, Y, Hf, Zr, LREEs
Compatible: Ni, Cr, Co, V, Sc



Concentration of incompatible elements in the melt decreases with increasing degree of melting

More conclusions about MORBs, and the processes beneath mid-ocean ridges

MORBs which show a depletion in most incompatible elements likely formed by melting of a depleted mantle – mantle that had suffered a melting event sometime in the past

Because the MORB pattern is nearly parallel to the depleted mantle, the degree of melting required to produce such MORBs must have been high (20-40%)