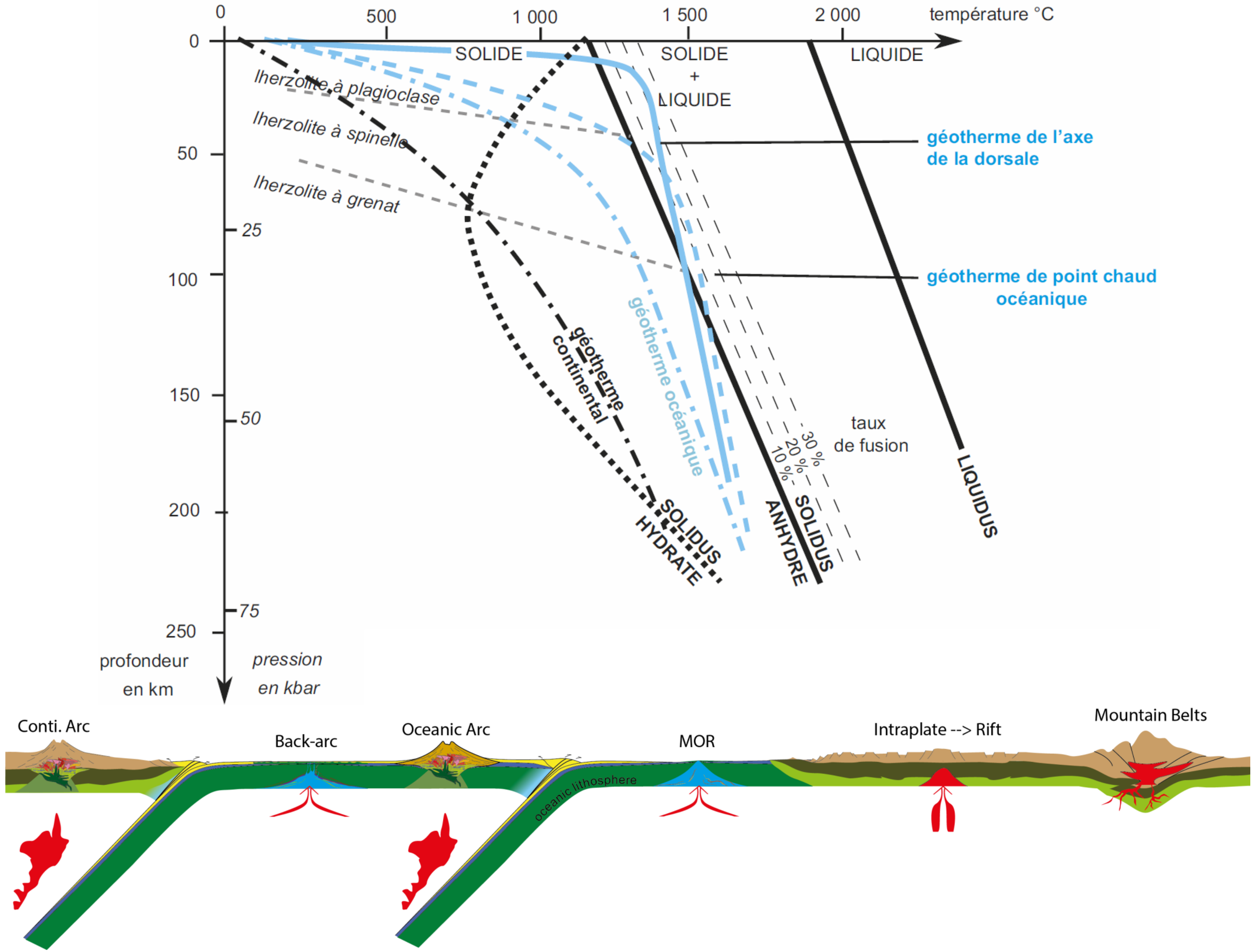
Les Basaltes

- Magma: Définition (s)
- Basaltes: classification → 3 grands groupes
- Notion de série
- Historique / Petro experimentale, diagrammes d'équilibre→ Origine des 3 grpes
- Evolution des basaltes (serie):

Crist Frac \ Melange \ Immiscibilité



0
500
1 000
1 500
2 000
température °C
0
50
100
150
200
250
25
50
75
SOLIDE
SOLIDE
+
LIQUIDE
LIQUIDE
lherzolite à plagioclase
lherzolite à spinelle
lherzolite à grenat
géotherme de l'axe de la dorsale
géotherme de point chaud océanique
géotherme continental
géotherme océanique
taux de fusion
30 %
20 %
10 %
SOLIDUS HYDRATE
ANHYDRE SOLIDUS
LIQUIDUS
profondeur en km
pression en kbar
Conti. Arc
Back-arc
Oceanic Arc
MOR
Intraplate --> Rift
Mountain Belts
oceanic lithosphere

DEFINITION(S)

- **Magma Primaire (primary melt)**

→Magma issue directement de sa source (manteau)

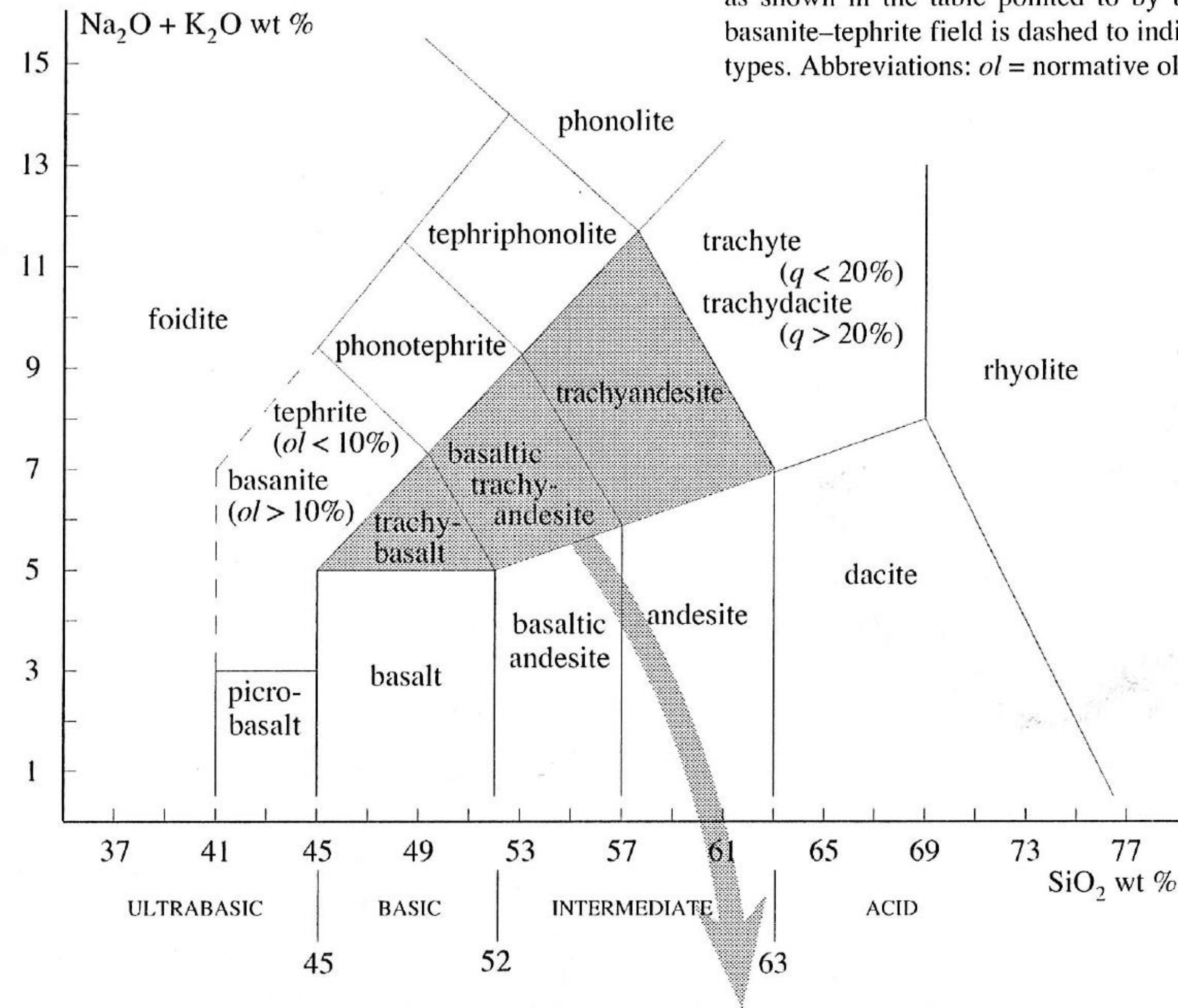
- **Magma Primitif (primitive melt)**

→Magma n’ayant pas (peu) subit d’évolution, le plus mafique d’une série

- **Magma Parent (parental melt)**

→ Celui dont la série découle par évolution

Fig. 2.14. Chemical classification of volcanic rocks using TAS (total alkali–silica diagram) (after Le Bas *et al.*, 1986, Fig. 2). Rocks falling in the shaded areas may be further subdivided as shown in the table pointed to by the arrow. The line between the foidite field and the basanite–tephrite field is dashed to indicate that further criteria must be used to separate these types. Abbreviations: *ol* = normative olivine; *q* = normative 100 * *Q* / (*Q* + *or* + *ab* + *an*).



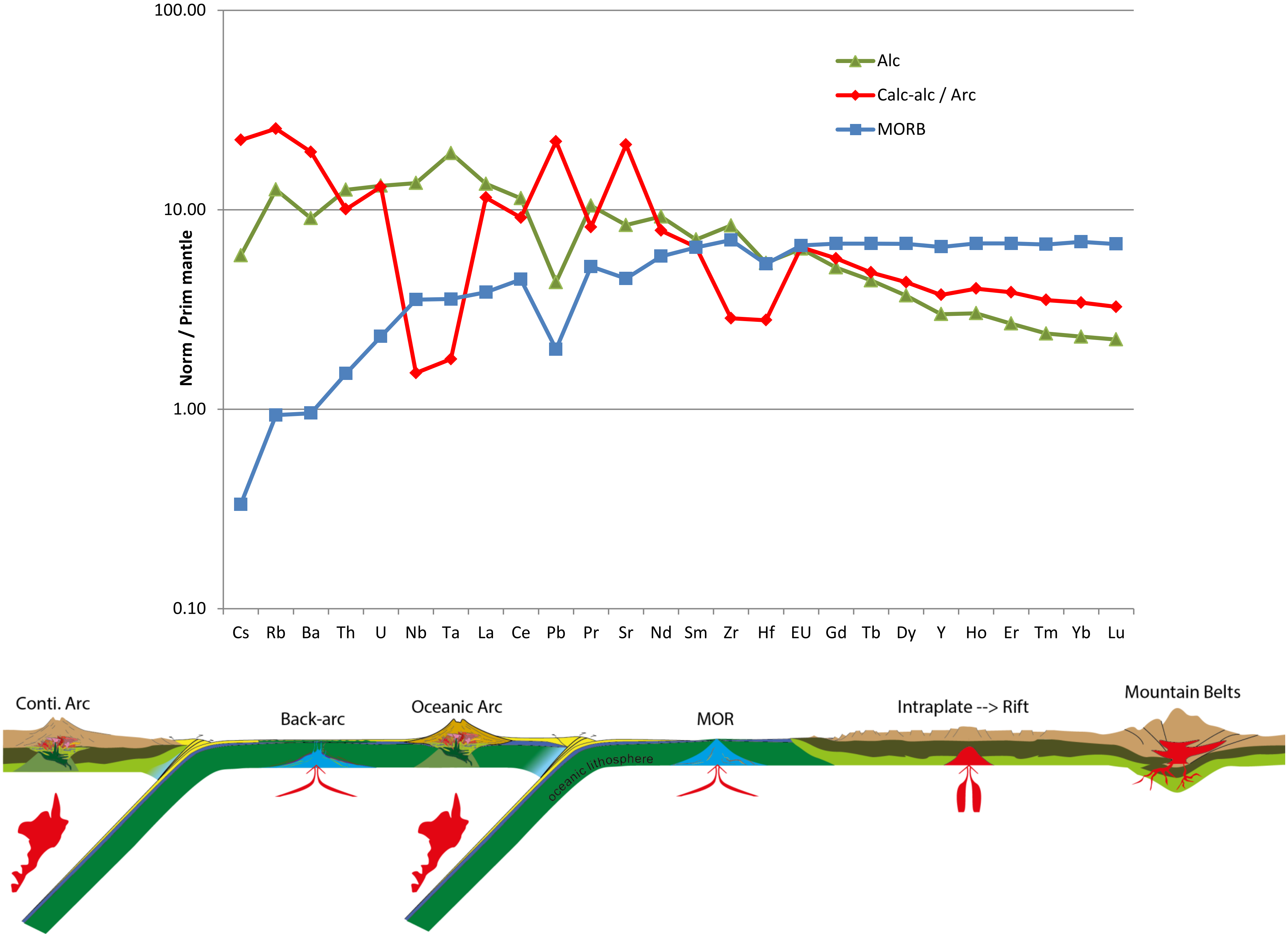
Further subdivisions of shaded fields	trachybasalt	basaltic trachyandesite	trachyandesite
$Na_2O - 2.0 \geq K_2O$	hawaiite	mugearite	benmoreite
$Na_2O - 2.0 < K_2O$	potassic trachybasalt	shoshonite	latite

Classification chimique des roches

Volcaniques

Combinaison de

Petro /Geoch / Texture



100.00
10.00
1.00
0.10
Norm / Prim mantle
Alc
Calc-alc / Arc
MORB
Cs
Rb
Ba
Th
U
Nb
Ta
La
Ce
Pb
Pr
Sr
Nd
Sm
Zr
Hf
EU
Gd
Tb
Dy
Y
Ho
Er
Tm
Yb
Lu
Conti. Arc
Back-arc
Oceanic Arc
MOR
Intraplate --> Rift
Mountain Belts
oceanic lithosphere

Roche volcanique = Cristaux + verre

mésostase interstitielle >50% vol

cristaux <50% vol → phénocristaux (>1mm)
→ microlites (<1mm)

Mineraux:

- -Olivine
- -Pyroxenes
- -Amphiboles
- -Plagioclase
- -Felds K
- -Micas (Biotite)
- -Feldspathoide (e.g. Nepheline)

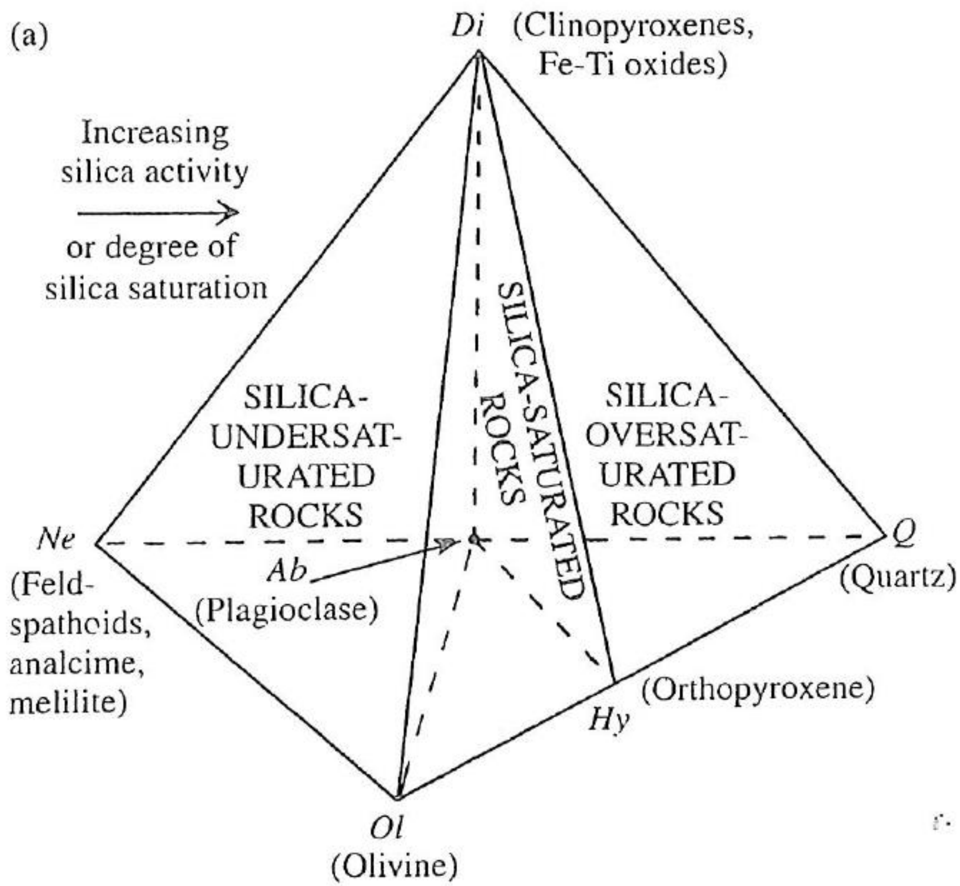
Texture = conditions et processus de cristallisation

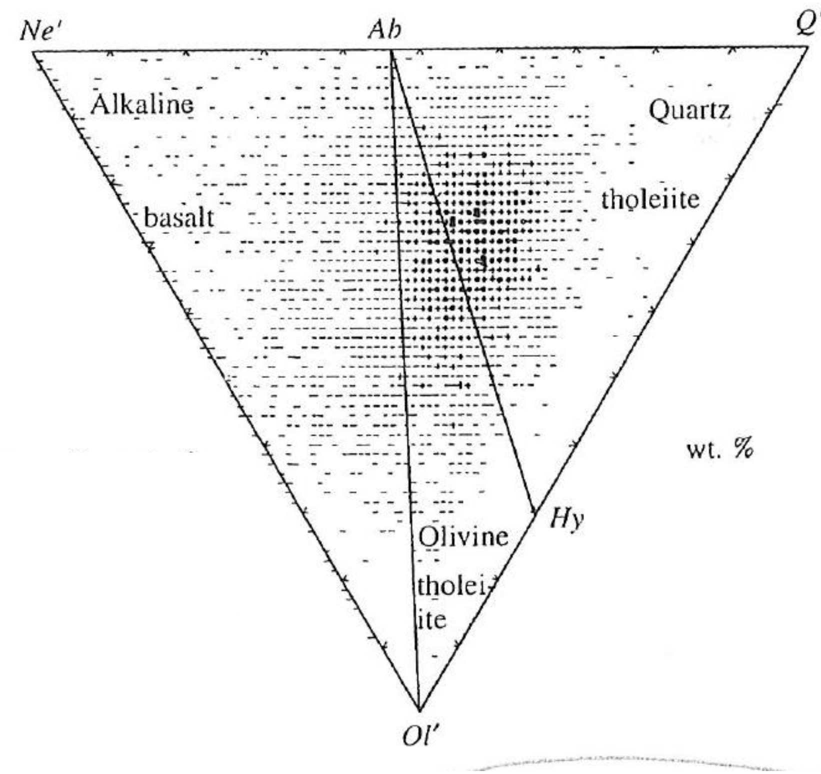
3 groupes de Basaltes

Norm CIPW

	Basaltes sursaturés		Basaltes olivine		Sous saturés
	Thol	Calc-alc	Thol	Calc-alc	Acalin
SiO2	50.92	52.04	49.22	50.15	43.52
TiO2	2.02	1.12	2.16	1.35	2.77
Al2O3	14.38	18.39	14.1	17.89	13.35
Fe2O3	1.97	1.57	2.01	1.68	2.08
FeO	9.85	7.86	10.03	8.38	10.42
MnO	0.12	0.15	0.17	0.14	0.18
MgO	6.86	5.24	8.75	6.57	10.74
CaO	10.9	10.08	10.35	10.05	11.6
Na2O	2.41	2.69	2.39	2.82	3.42
K2O	0.3	0.69	0.56	0.76	1.22
P2O5	0.2	0.16	0.25	0.21	0.69
Norm					
qz	1.88	2.34	-	-	-
or	2.23	4.05	3.31	4.48	7.23
ab	20.36	22.73	20.2	23.85	4.63
an	27.32	36.1	26.11	33.92	17.48
ne	-	-	-	-	13.16
lc	-	-	-	-	-
di	20.89	10.59	19.21	11.94	28.78
hy	20.17	19.4	17.22	14.3	-
ol	-	-	6.35	6.03	18.83
mt	2.86	2.28	2.91	2.43	3.02
il	3.84	2.13	4.11	2.57	5.26
ap	0.46	0.39	0.6	0.49	1.63
XMg	0.55	0.54	0.61	0.58	0.65

Norm CIPW → 3 grand groupes de basaltes





Basaltes sous saturés, alcalin (Ne Normative)

Basaltes sur saturés, tholeiitique à Qtz (Qtz normatif)

Basaltes tholeiitique à olivine

Yoder & Tilley 1969

Notion de séries

Irvine & Baragar, 1971

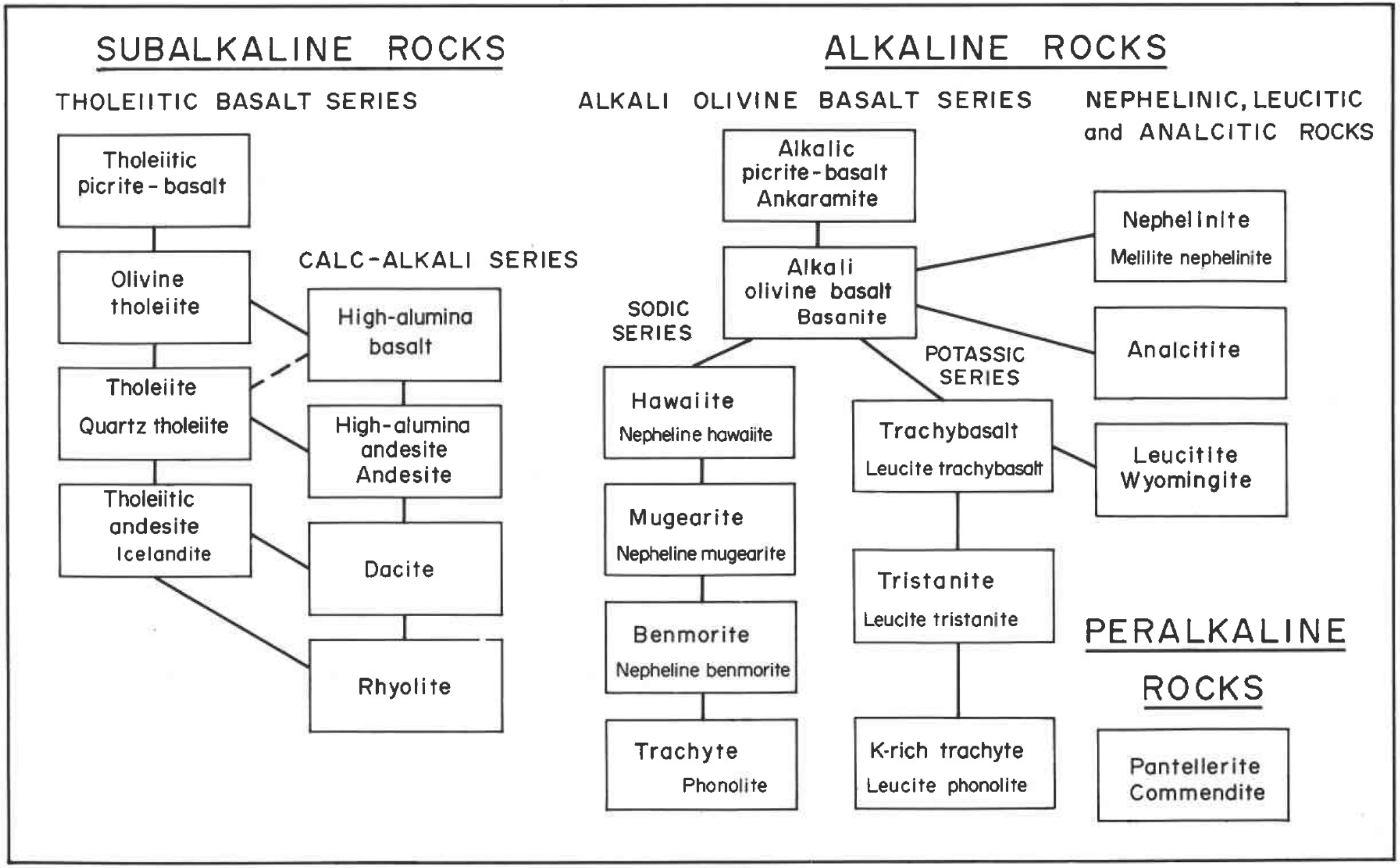
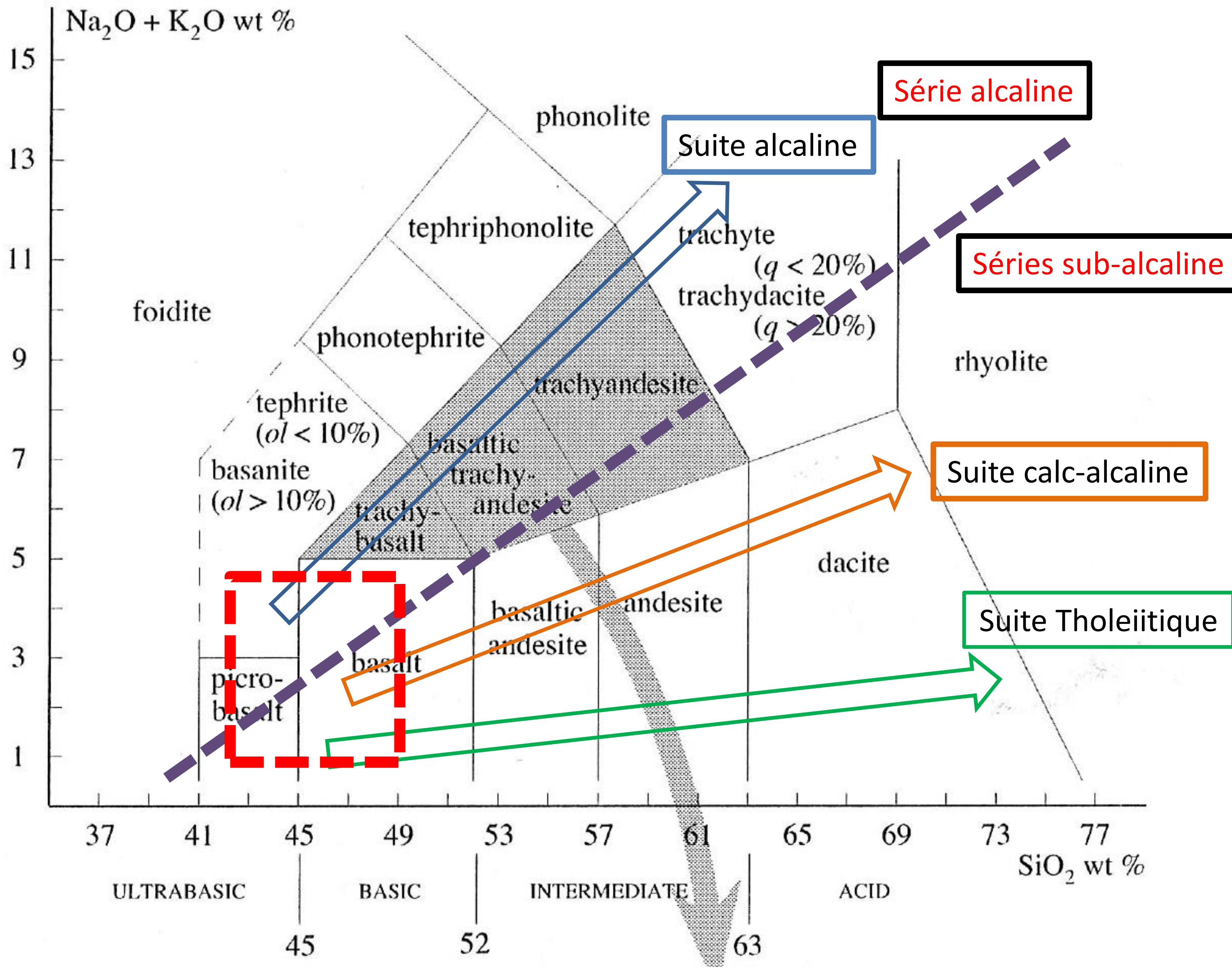


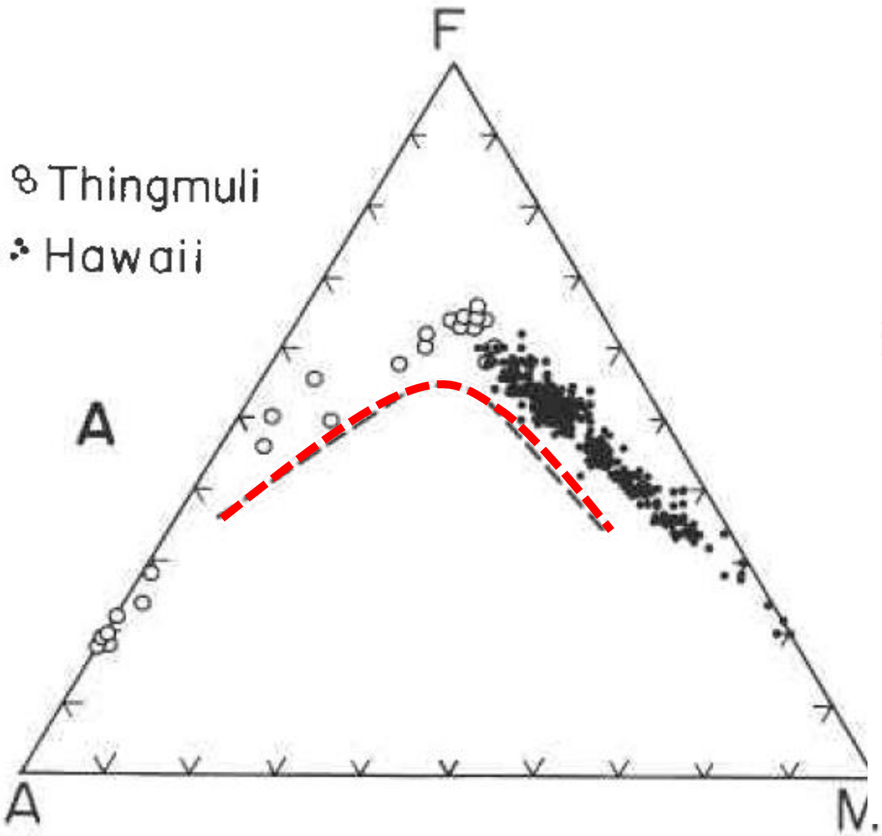
FIG. 1. General classification scheme for the common volcanic rocks. The lines joining boxes serve to outline common associations. The rocks indicated by small print within the boxes are variants of the main rock.



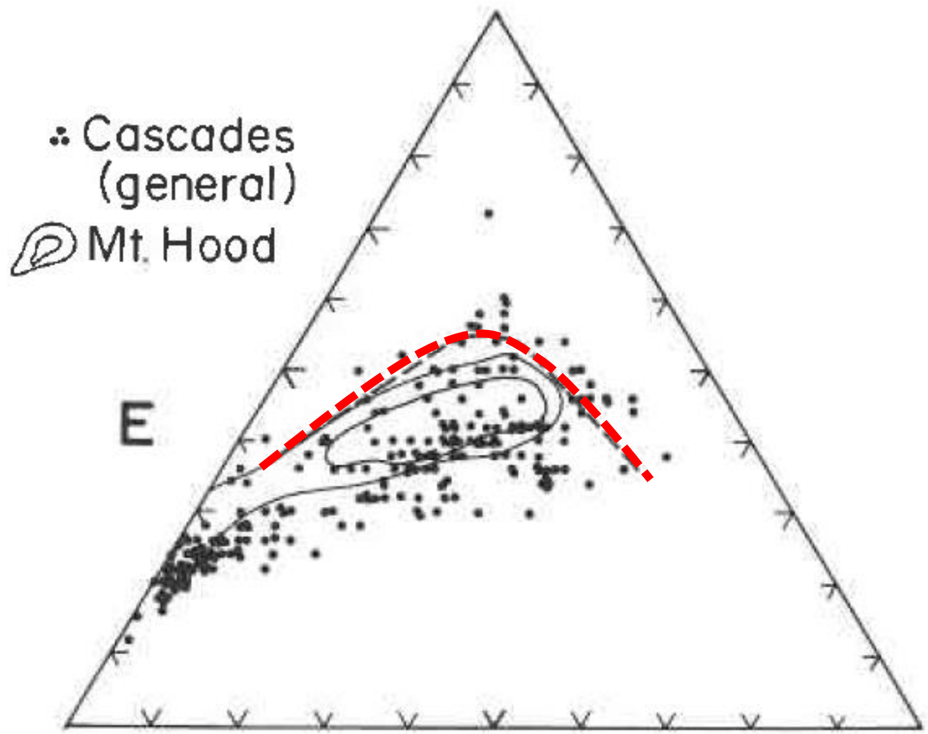
$Na_2O + K_2O$ wt %
15
13
11
9
7
5
3
1
Série alcaline
Suite alcaline
Séries sub-alcaline
Suite calc-alcaline
Suite Tholeiitique
phonolite
tephriphonolite
trachyte
(q < 20%)
trachydacite
(q > 20%)
foidite
phonotephrite
rhyolite
trachyandesite
tephrite
(ol < 10%)
basaltic
trachy-
andesite
basanite
(ol > 10%)
trachy-
basalt
dacite
basaltic
andesite
andesite
basalt
picro-
basalt
37
41
45
49
53
57
61
65
69
73
77
SiO_2 wt %
ULTRABASIC
BASIC
INTERMEDIATE
ACID
45
52
63

Irvine & Baragar, 1971

Tholeitique



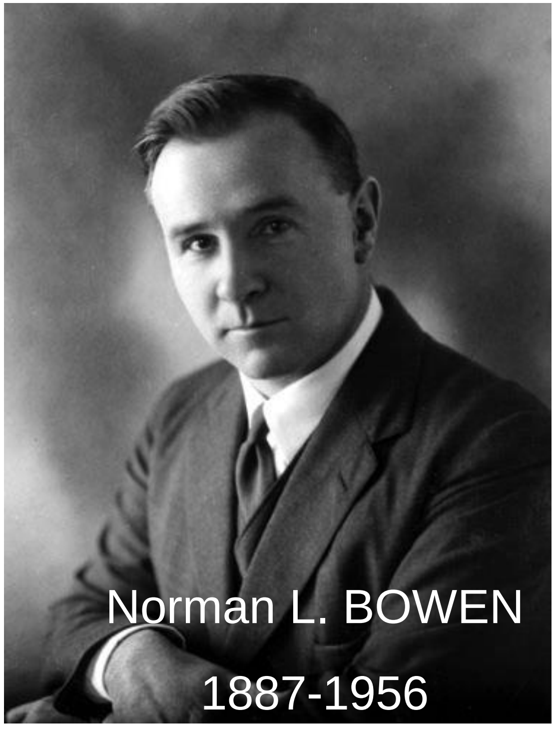
Calc-Alcaline



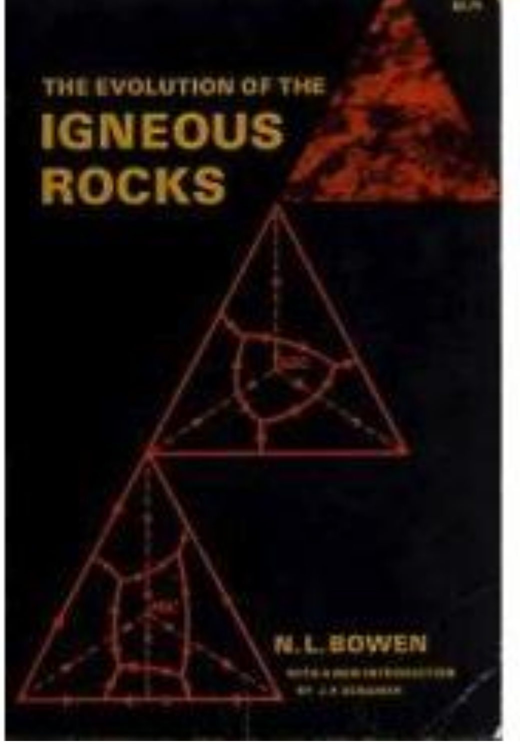
Compréhension de la formation et l'évolution des basaltes → Pétrologie expérimentale

- Des dizaines de milliers d'expériences !!

Dans de multiple systèmes chimique.



Bowen, N. L., Evolution of the Igneous Rocks, Princeton University Press, Princeton, 1928.



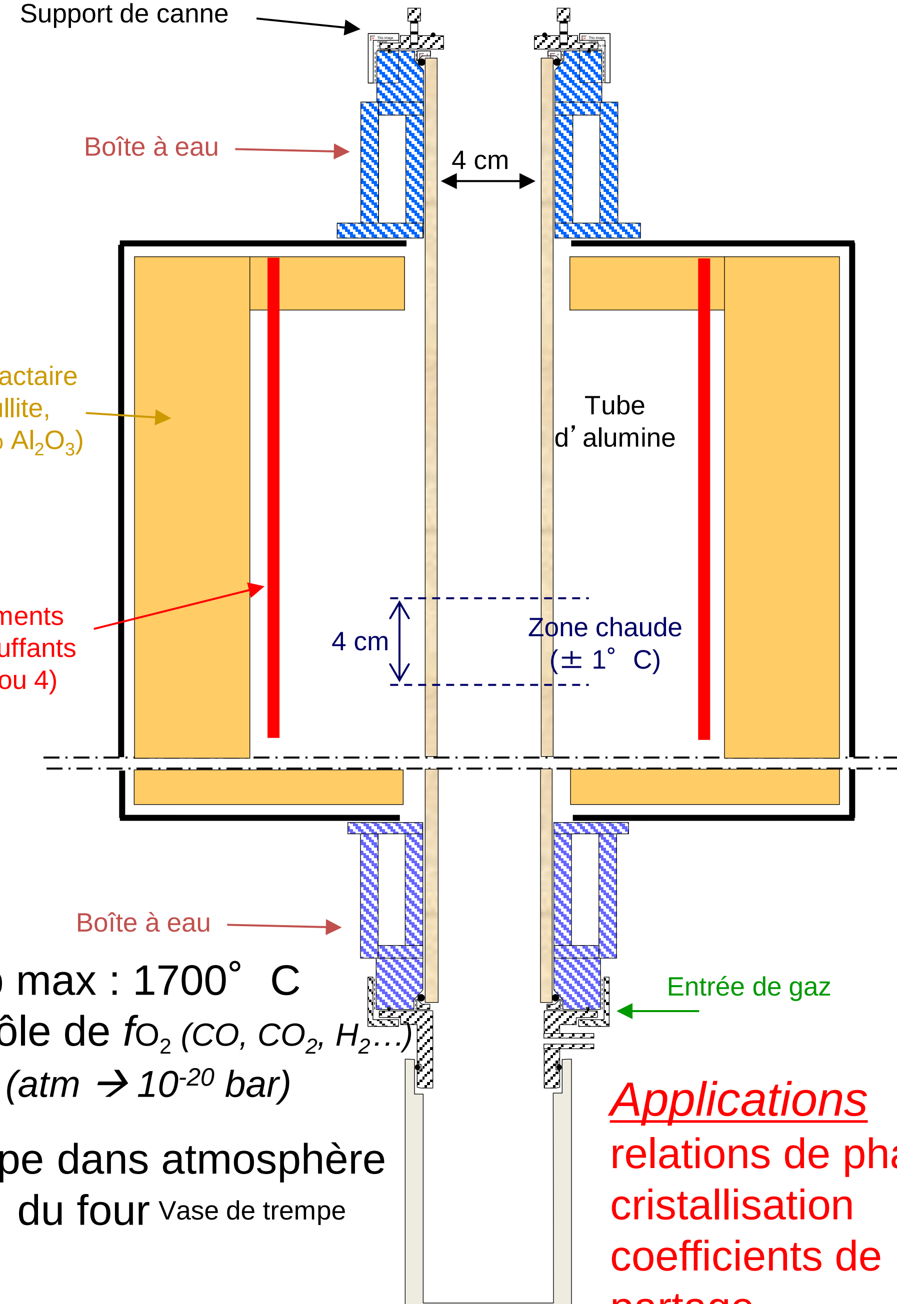
Four « simple »à moufle

-Temp max : 1650° C
 pas de flux de gaz

Applications

Synthèse de verres
cristallisation

Four à atmosphère controlée



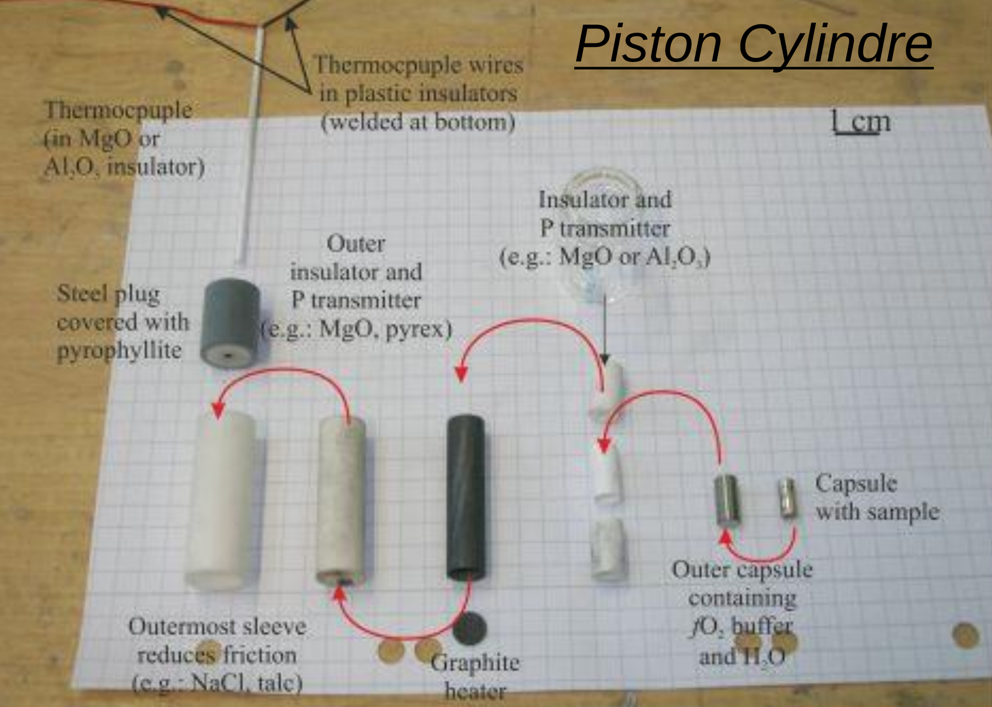
-Temp max : 1700° C
-contrôle de fO_2 *(CO, CO_2, H_2…)*
(atm → 10^{-20} bar)

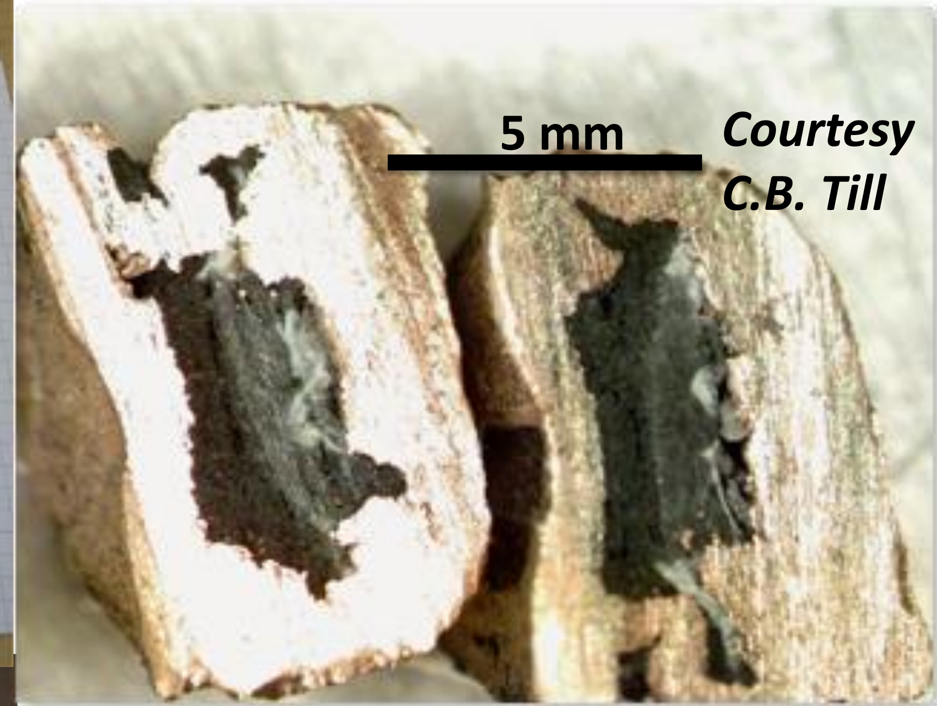
- trempe dans atmosphère du four

Applications

relations de phases
cristallisation
coefficients de partage

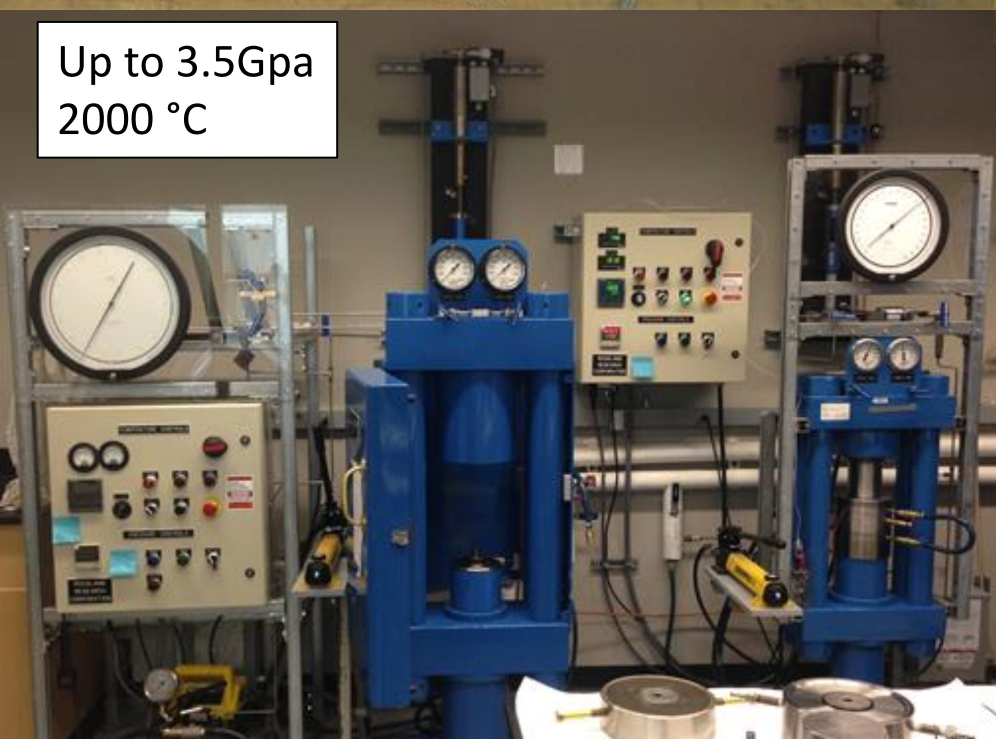
Piston Cylindre

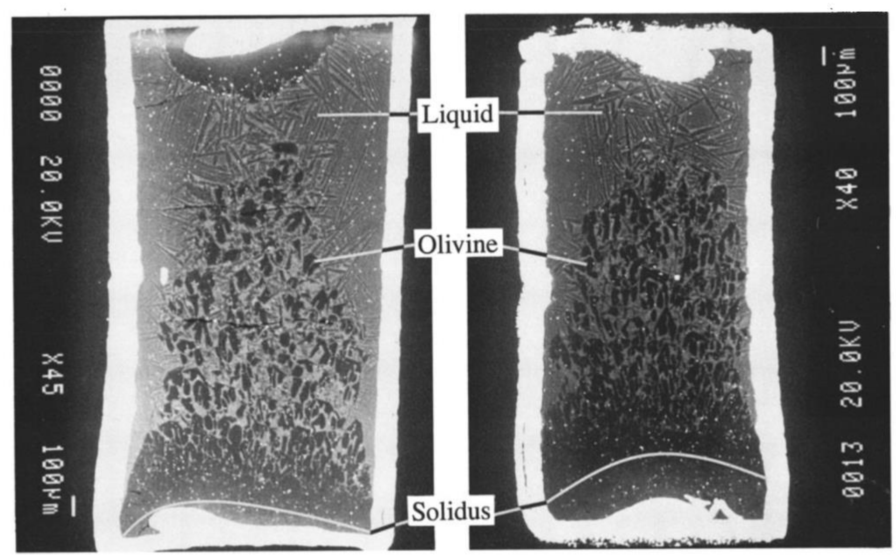




Courtesy C.B. Till

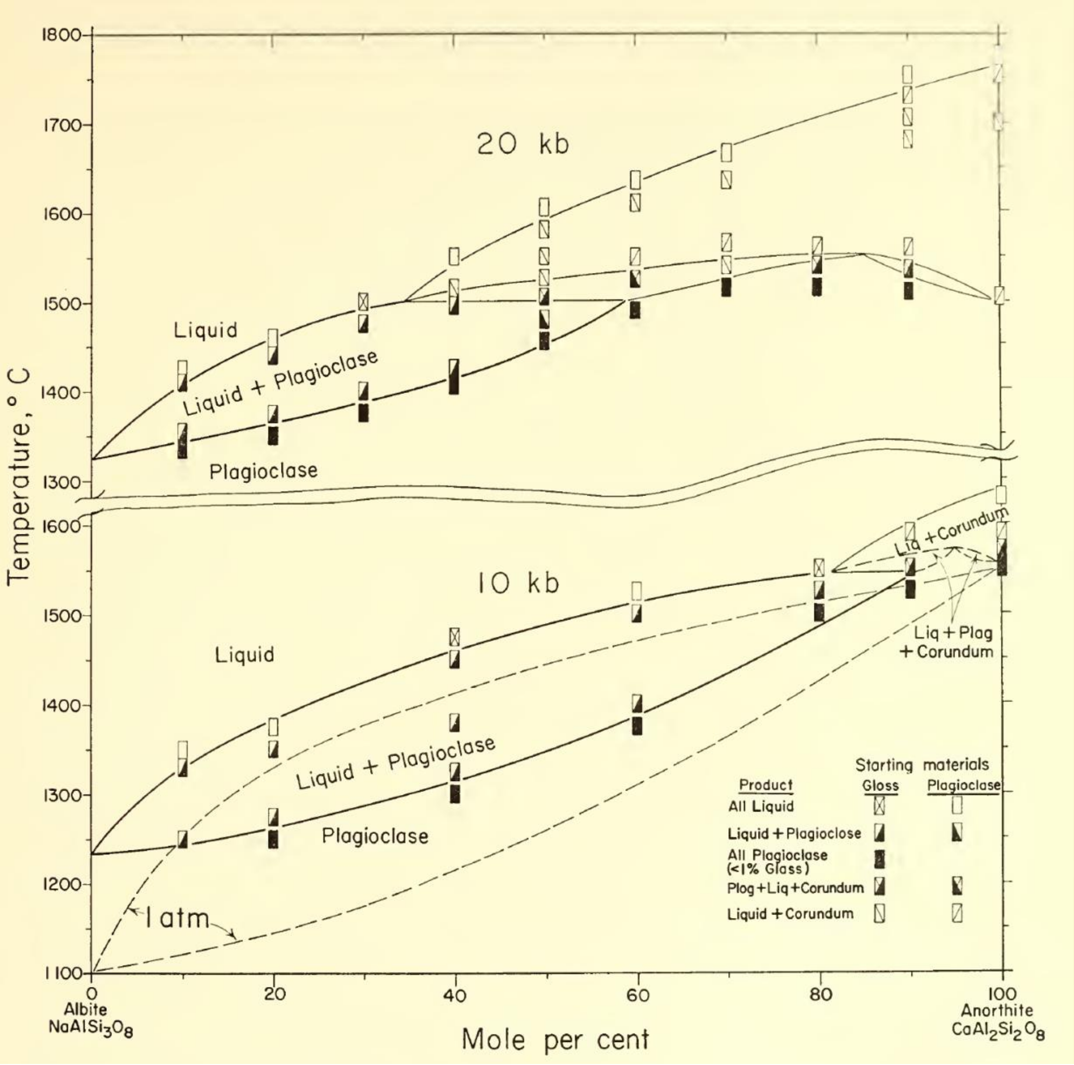
Up to 3.5Gpa
2000 °C





Peridotite KLB-1 5 GPa

Système binaire, simple, comportement de phase commune



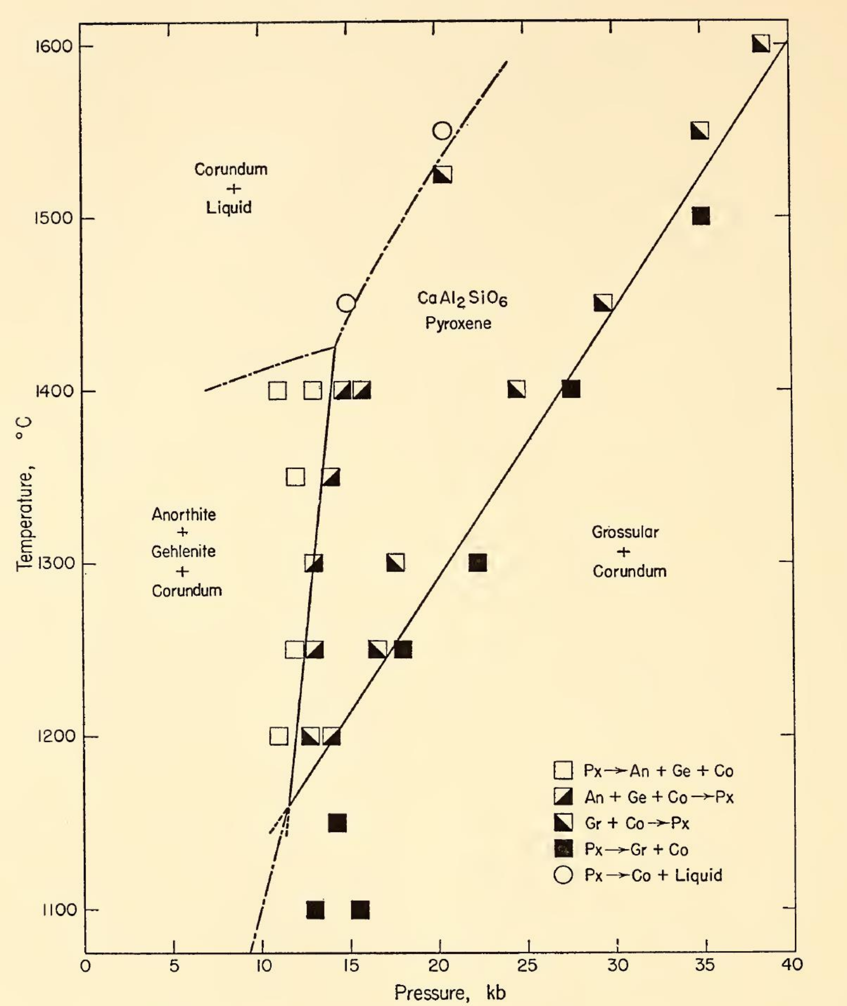
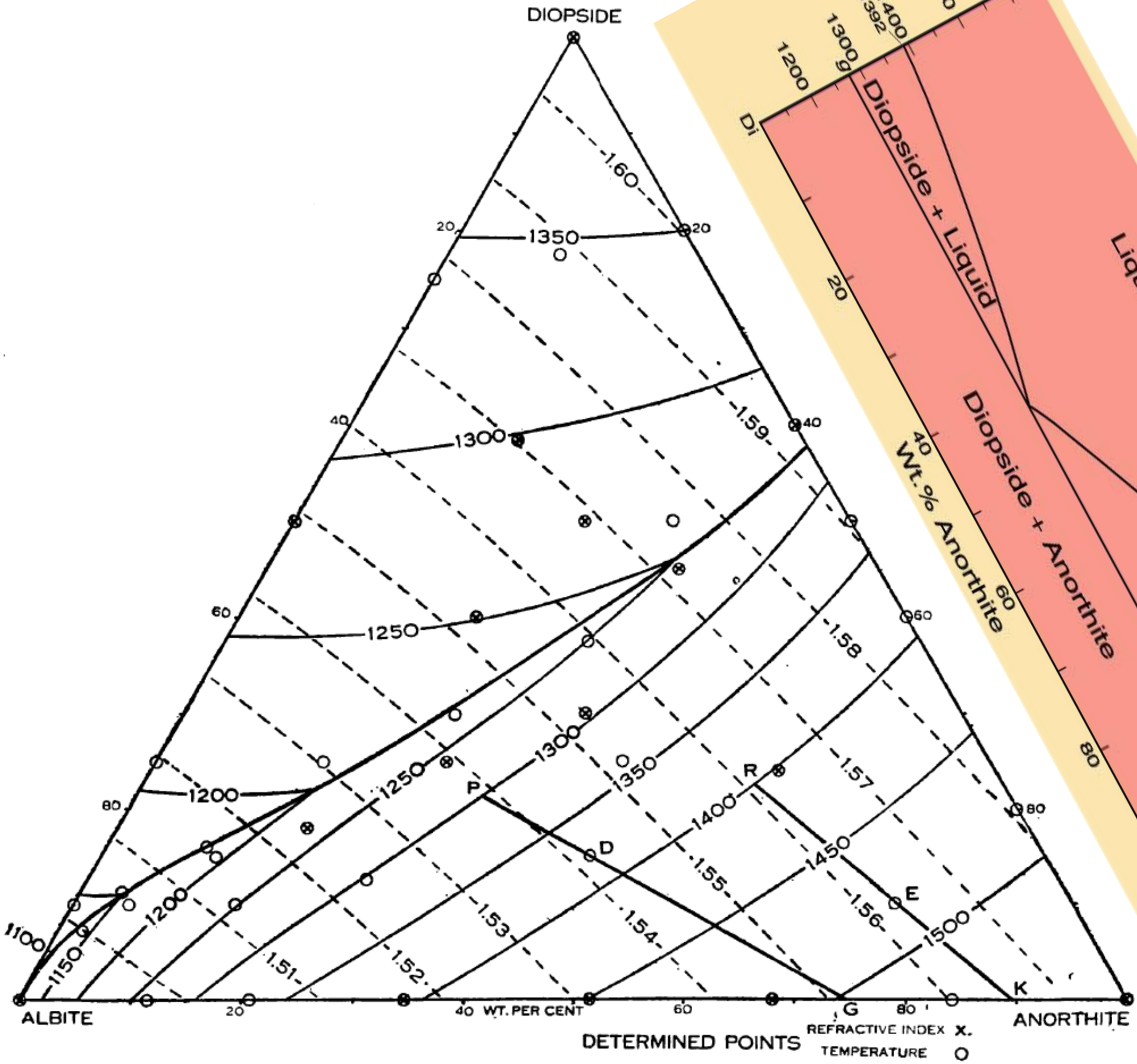
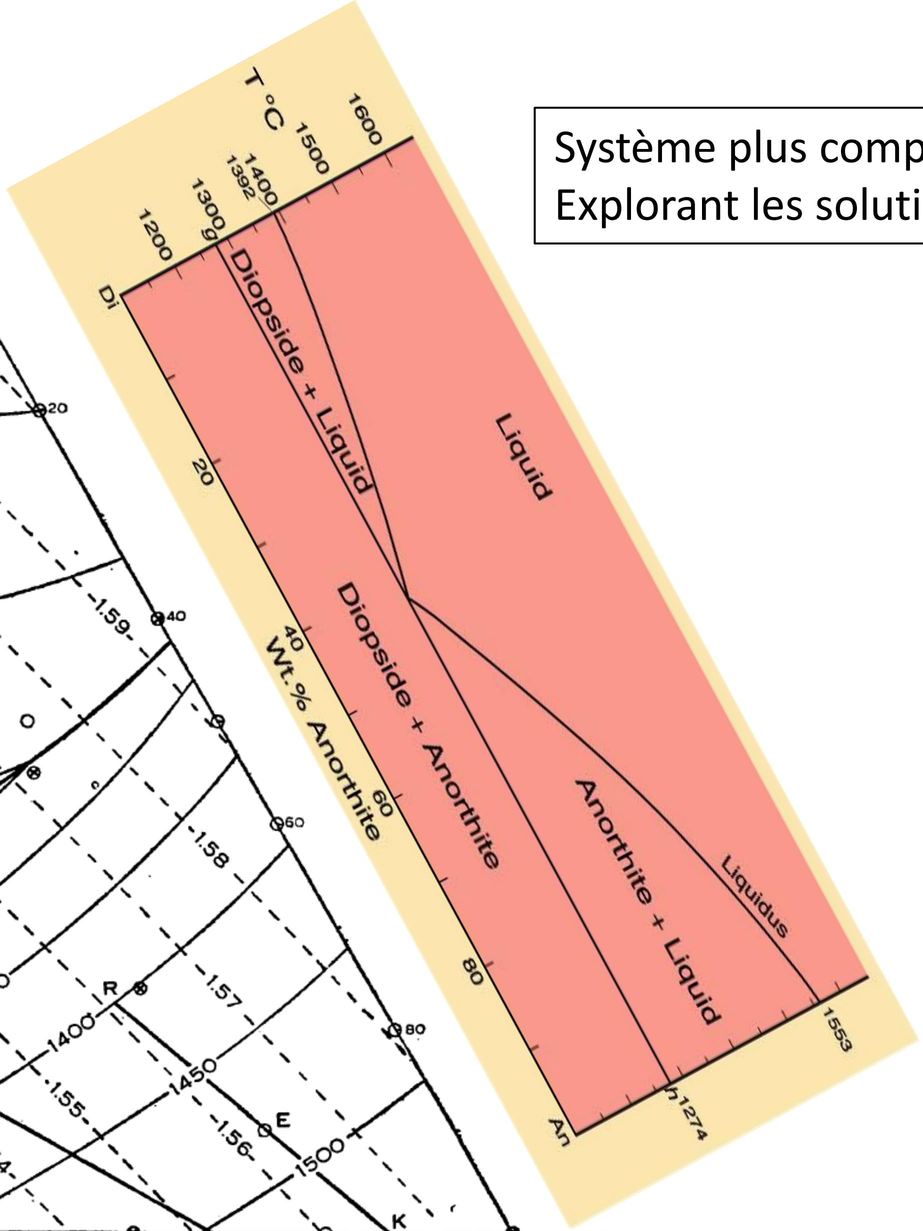


Fig. 23. The stability field of $CaAl_2SiO_6$ pyroxene.

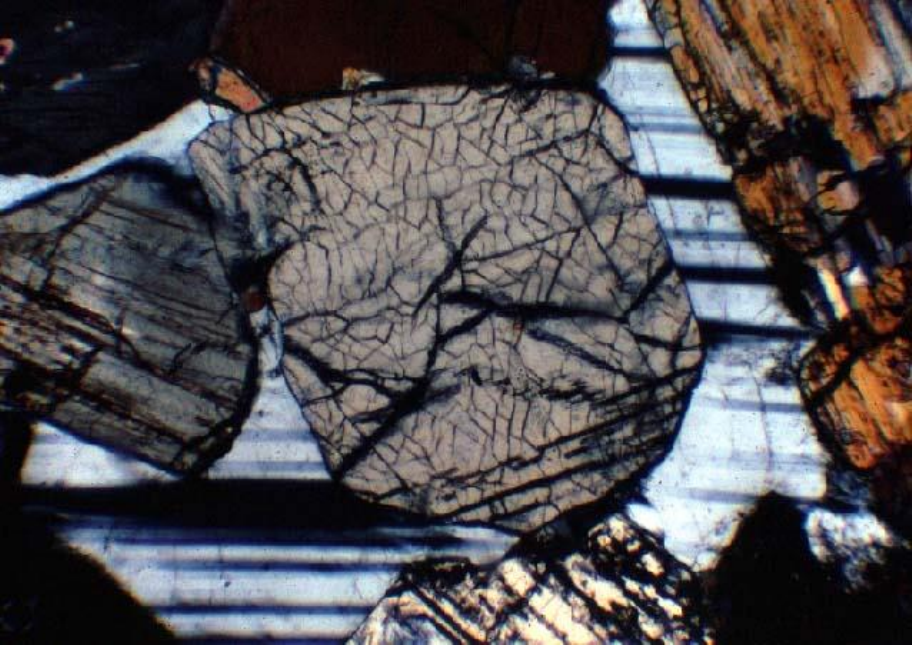
Lindsley, 1965, Carnegie Year Book



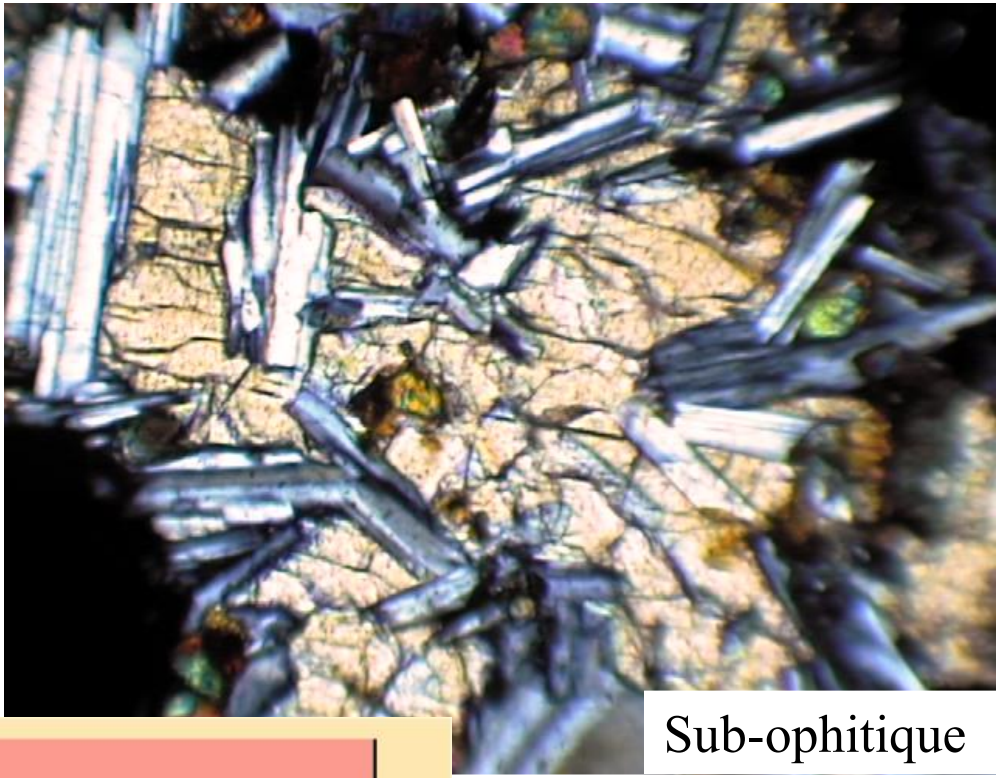


Système plus complexe,
Explorant les solutions solides

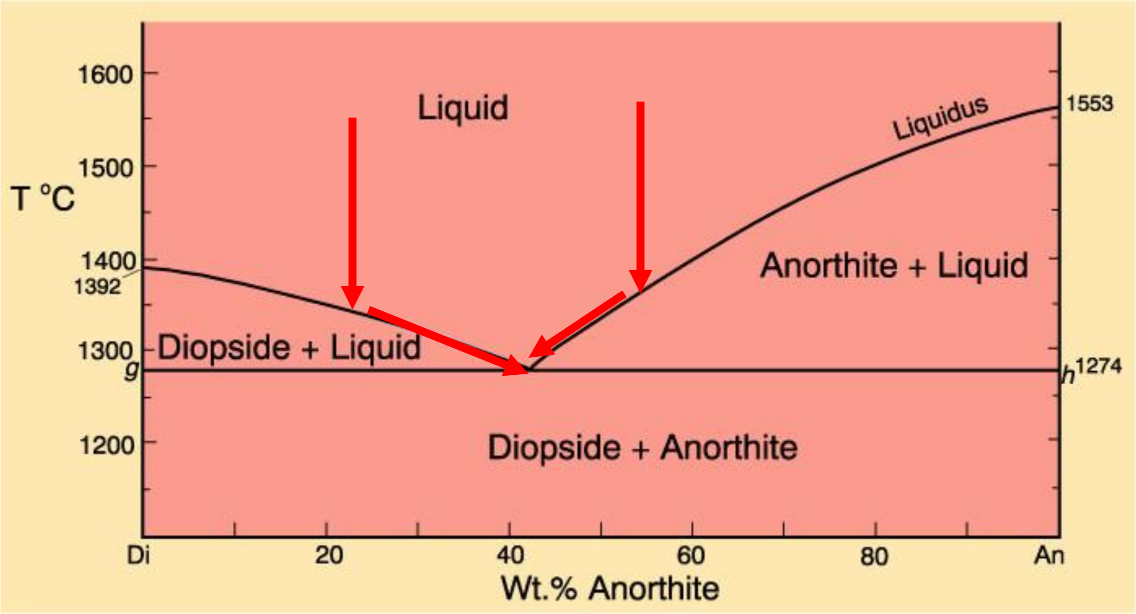
Isobaric T-X phase diagram at atmospheric pressure.
After Bowen (1915), Amer. J. Sci. 40, 161-185.



Le pyroxène se forme avant le plagioclase



Sub-ophitique



Le plagioclase se forme avant le pyroxène

Système manteau, simplifié

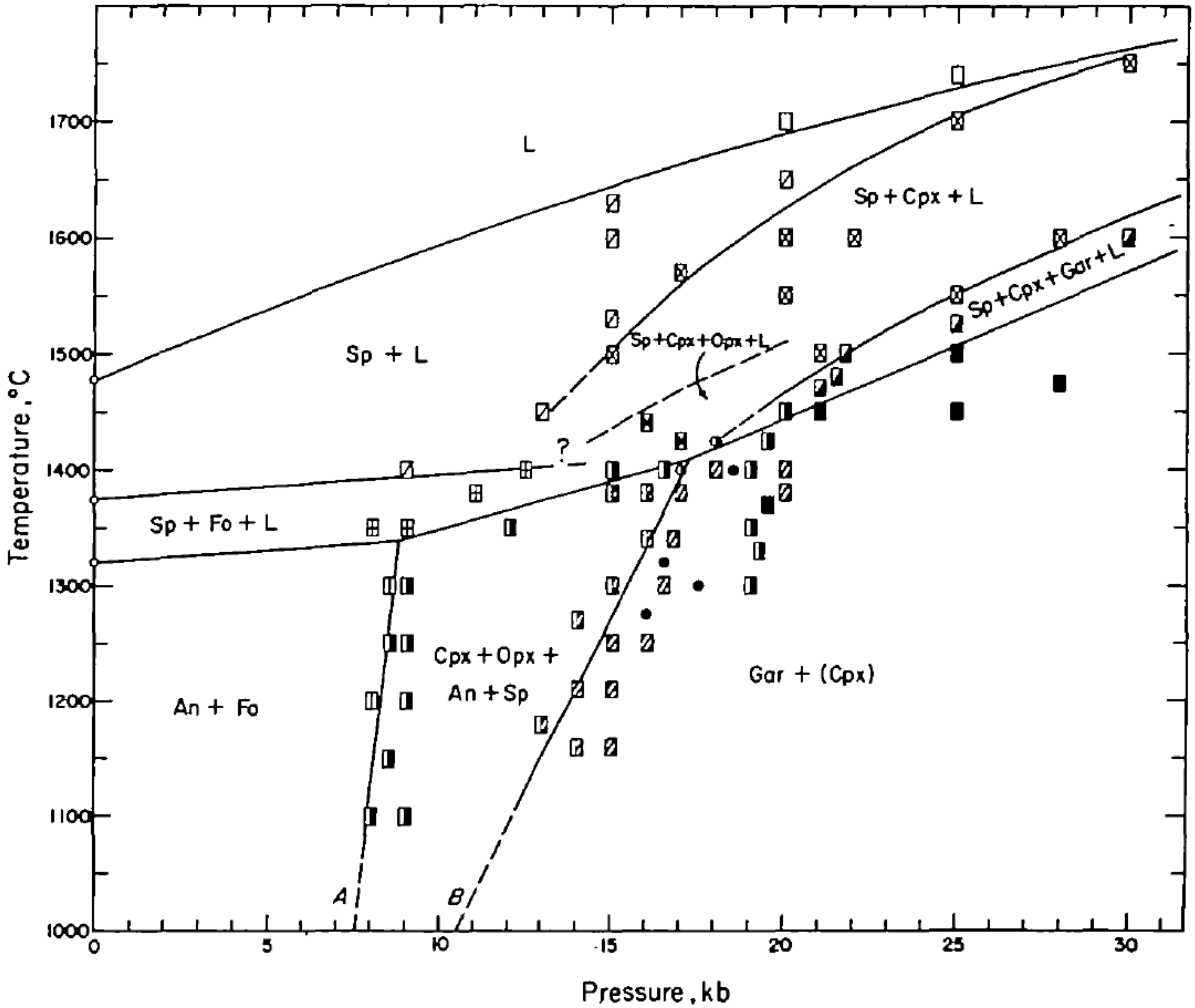


FIG. 1. Pressure–temperature plane for the 1:1 composition (molecular ratio) of anorthite and forsterite. An, anorthite; Cpx, clinopyroxene solid solution; Fo, forsterite; Gar, garnet; L, liquid; Opx, orthopyroxene solid solution; Sp, spinel. Symbols in the subsolidus region: solid rectangles, Gar+Cpx formed from An+Fo; half-solid rectangles, Cpx+Opx+An+Sp formed from An+Fo; shaded rectangles, Gar+Cpx formed from An+Fo when seeded with a small amount of Gar+Cpx; half-shaded rectangles, Cpx+Opx+An+Sp formed from An+Fo when seeded with a small amount of Gar+Cpx; open rectangles with vertical line, An+Fo unchanged; solid circles, garnet not broken down; half-solid circles, garnet broken down.

Kushiro and Yoder 1966

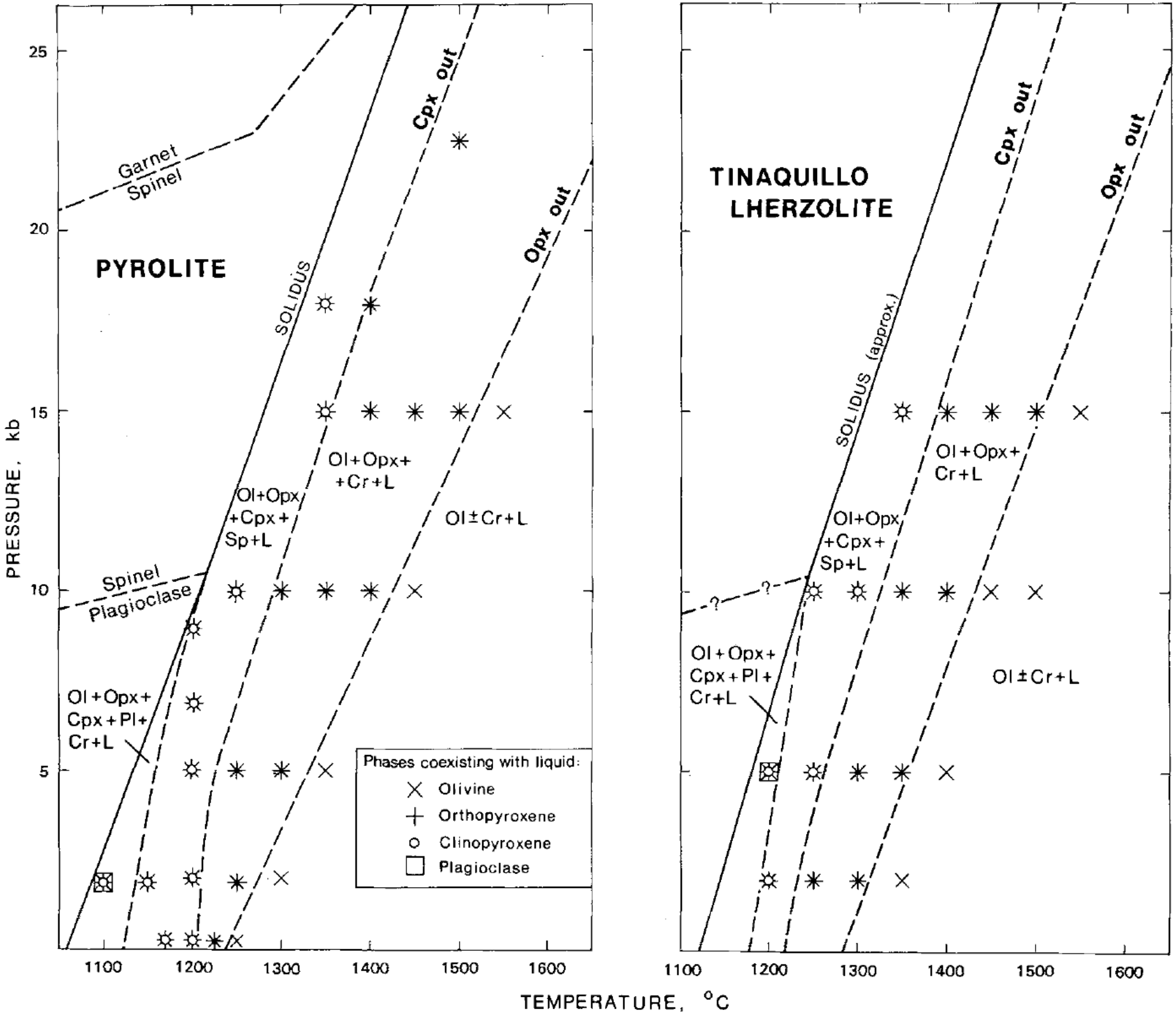
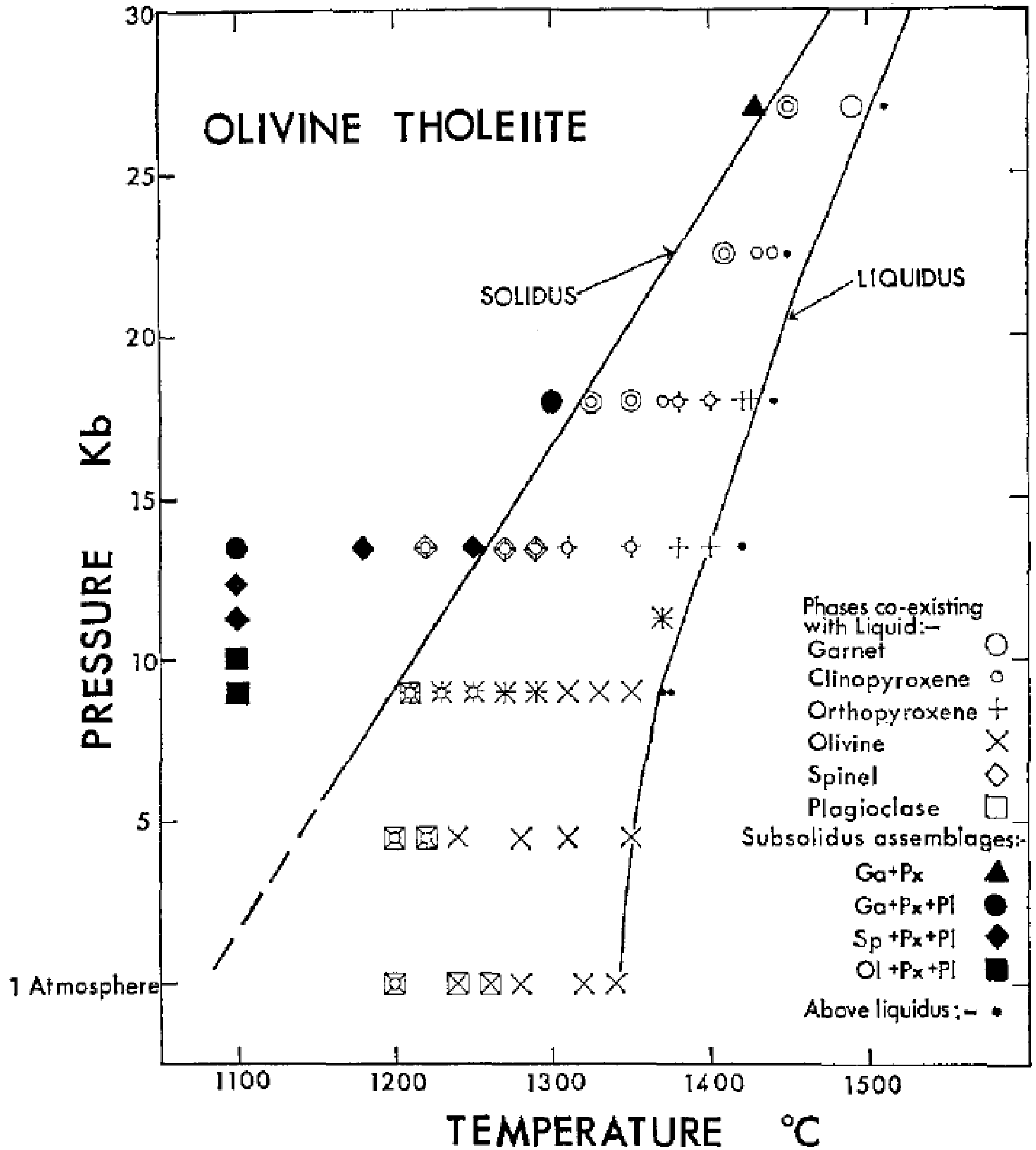


Fig. 1. *P-T* diagram for melting of pyrolite (composition of Ringwood 1966) and Tinaquillo lherzolite. Ol: olivine; Opx: orthopyroxene; Cpx: clinopyroxene; Sp: spinel; Cr: chrome spinel; Pl: plagioclase; L: liquid. Data for 18 and 22.5 kb pyrolite runs from Green and Ringwood (1967b). Plagioclase-spinel peridotite and spinel-garnet peridotite transition boundaries from Green and Ringwood (1970). The solidus and subsolidus boundaries for Tinaquillo lherzolite are estimated

Système Naturel multicomponent

Exp. de Fusion

Jacques & Green 1980

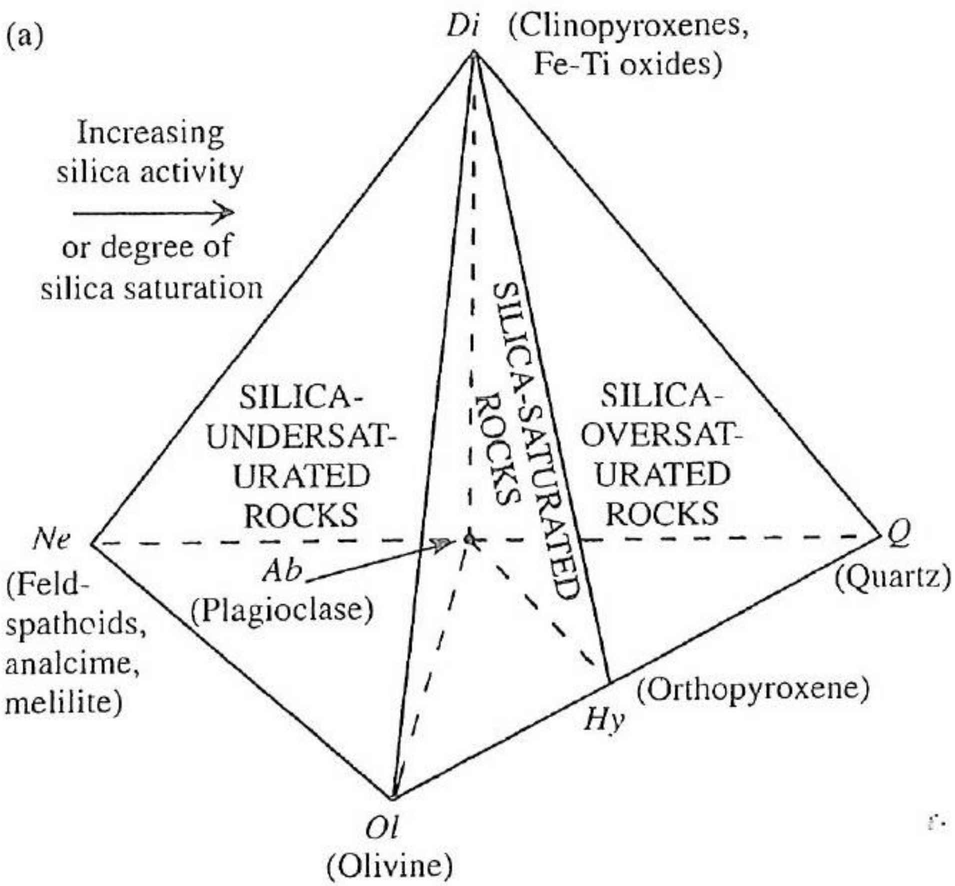


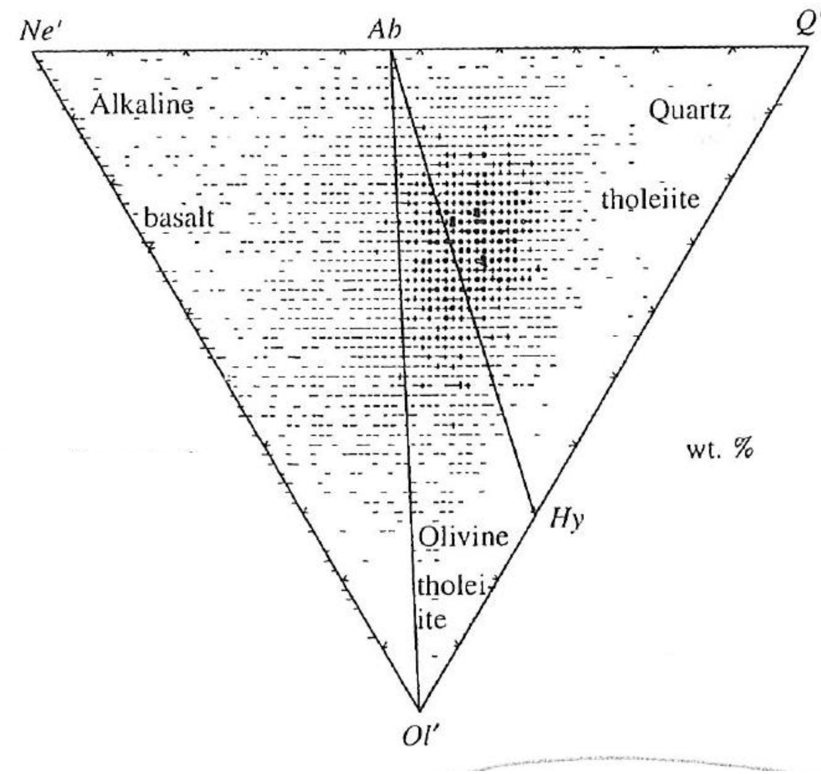
Exp. de crystallisation

Fig. 4. Detail of melting experiments carried out on the olivine tholeiite composition at high pressures. Run descriptions are given in Table 4

Green & Ringwood 1967

3 grand groupes de basaltes: Origine





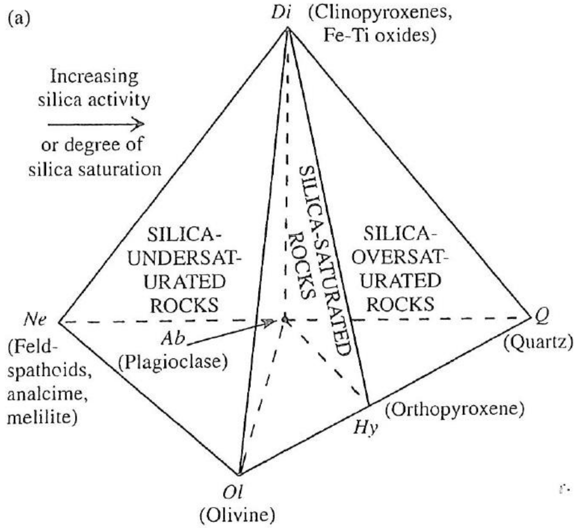
Basaltes sous saturés, alcalin (Ne Normative)
Basaltes sur saturés, tholeiitique à Qtz (Qtz normatif)
Basaltes tholeiitique à olivine

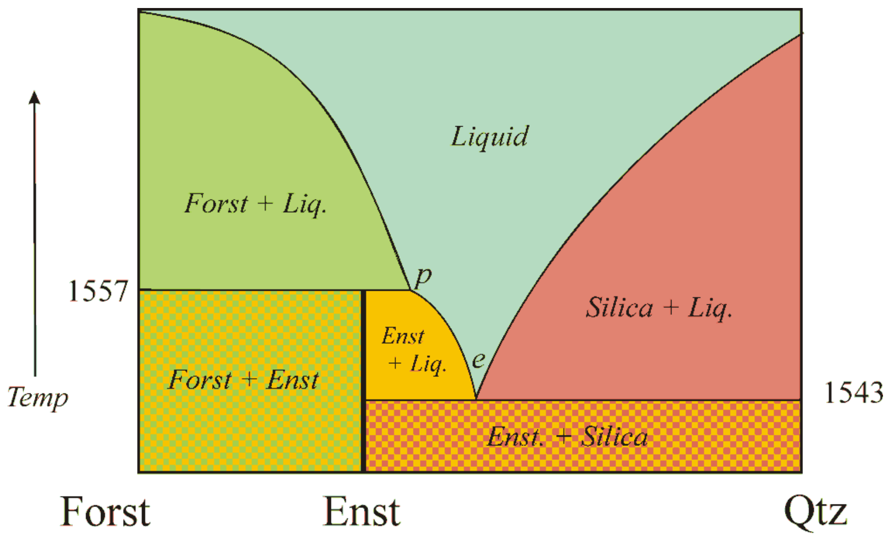
Yoder & Tilley 1969

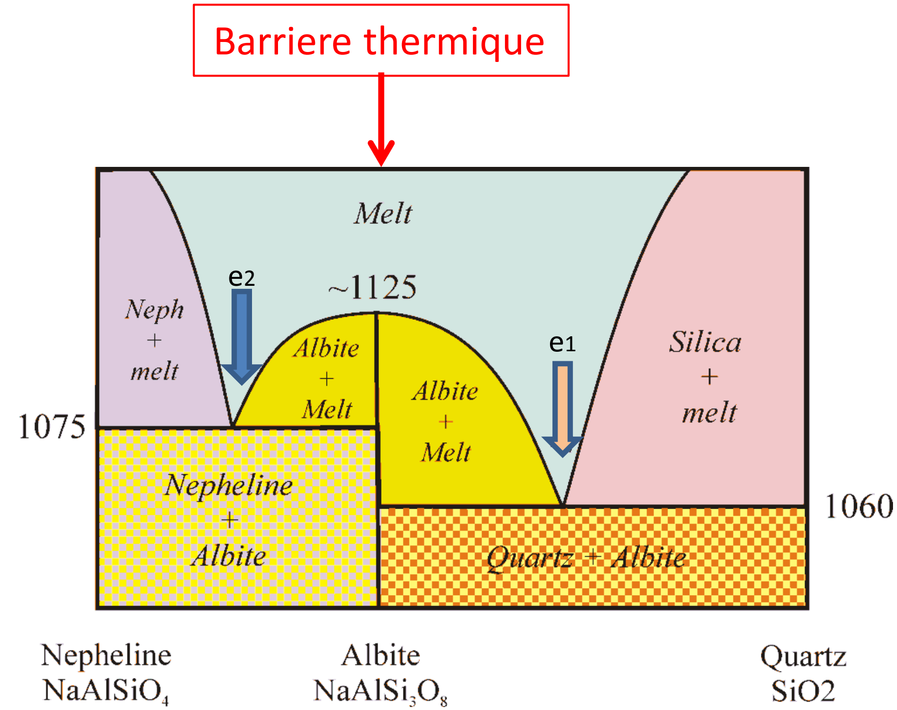
A la surface !!

Relation de phases a 1 atm

Plan de sous saturation = barrière thermique







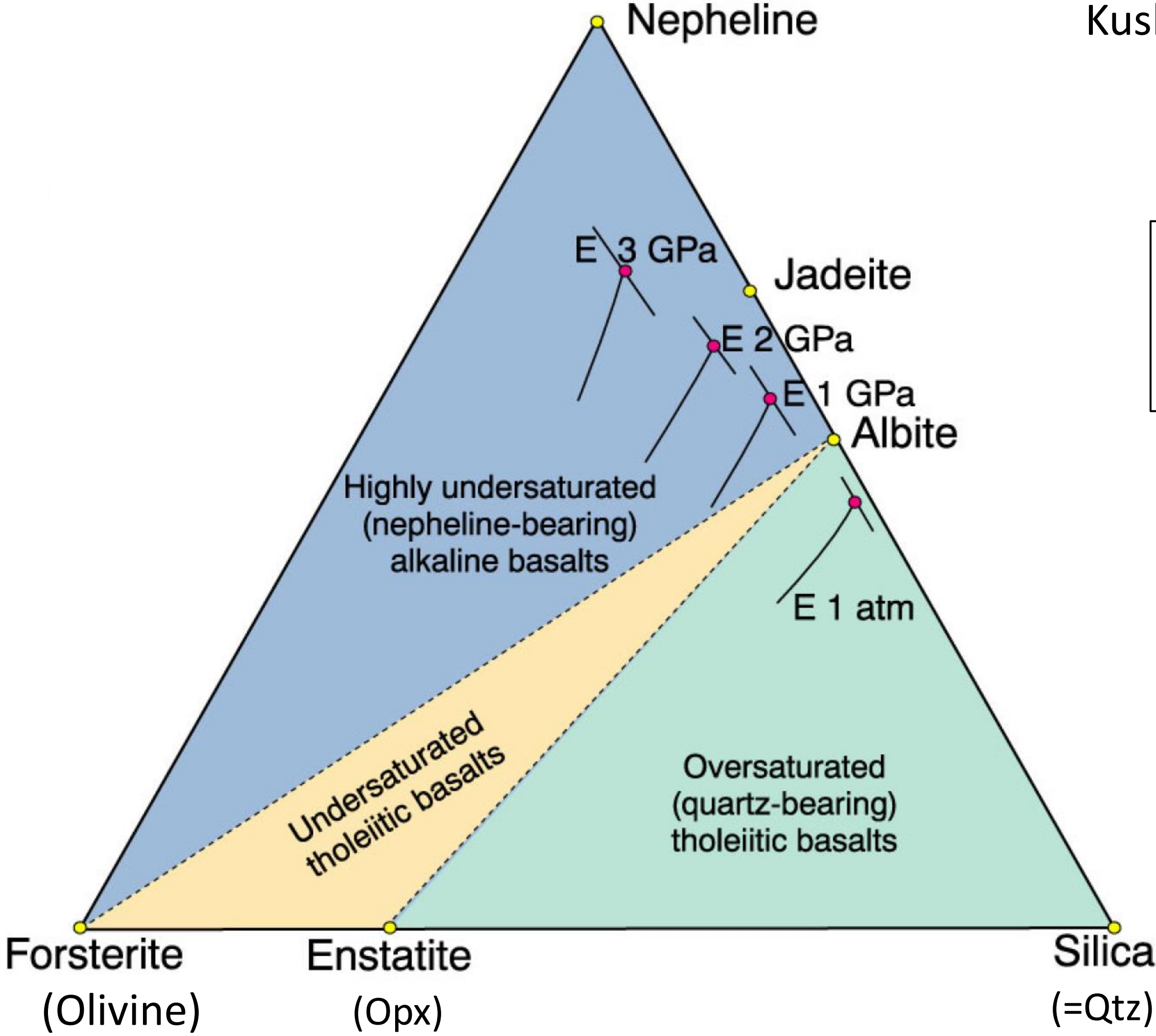
p - oliv + liq $\longrightarrow$ opx

e - liq $\longrightarrow$ opx + qtz

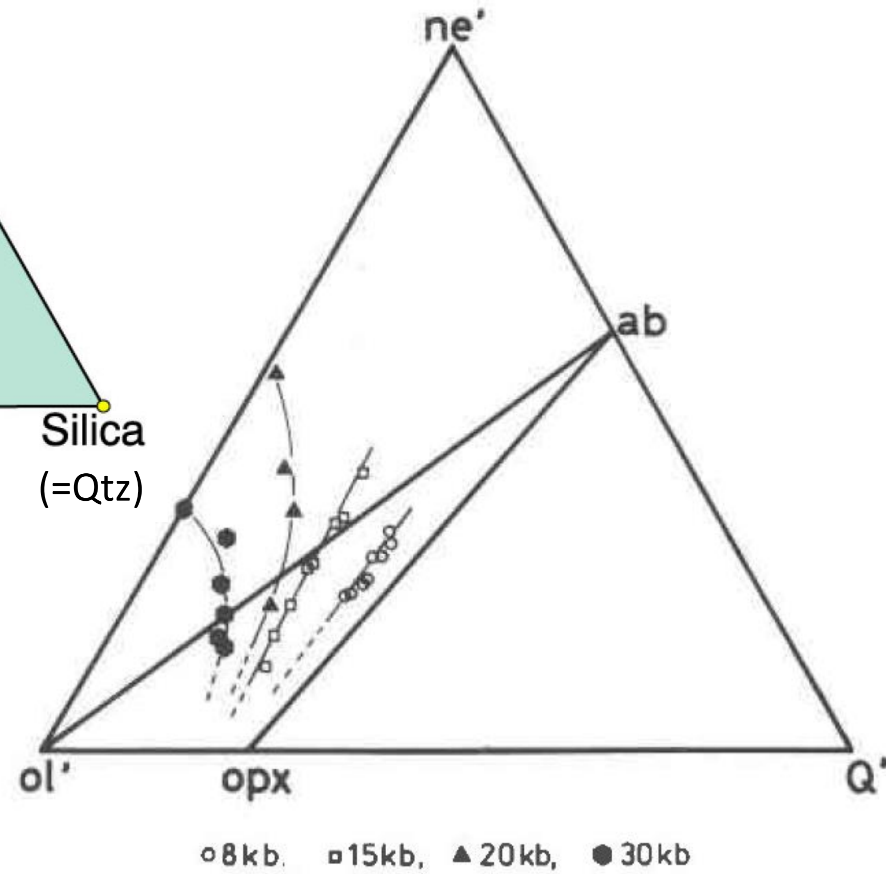
$\boldsymbol{e_1}$ - liq $\longrightarrow$ albite + qtz

$\boldsymbol{e_2}$ - liq $\longrightarrow$ neph + albite

Kushiro (1968) Takahashi & Kushiro 1983.



Effet de la Pression
Sur la position de l'Eutectique
et des liquides dérivés



1983

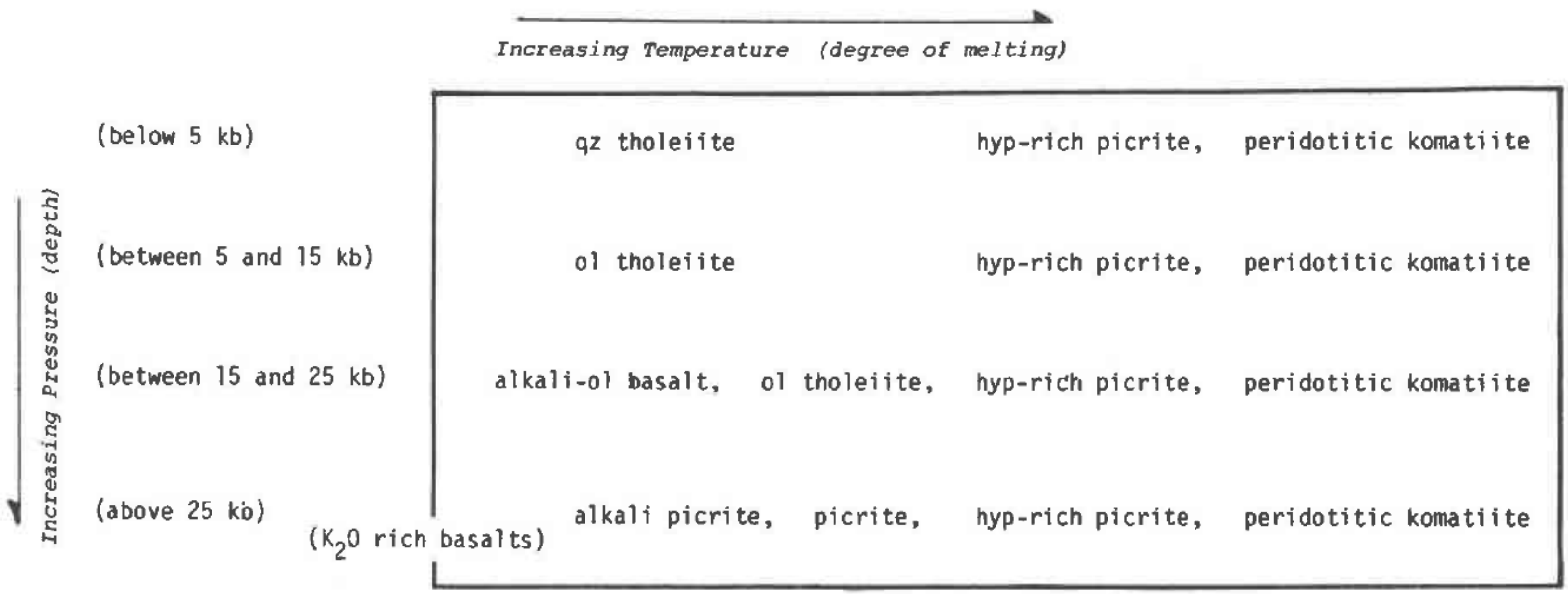


Fig. 15. A petrogenetic grid showing the compositional diversity of basaltic magmas formed by partial melting of dry peridotite at various pressure and temperature conditions.

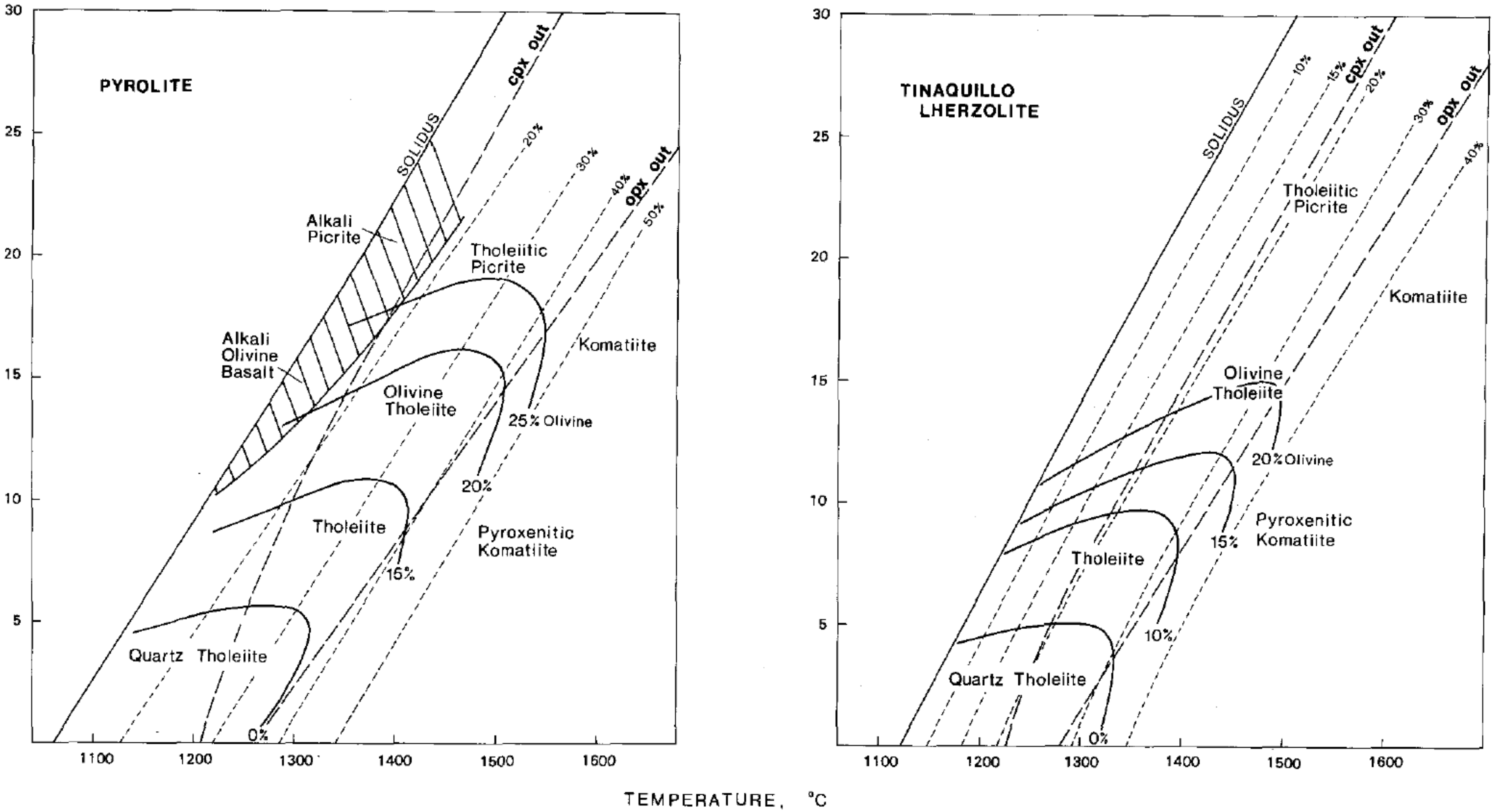


Fig. 9. *P-T* diagram for partial melting of pyrolite and Tinaquillo lherzolite indicating compositions of liquids generated. *Long-dashed lines* indicate disappearance of residual phases, *short-dashed lines* indicate percentage melting, and *solid lines* indicate percent normative olivine in the melt

Effet de la Composition du manteau

Kushiro 2001

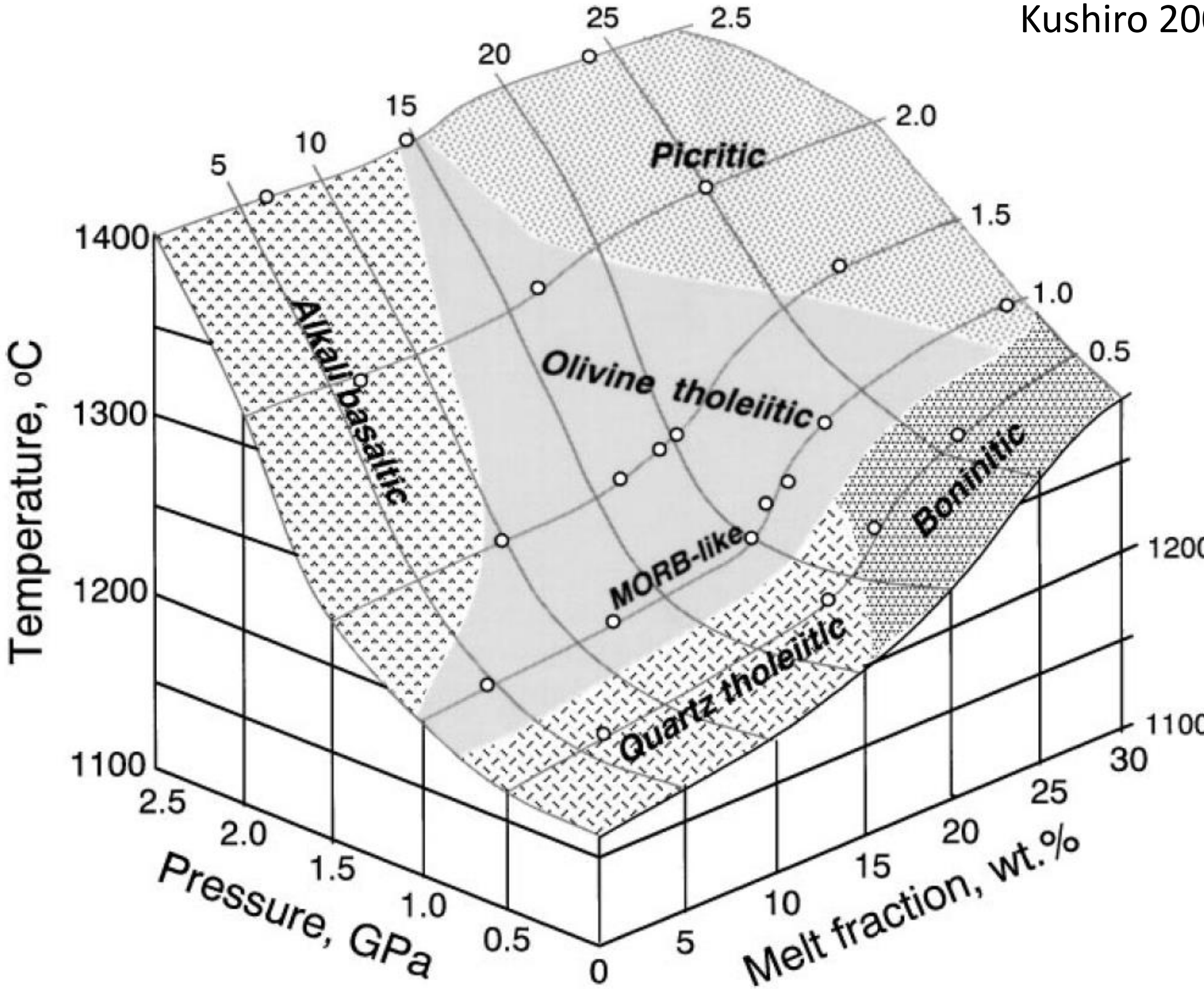
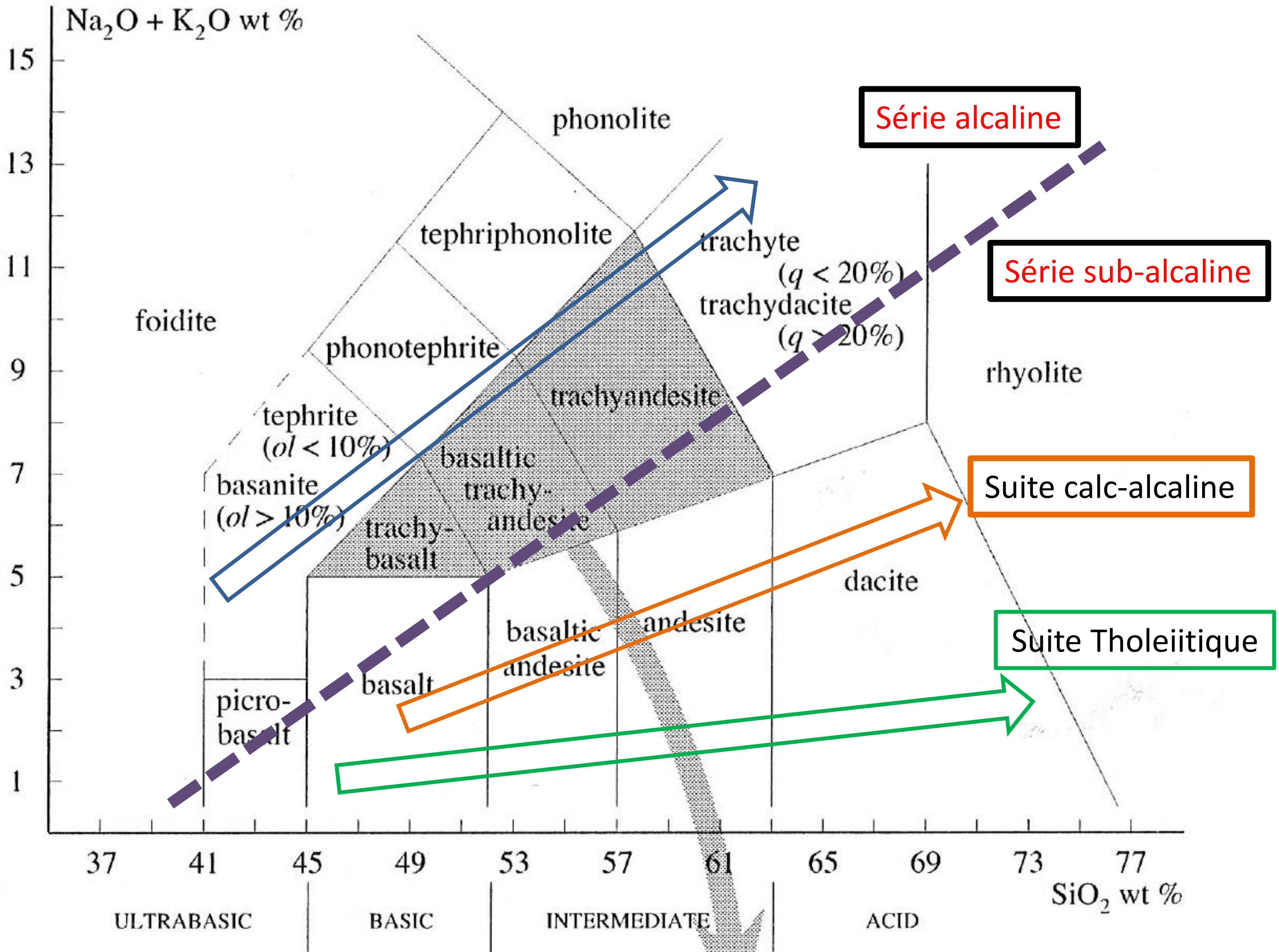


Figure 1 Changes of melt fraction as a function of pressure and temperature for PHN1611 peridotite (Kushiro 1996). Approximate compositional ranges of melts of representative magma types are shown.

Variabilités des basaltes

→ variabilités des processus de fusion du manteau !! f(P, T, X)

Evolution des basaltes



Evolution des basaltes

- Cristallisation fractionnée
- Melange (Mixing)
- Immiscibilité

TABLE I

MINERAL AND ROCK SEQUENCE AT GARABAL HILL (*after Harker*)

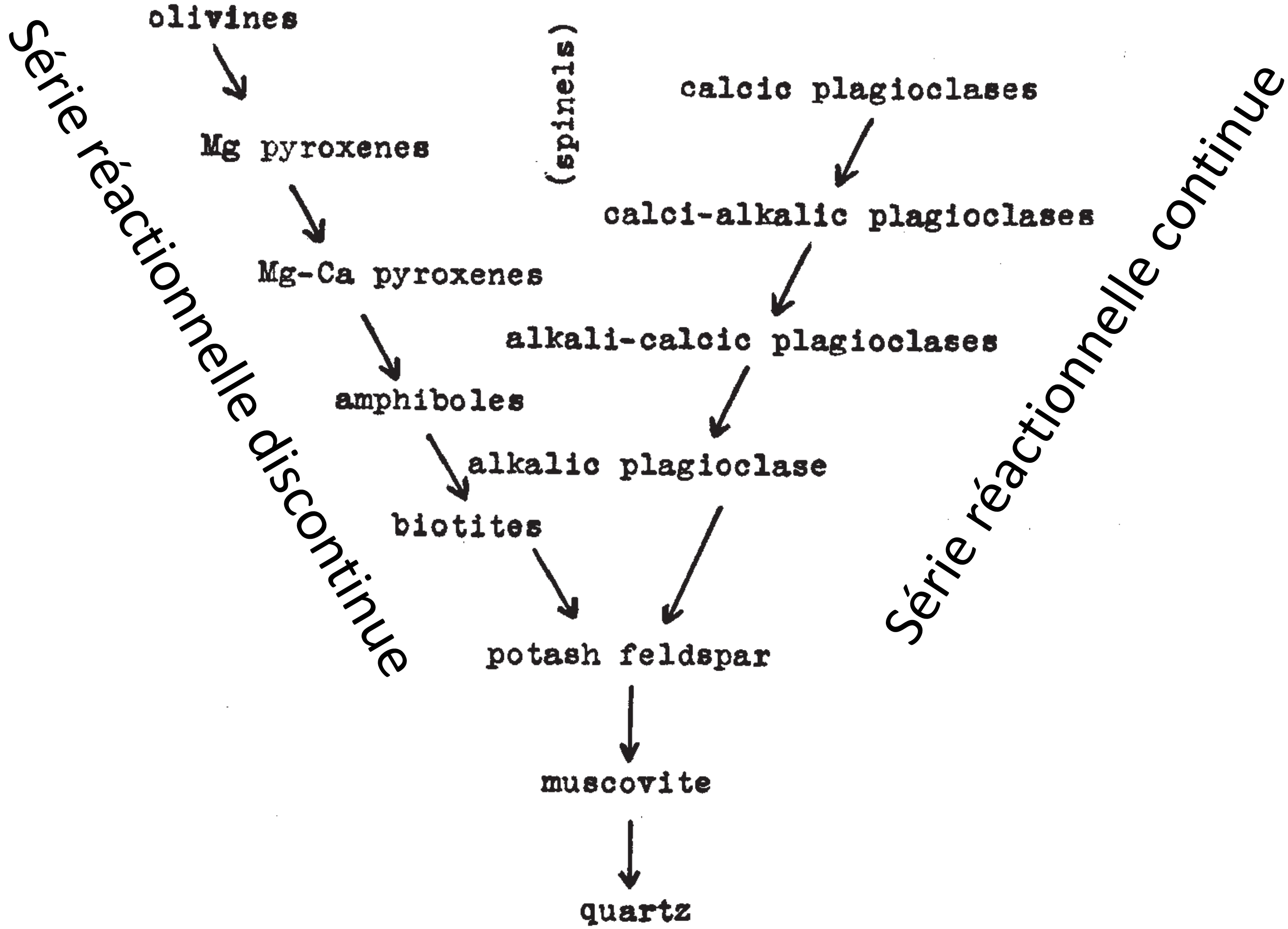
	1. Iron Ore	2. Olivine	3. Augite (diallage)	4. Brown Hornblende	5. Green Hornblende	6. Biotite	7. Plagioclase	8. Orthoclase	9. Quartz
A. Olivine-diallage rock	+	+	+	+	—	—	—	—	—
B. Biotite-diorite	+	—	—	—	+	+	+	—	—
C. Hornblende-biotite-granite	+	—	—	—	+	+	+	+	+
D. Porphyritic biotite-granite	+	—	—	—	—	+	+	+	+
E. Eurite vein	+	—	—	—	—	—	+	+	+

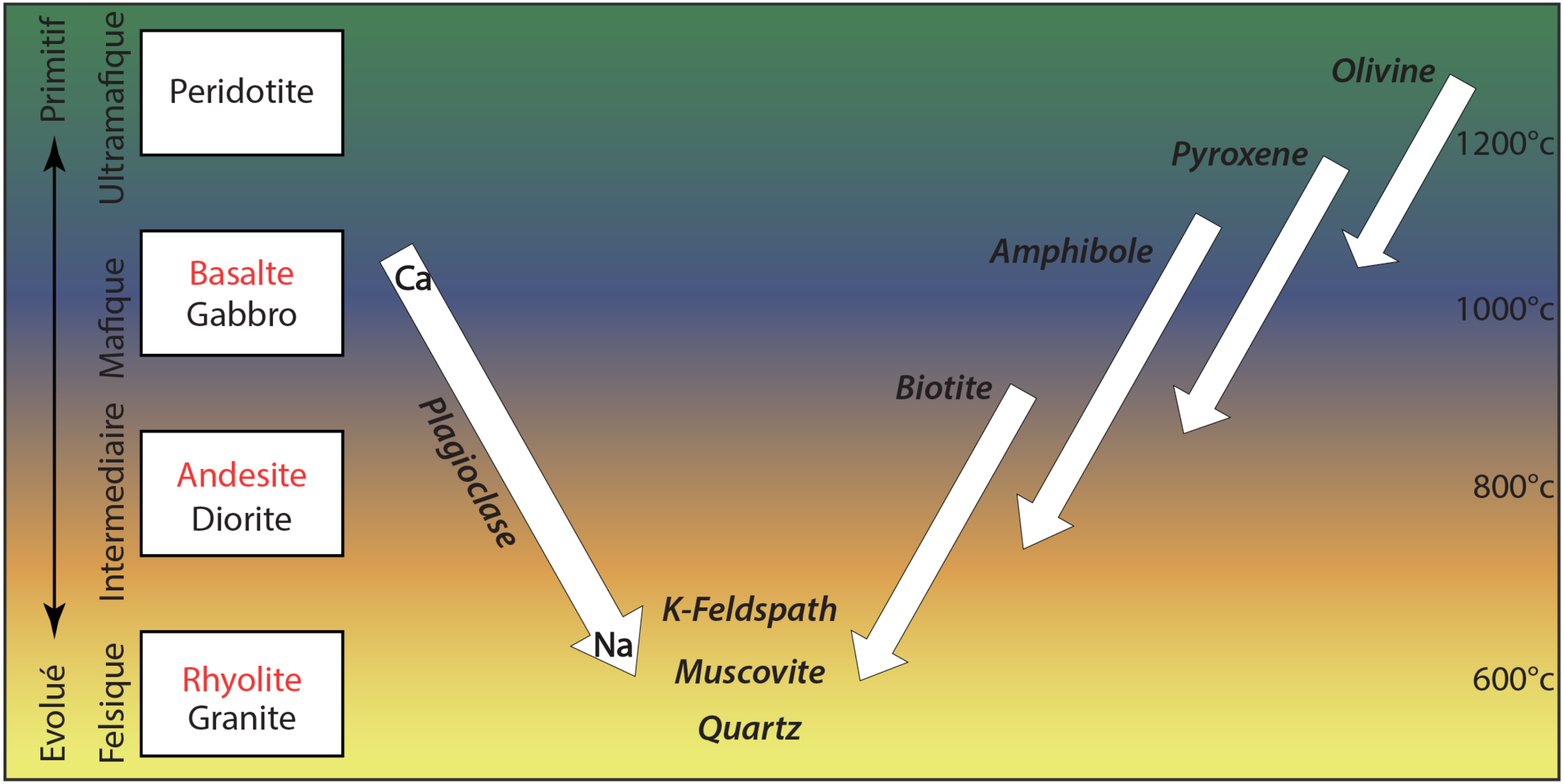
THE REACTION PRINCIPLE IN PETROGENESIS

N. L. BOWEN
Geophysical Laboratory, Carnegie Institution of Washington *1922*

TABLE II

REACTION SERIES IN SUB-ALKALINE ROCKS





Primitif
Evolué
Ultramafique
Mafique
Intermediaire
Felsique
Peridotite
Basalte
Gabbro
Andesite
Diorite
Rhyolite
Granite
Ca
Plagioclase
Na
Olivine
Pyroxene
Amphibole
Biotite
K-Feldspath
Muscovite
Quartz
1200°c
1000°c
800°c
600°c

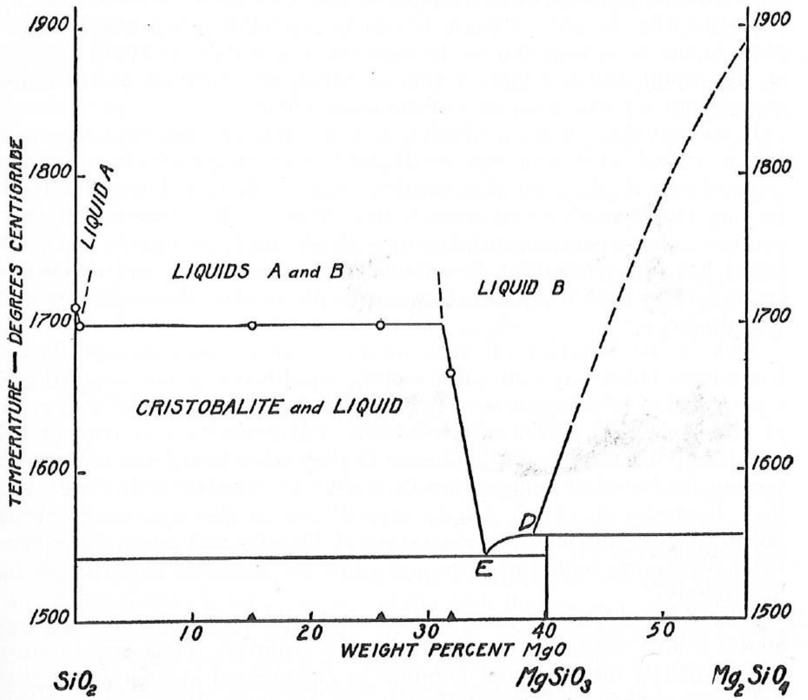
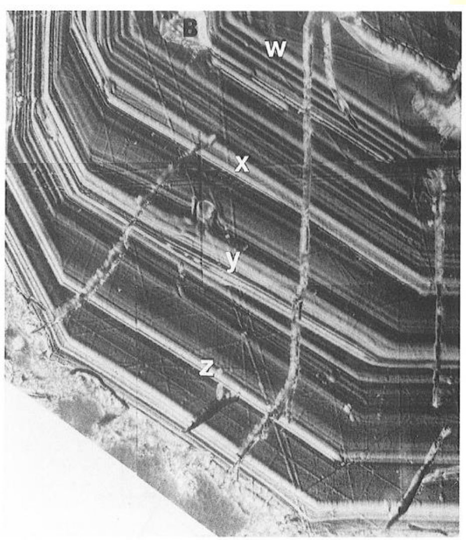
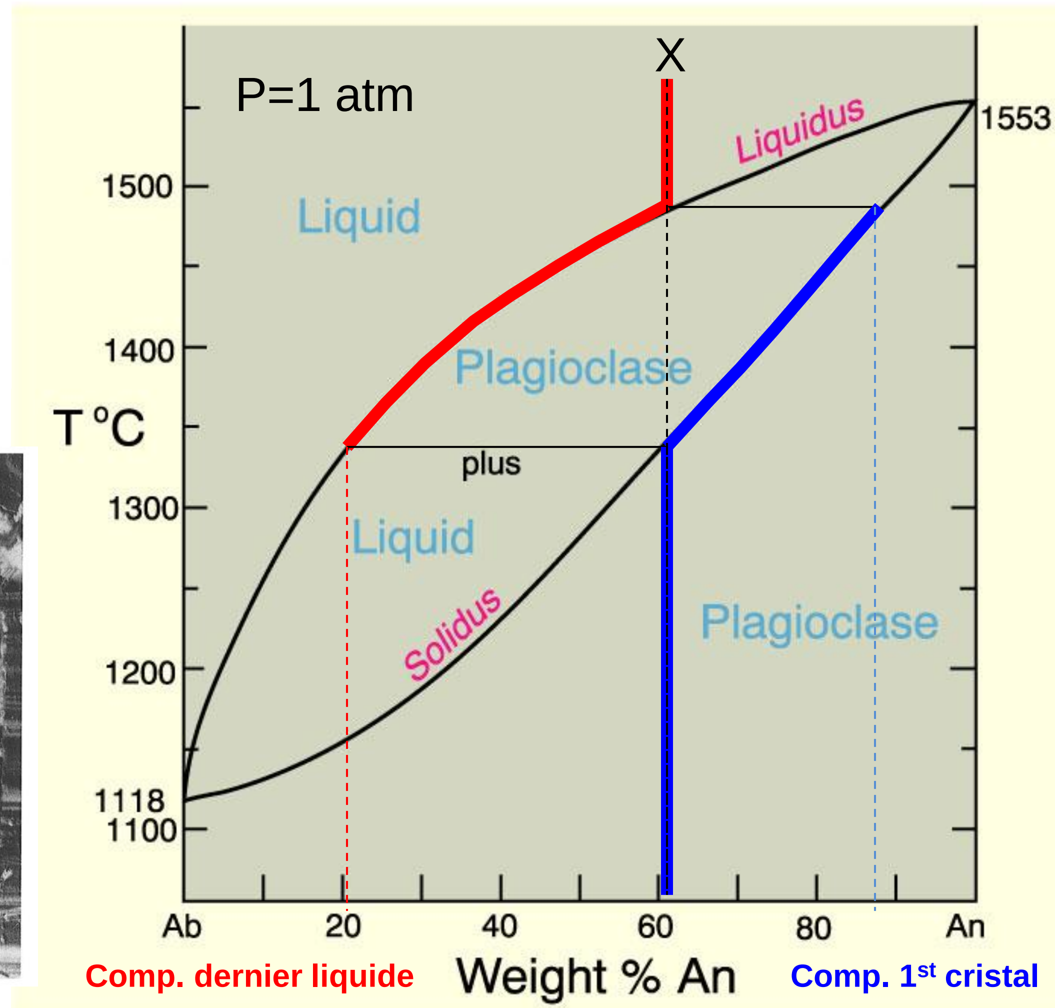
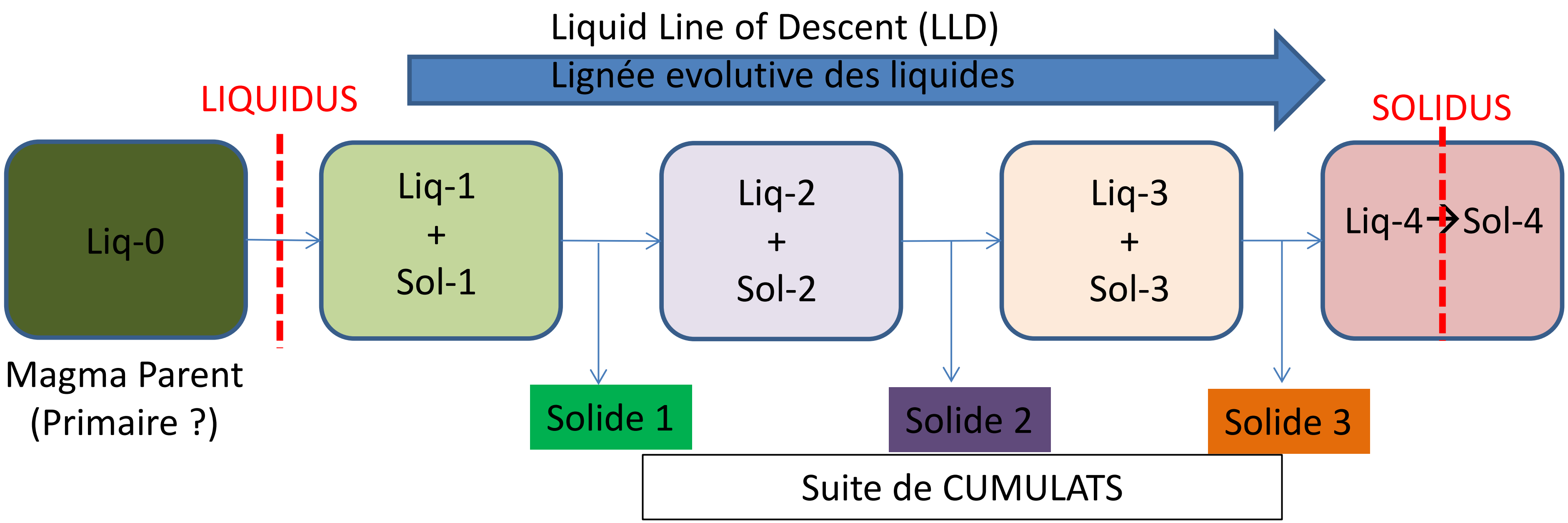


FIG. 7. Equilibrium diagram (after Bowen and Andersen) of the system, forsterite-silica (with additions by Greig in high silica compositions).





Cristallisation fractionnée

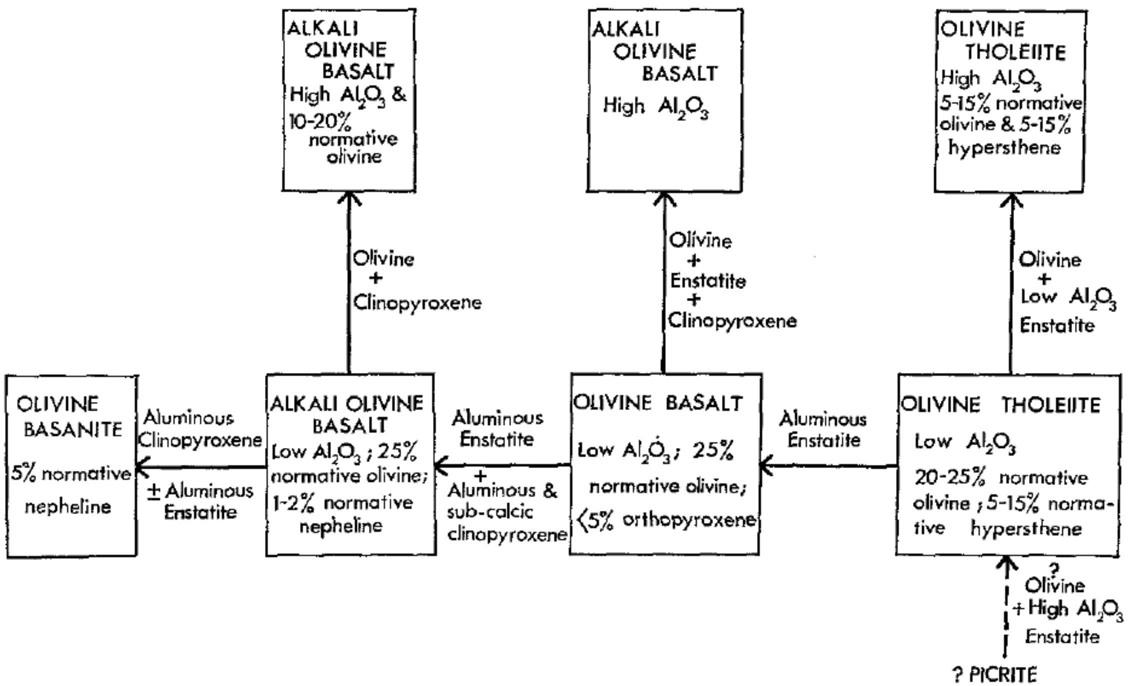


Processus de fractionnement complexe
f(P, T, X) et conditions Physique de transfert / cristallisation

CF opère à tous les niveaux,
de la source jusqu'au site des produits finaux

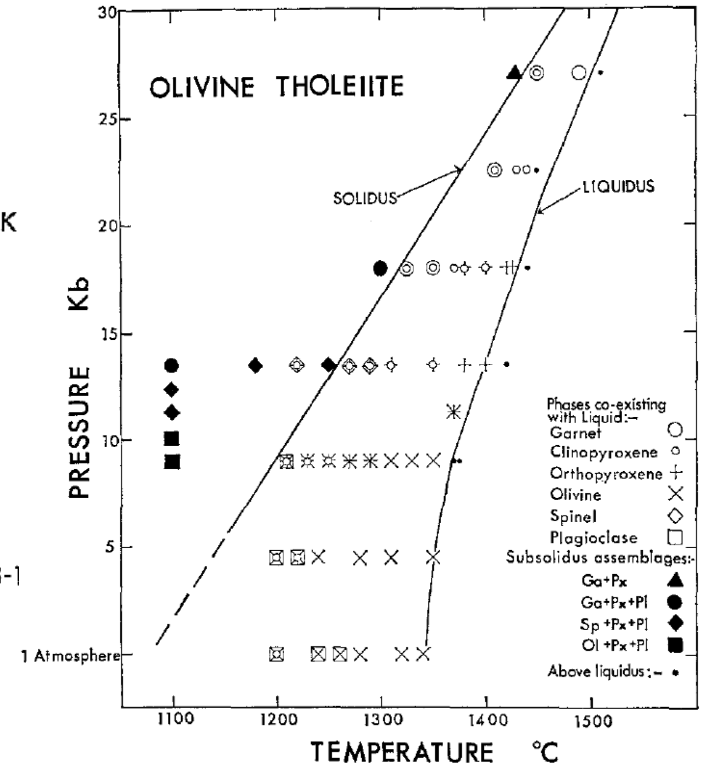
In-situ / filtre-presse / convection / segregation/ percolation

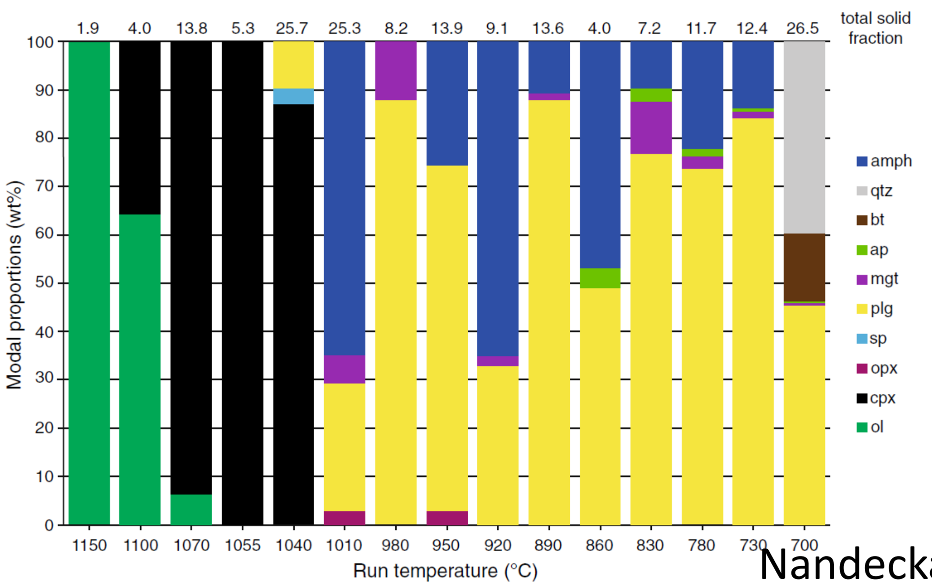
'CLOSED SYSTEM' FRACTIONATION OF BASALTIC MAGMA AT VARIOUS PRESSURES



9 K

13-1





Nandeckar 2014

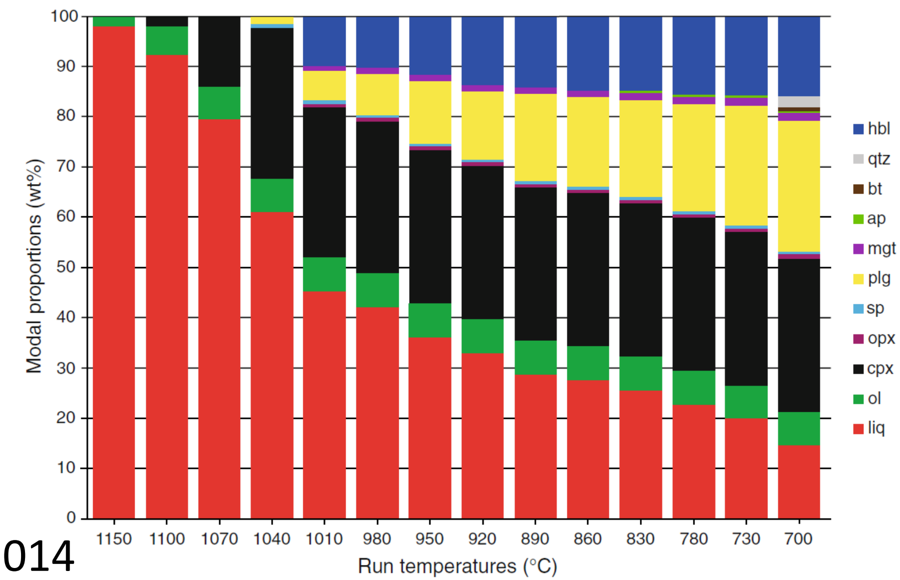
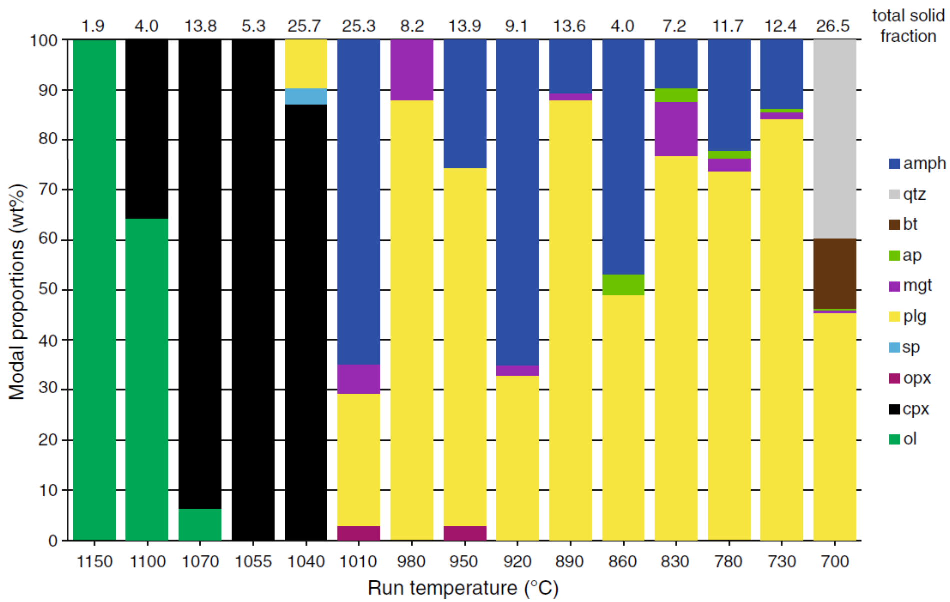
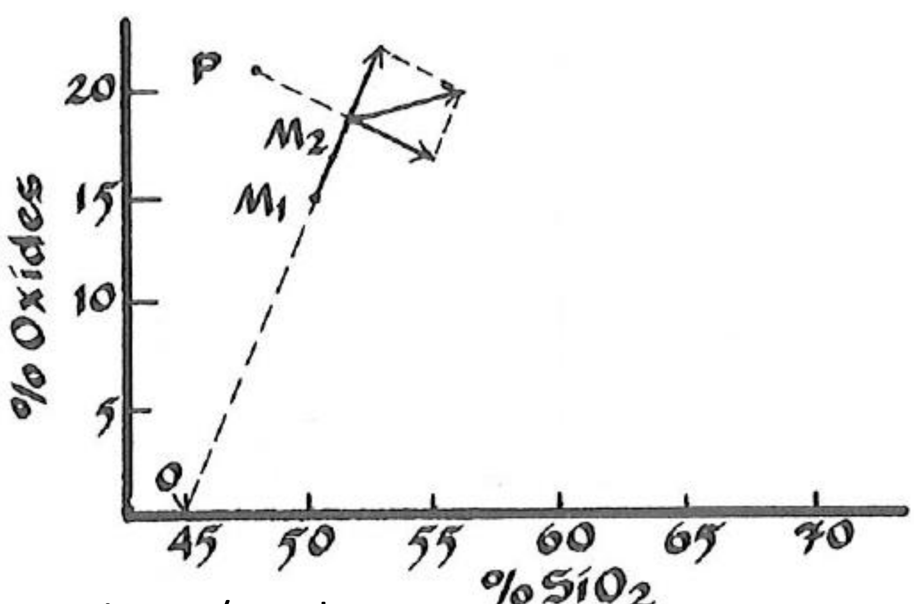
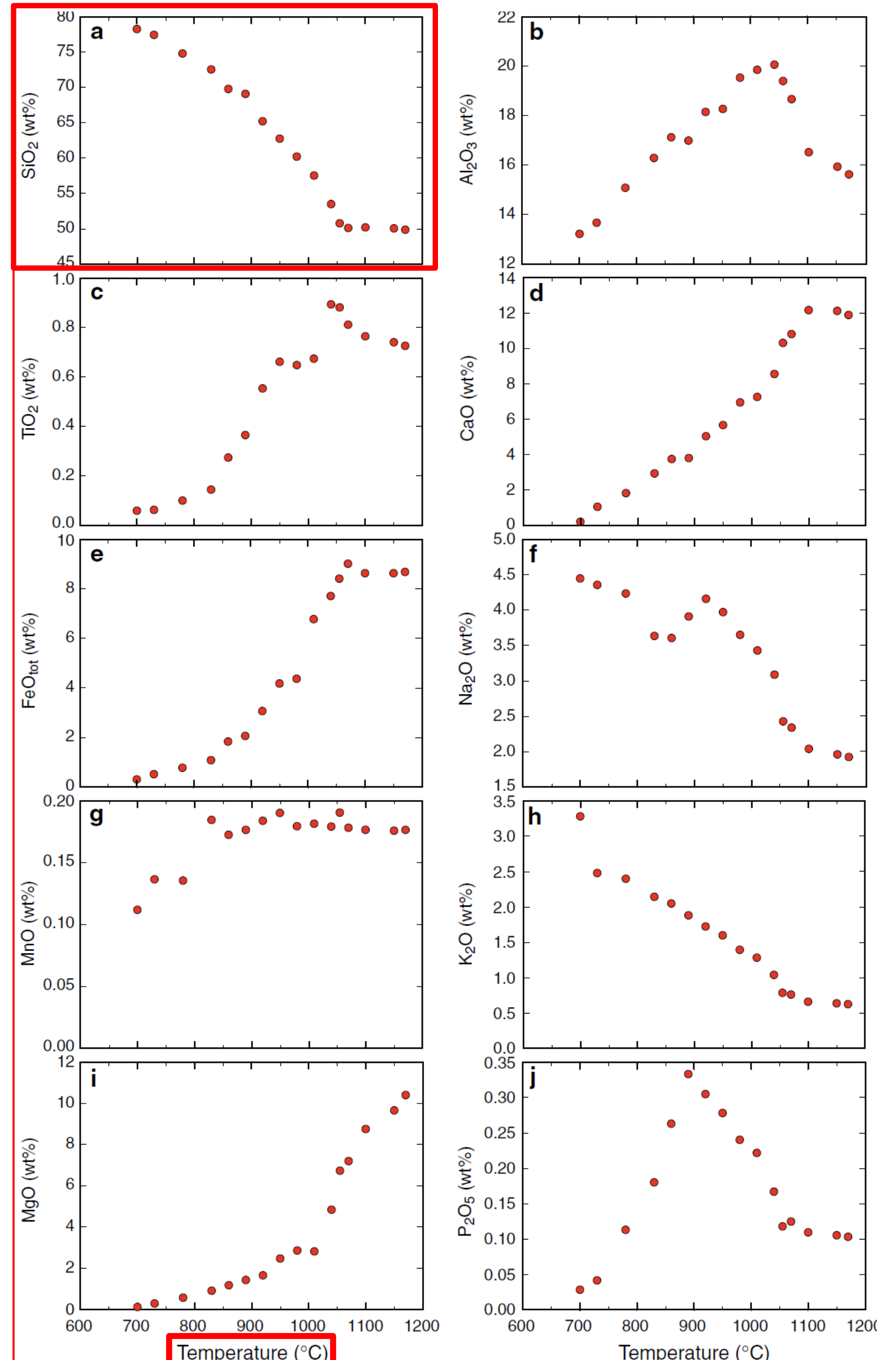


Diagramme de Harker





Mc Birney / Book



= SiO2

Evolution des basaltes

- Cristallisation fractionnée
- Melange (Mixing)
- Immiscibilité

MIXING

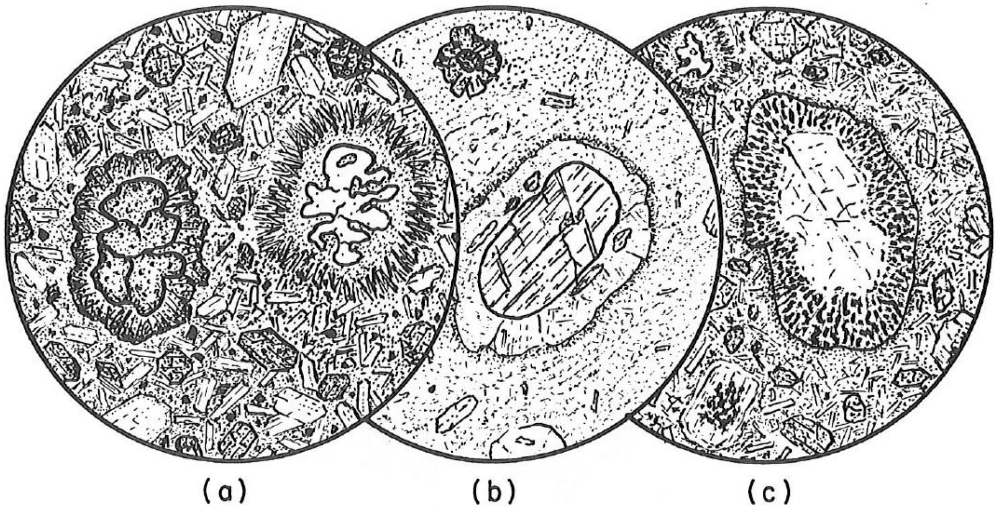
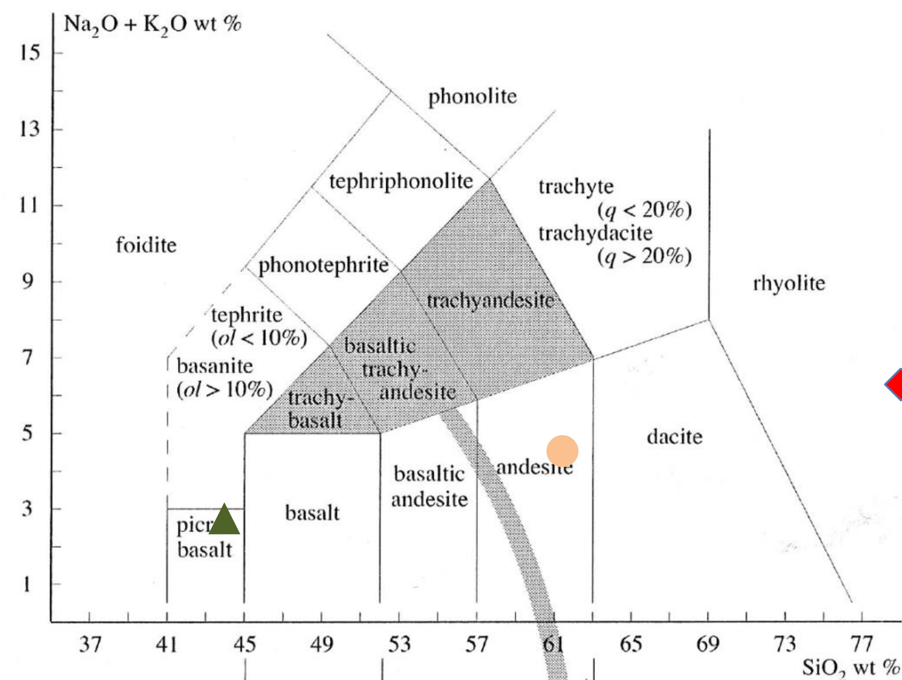


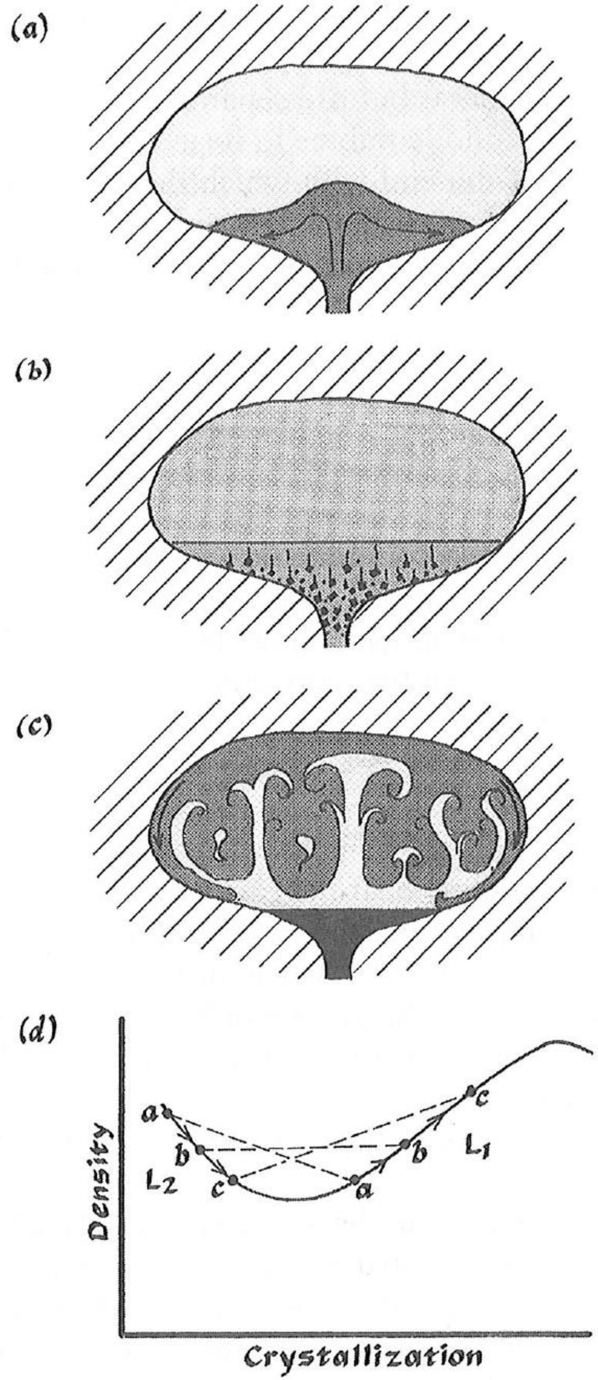
Figure 5-9 Textures of contaminated volcanic rocks. (a) Xenocrysts of quartz are jacketed by pyroxene, and nearby crystals of olivine have reaction rims of the same mineral. Specimen is from a basaltic lava erupted through granitic basement rocks in southeastern Guatemala. (b) Rounded and resorbed xenocrysts of plagioclase have reacted with a rhyolitic liquid and precipitated a rim of potassium feldspar. A small grain of olivine is rimmed with pyroxene. The specimen is from a group of mixed rhyolitic and basaltic lavas near the Gardiner River, Yellowstone National Park. (c) An alkali basalt from the vicinity of Gharian, Libya, contains xenocrysts of potassium feldspar and quartz derived from granitic rocks through which the magma rose. The feldspar is rimmed with a vermicular zone of glass.

0.5 Bas + 0.5 Rhy = And !

Présence de phénocristaux (Xénocristaux)
En déséquilibre /résorption avec le liquide
+
Assemblage (microlithes) en équilibre avec le liquide



Recharge / évolution dans les chambres superficielles



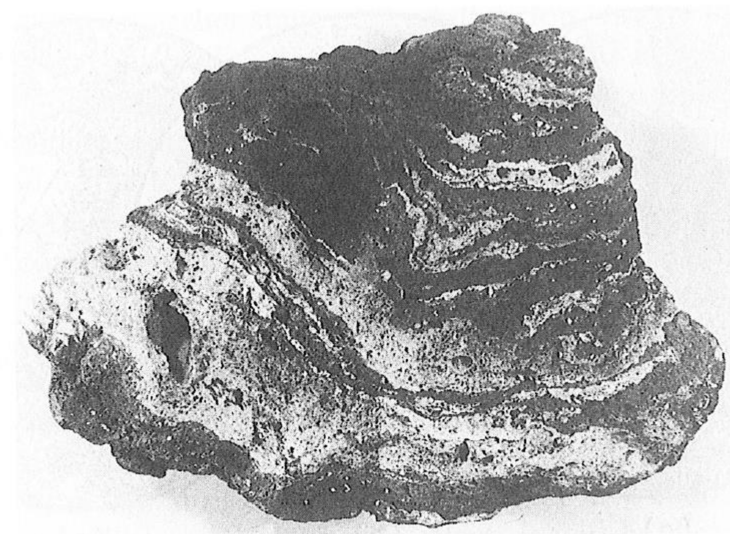
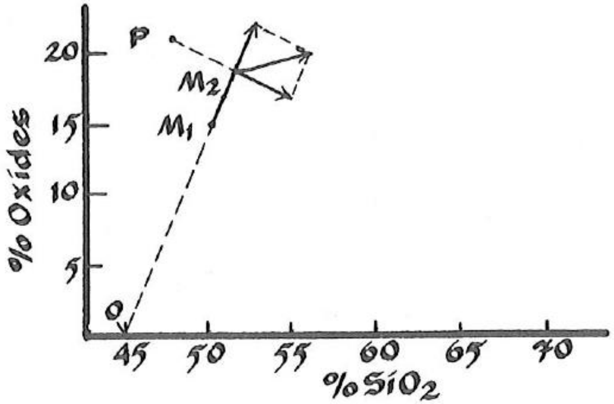
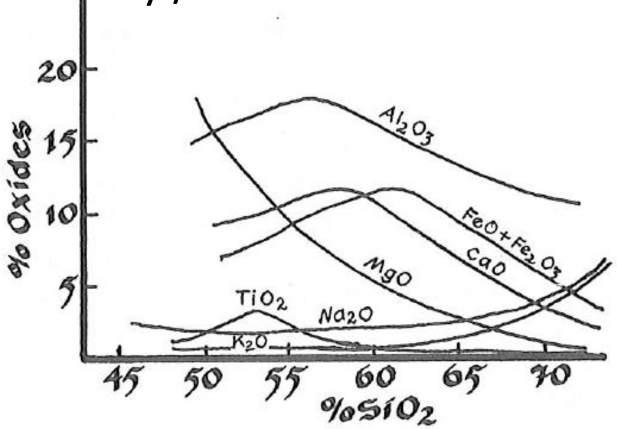


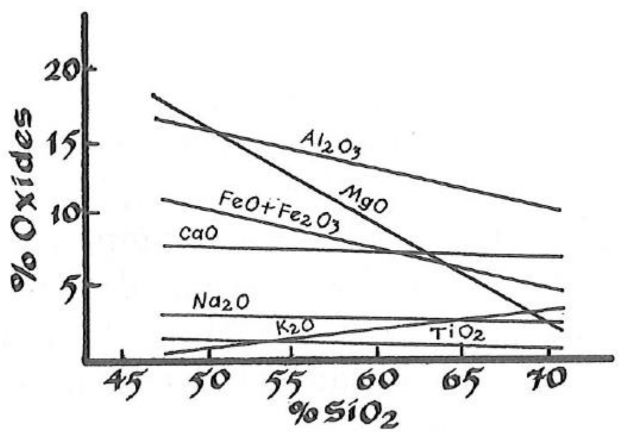
Figure 5-10 A mixture of basalt and rhyolite in a bomb ejected from a cinder cone on the flank of Newberry Volcano, Oregon. The mixing must have taken place during rapid eruption from two magmatic bodies in close proximity at a shallow depth beneath the volcano.

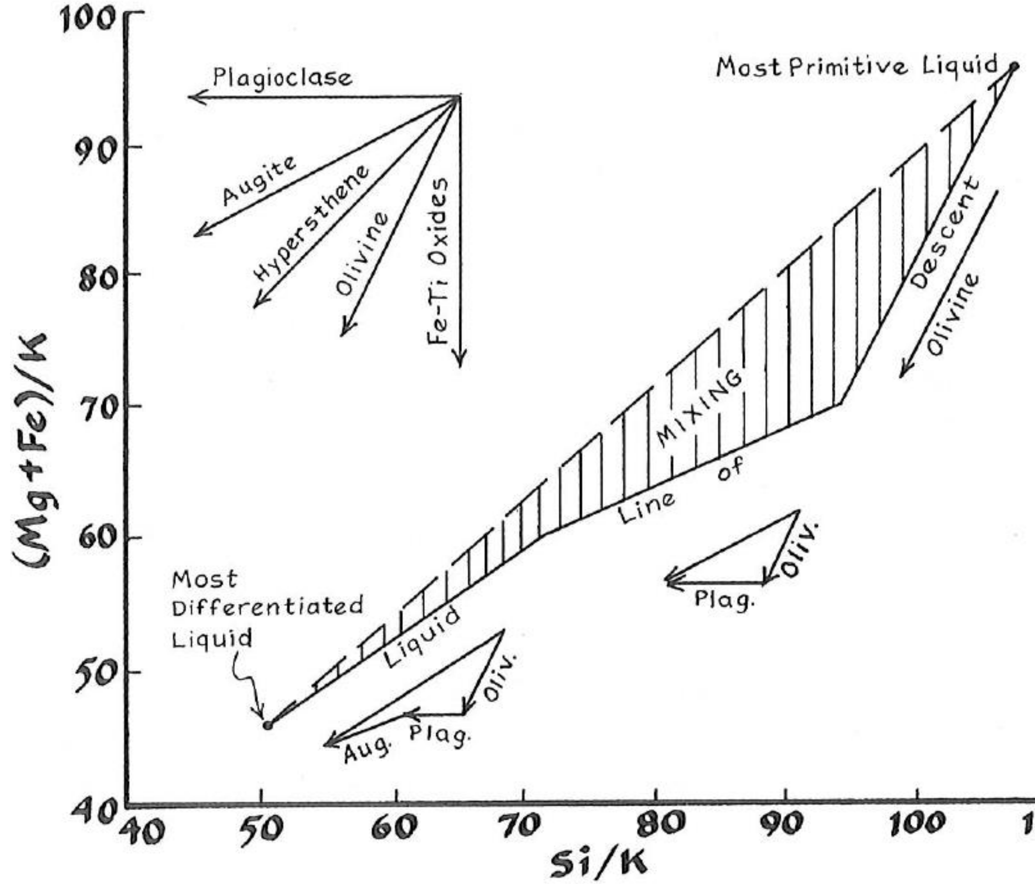
Figure 5-11 Because of the density minimum in the basic range of tholeiitic magmas (Fig. 2-12), it is possible that a new injection of hot basic magma L_2 could be denser than a slightly more evolved magma, L_1, that had already begun to differentiate in a shallow chamber. On intrusion, the denser new magma would pond at the base of the reservoir (a), but on cooling and crystallizing, the new magma could fractionate olivine and become lighter, whereas the original magma could fractionate olivine and plagioclase and evolve toward *a* more iron-rich and denser composition (b). If this process continues, the density relationships might be reversed (c), in which case the two liquids could overturn; if mixed turbulently, the resulting magma could have an intermediate composition and density. The schematic diagram (d) at the bottom shows the density relationships with tie-lines connecting the two magmas at each of the stages above. (Based on a model by R. S. J. Sparks, P. Meyer, and H. Sigurdson, 1980, *Earth & Planet. Sci. Ltrs.* 46:419–430.)



Mc Birney / Book



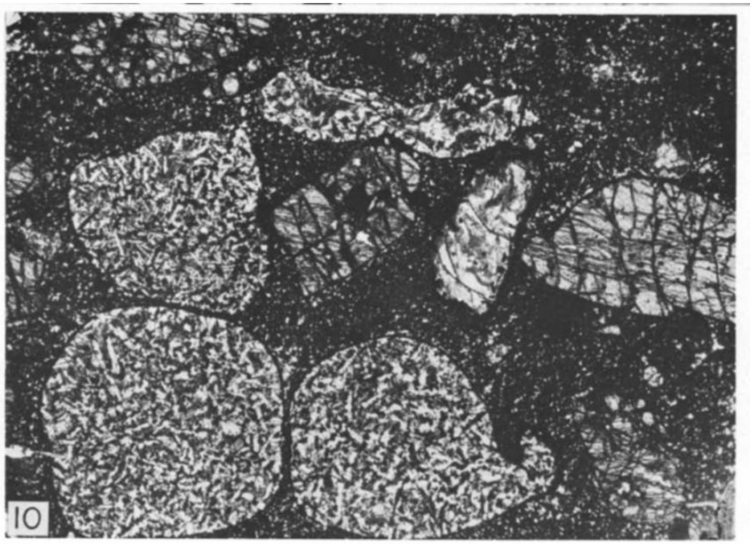


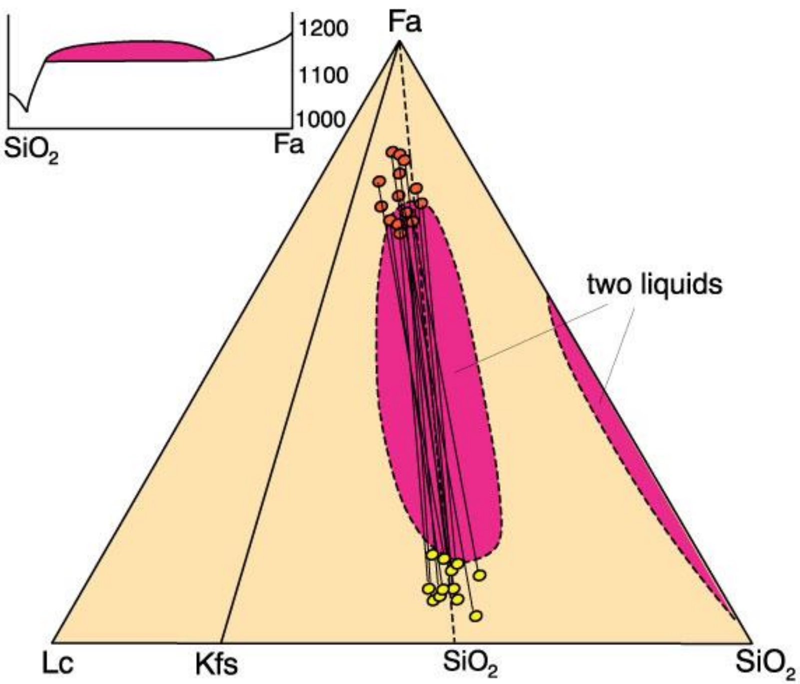


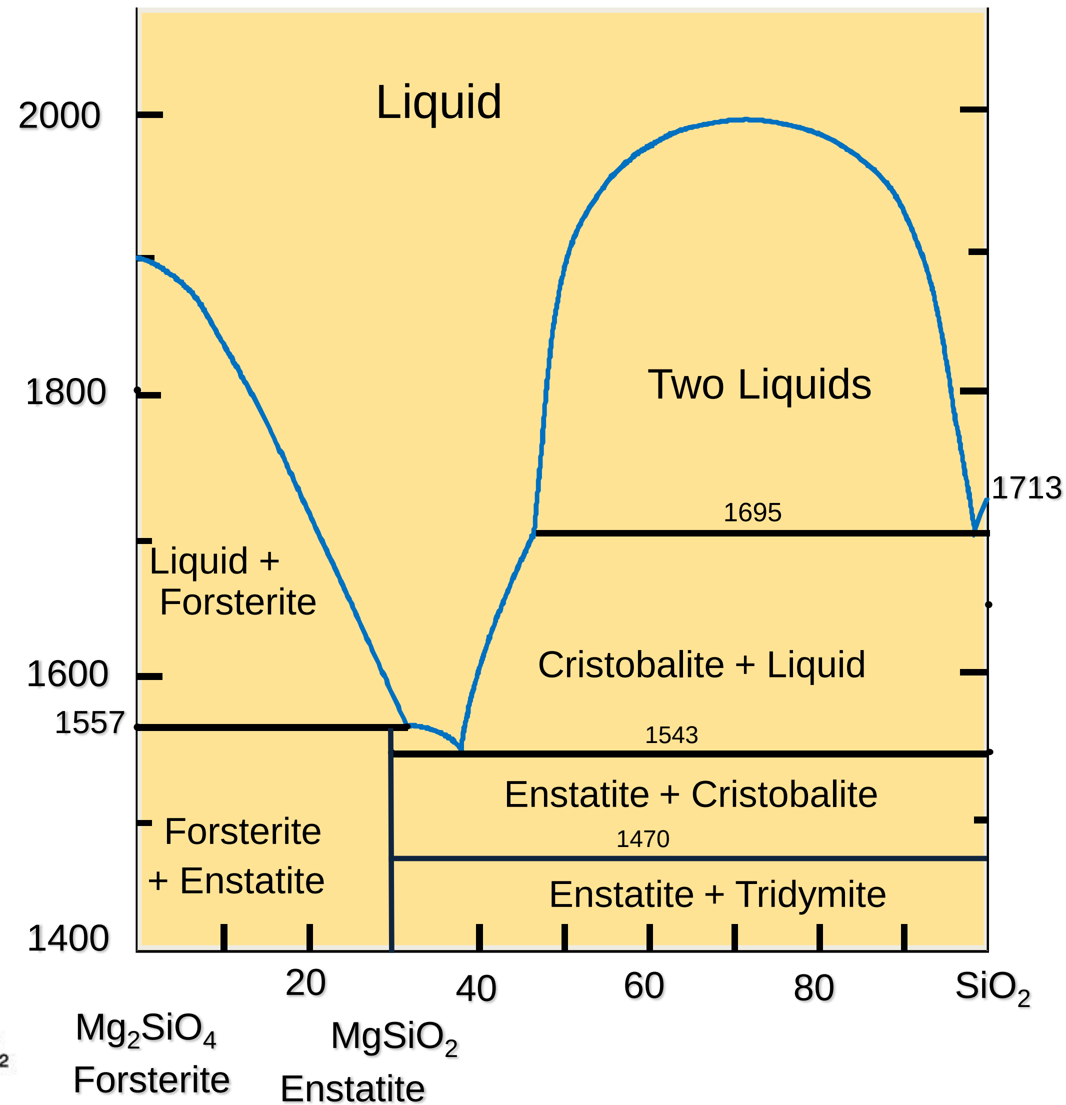
Evolution des basaltes

- Cristallisation fractionnée
- Melange (Mixing)
- Immiscibilité

Immiscibilités







Carbonatite

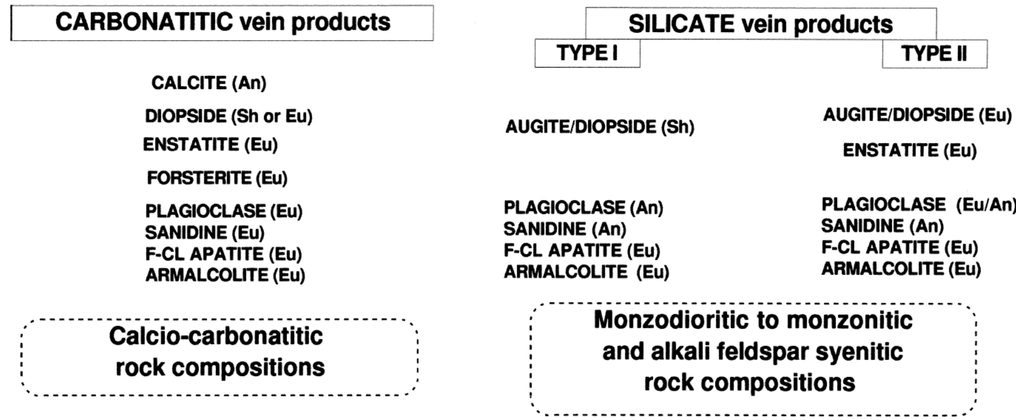
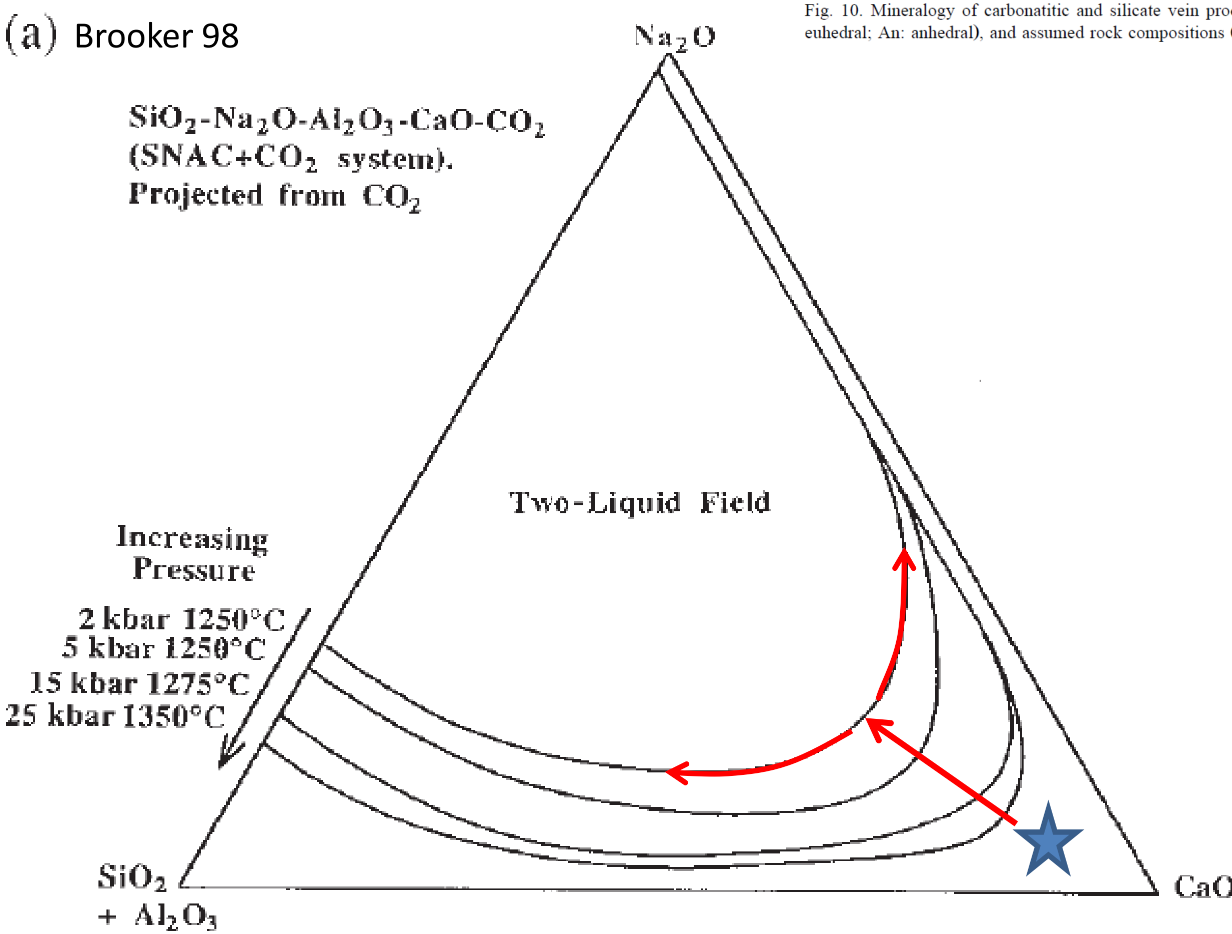
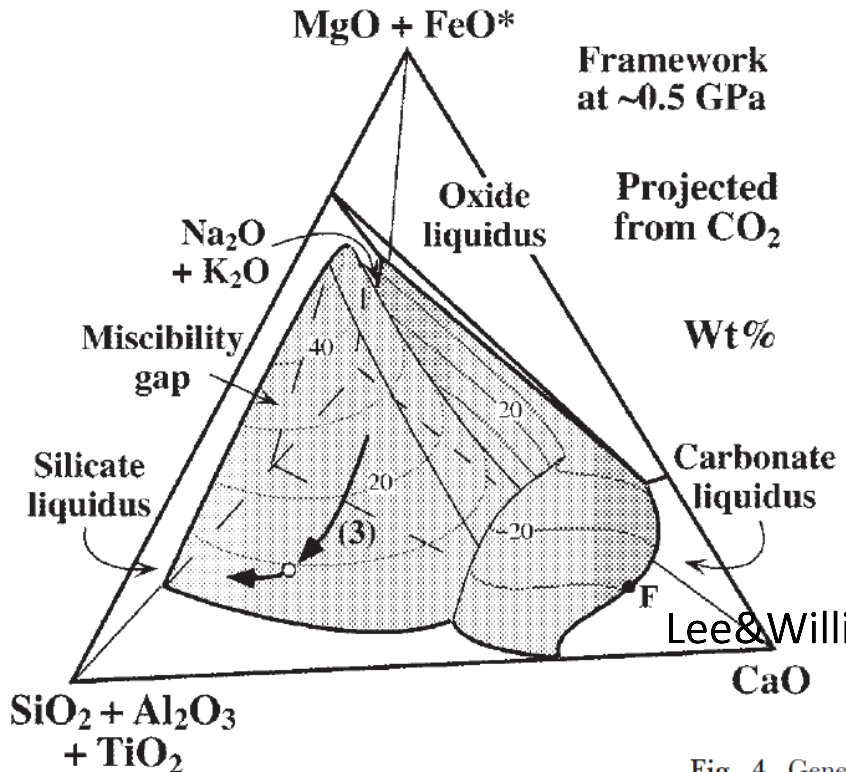


Fig. 10. Mineralogy of carbonatitic and silicate vein products, with the crystallization habit of each type of mineral (Sh: subhedral; Eu: euhedral; An: anhedral), and assumed rock compositions (see text for explanation).

Chalot-Prat 99

(a) Brooker 98





Lee&Willie 98

Fig. 4. Generalized pseudoquaternary phase diagram at 0·5 GPa (projected from CO_2), showing dark- and light-shaded liquidus surfaces for the silicate–carbonate field boundary and liquid miscibility gap, with contours for wt % (MgO + FeO*). The large oxide liquidus volume near the (MgO + FeO*) apex is related to the periclase field (Fig. 1b). (See Fig. 1b for liquid F.) Arrow (3) corresponds to path (3) in Fig. 3.