# Lecture 9 - Ternary Systems

**Monday, February 14th, 2005**

# C = 3: Ternary Systems:

## Example 1: Ternary Eutectic

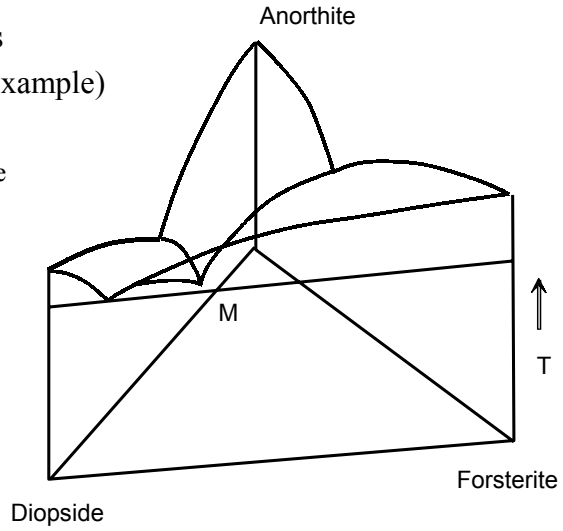
### Di - An - Fo

Note three binary eutectics

No solid solution (in this example)

Ternary eutectic = M

(which is the lowest temperature in the system at $1270^0$C)



# T - X Projection of Di - An - Fo

This is a good analog of a basaltic magma WHY?

Liquidus resembles 3 hills with summits at An, Di and Fo with intervening valleys (cotectics) Arrows indicate decreasing temperature

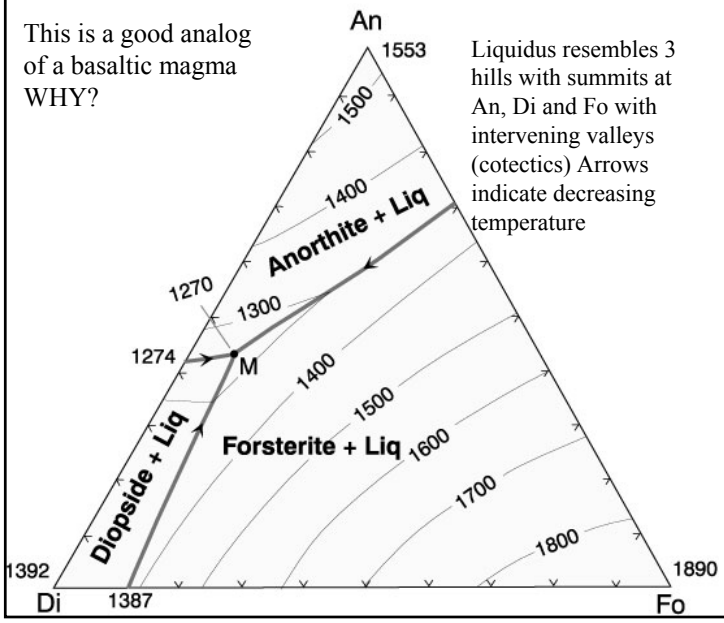
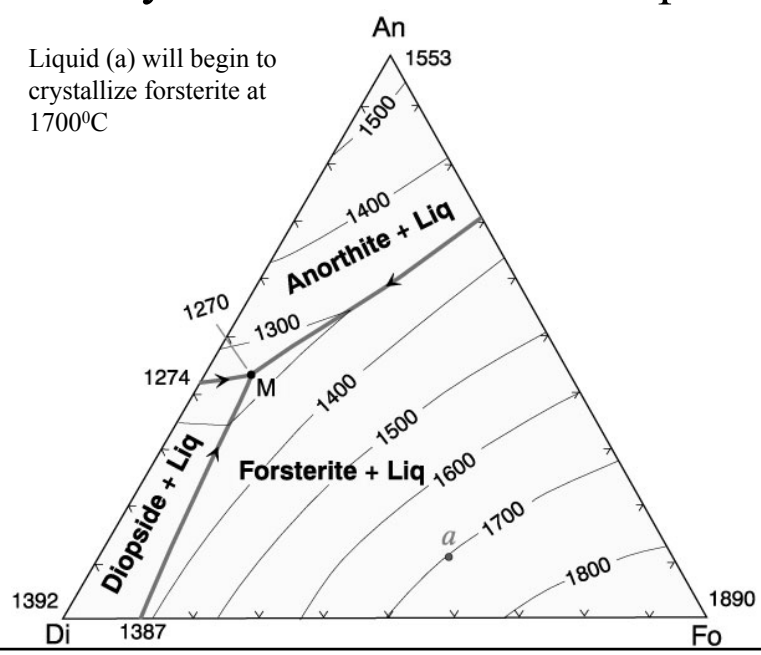



**Figure 7-2. Isobaric diagram illustrating the liquidus temperatures in the Di-An-Fo system at atmospheric pressure (0.1 MPa). After Bowen (1915), A. J. Sci., and Morse (1994), Basalts and Phase Diagrams. Krieger Publishers.**

# Crystallization Relationships

Liquid (a) will begin to crystallize forsterite at $1700^0$C

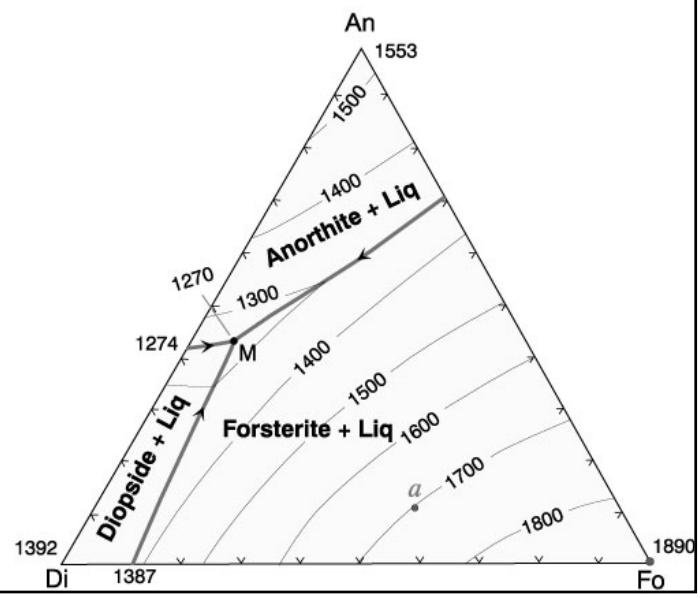


Pure Fo forms

Just as in binary system

$\phi = ?$

$F = ?$

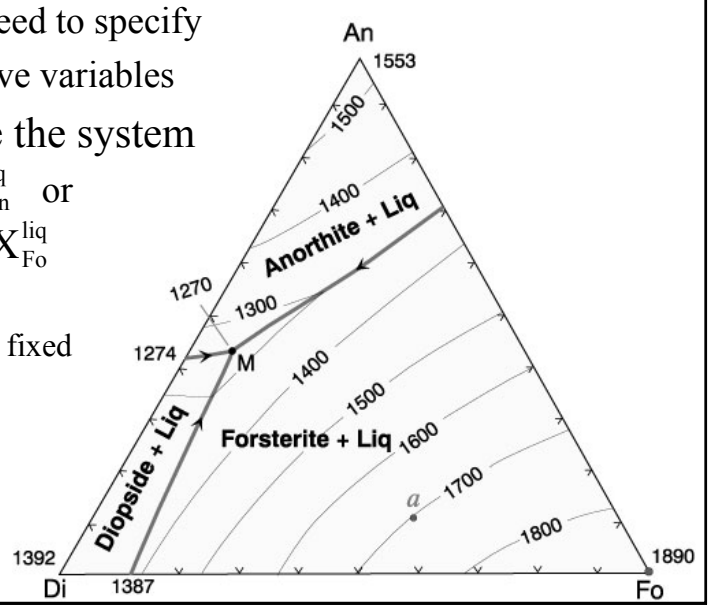


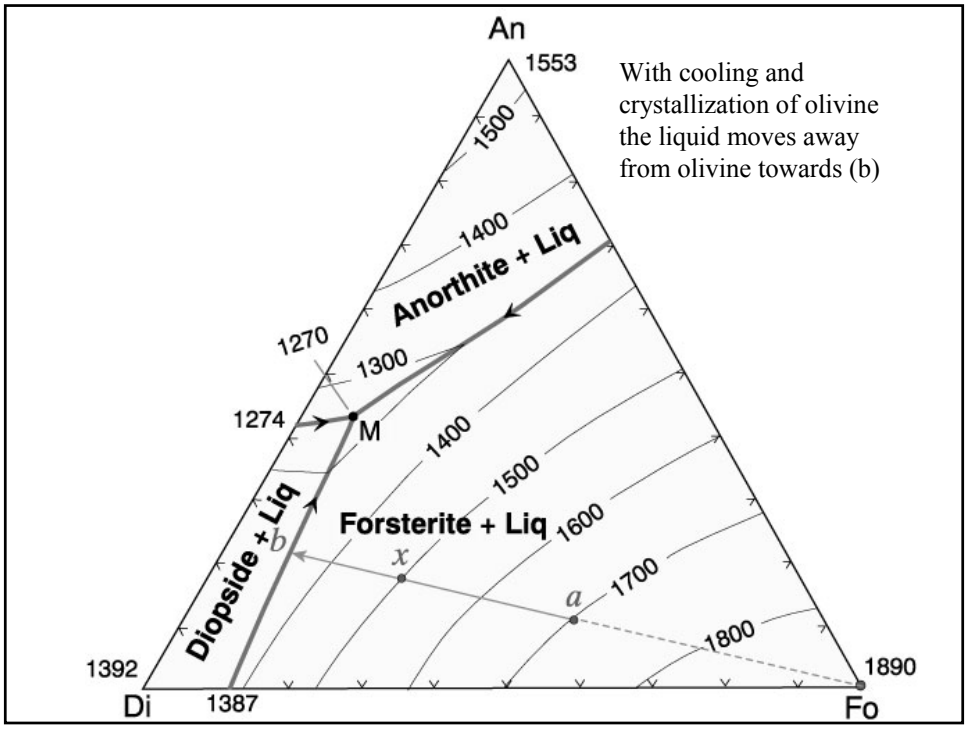

- $\phi = 2$ (Fo + Liq)
- $F = 3 - 2 + 1 = 2$

If on liquidus, need to specify only 2 intensive variables to determine the system

- T and $X_{An}^{liq}$ or
- $X_{An}^{liq}$ and $X_{Fo}^{liq}$

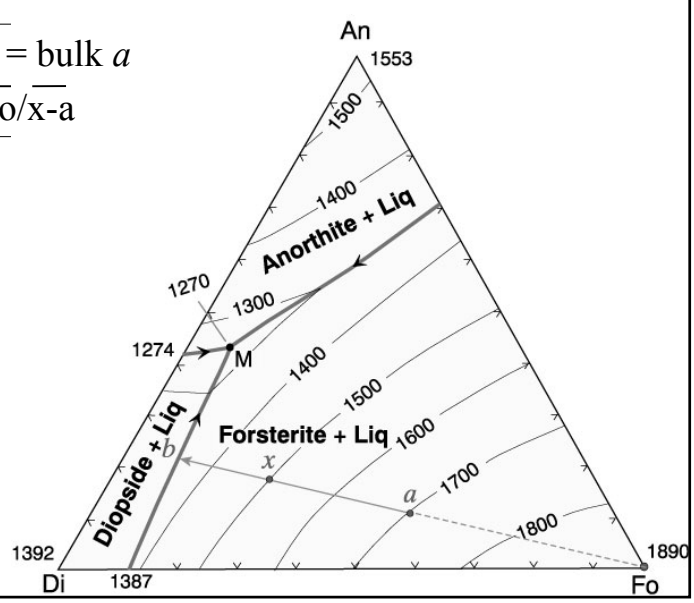
X of pure Fo is fixed

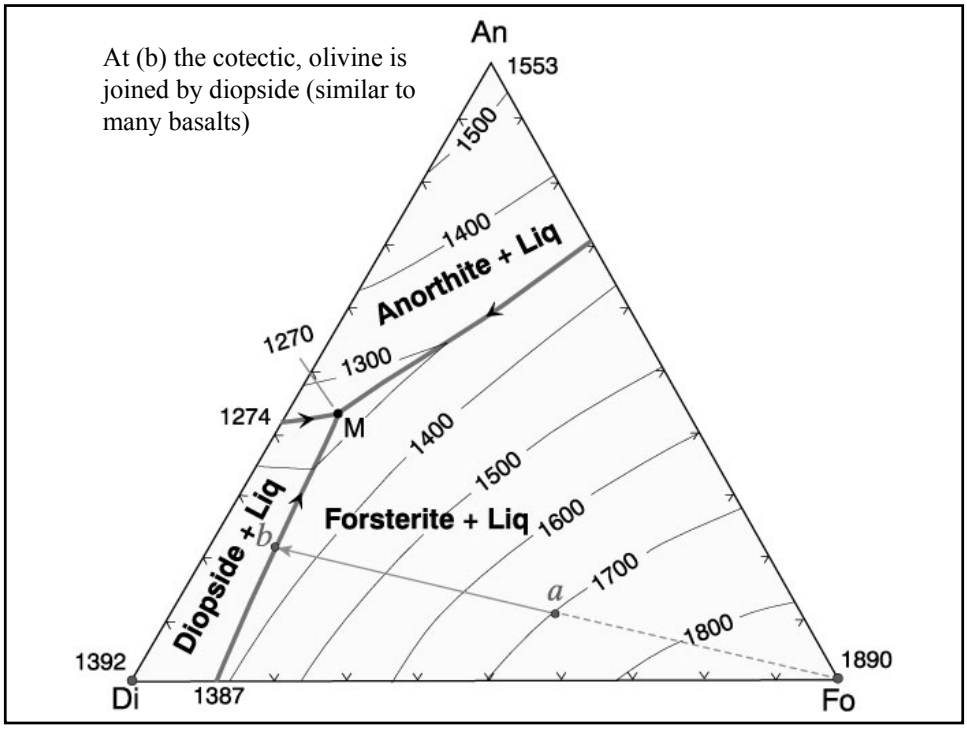





Lever principle → relative proportions of liquid & Fo

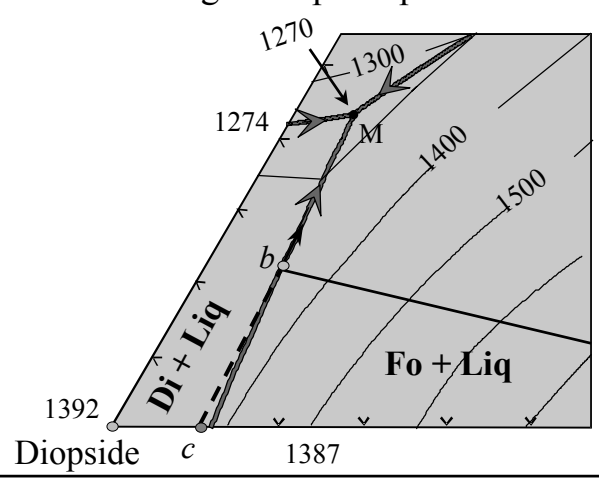
- At 1500°C
  - Liq $x$ + Fo = bulk $a$
  - x/Fo = $\overline{\text{a-Fo}}/\overline{\text{x-a}}$



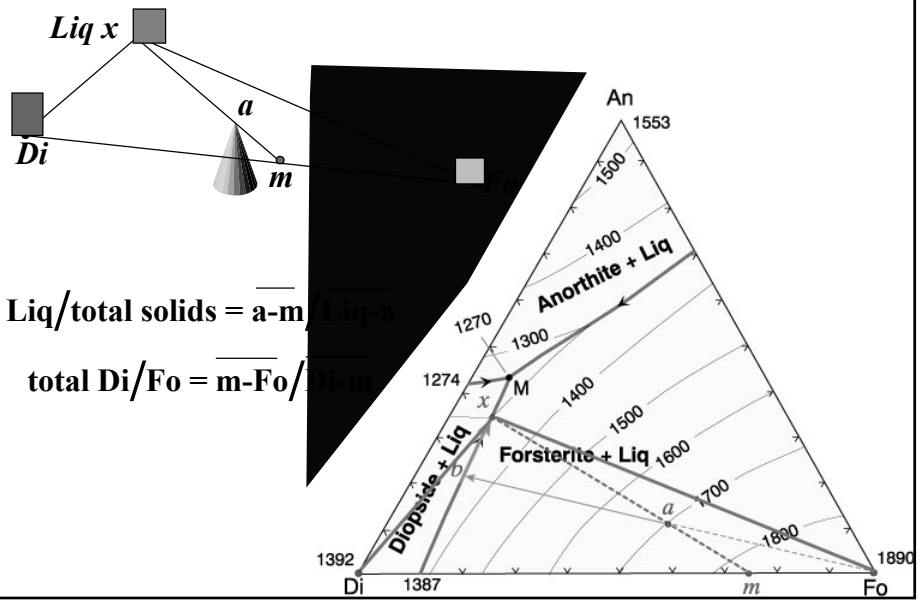



- New continuous reaction as liquid follows cotectic:

  $Liq_A \rightarrow Liq_B + Fo + Di$
- Bulk solid extract is given by point (c) (mostly olivine)
- Di/Fo in bulk solid extract using lever principle



- At 1300°C liquid = X
- Imagine triangular plane X - Di - Fo balanced on bulk *a*



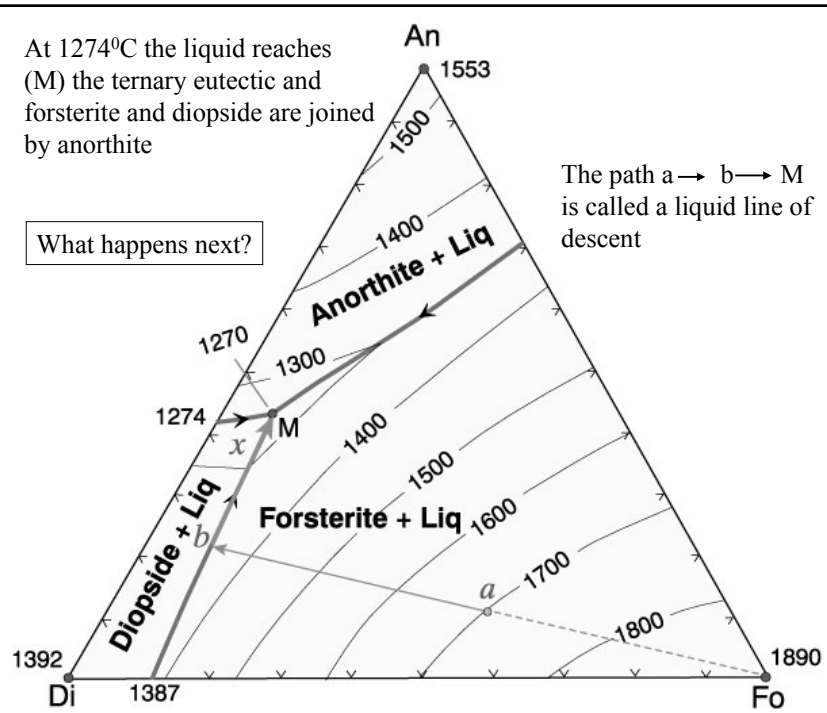

**Liq/total solids = $\overline{\text{a-m}}$/$\overline{\text{Liq-a}}$**

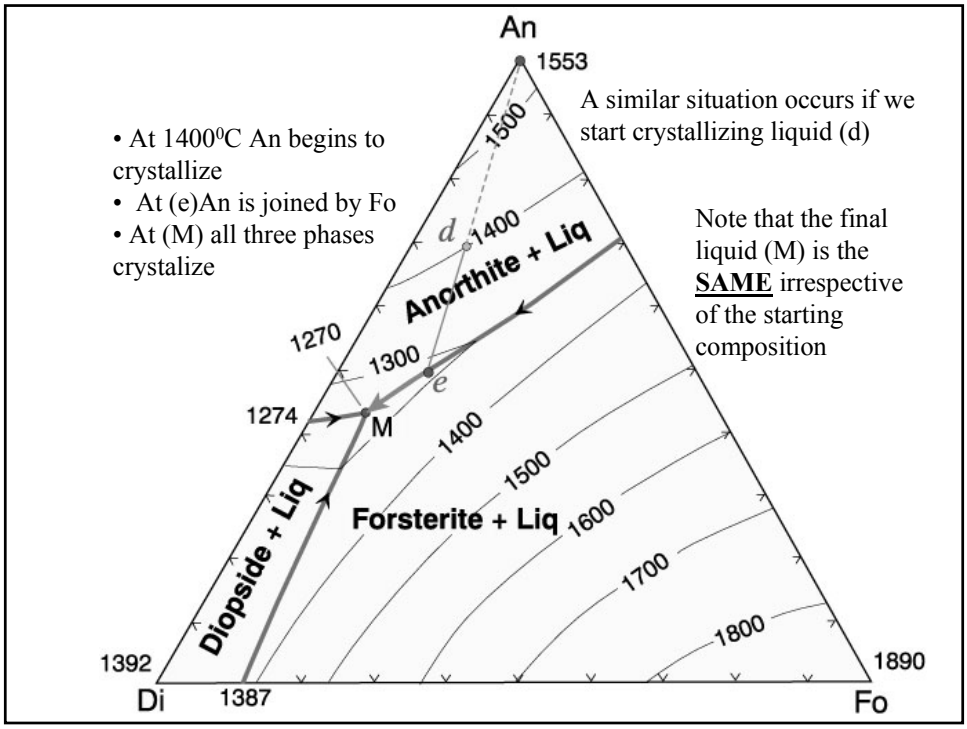
**total Di/Fo = $\overline{\text{m-Fo}}$/$\overline{\text{Di-m}}$**

At 1274°C the liquid reaches (M) the ternary eutectic and forsterite and diopside are joined by anorthite

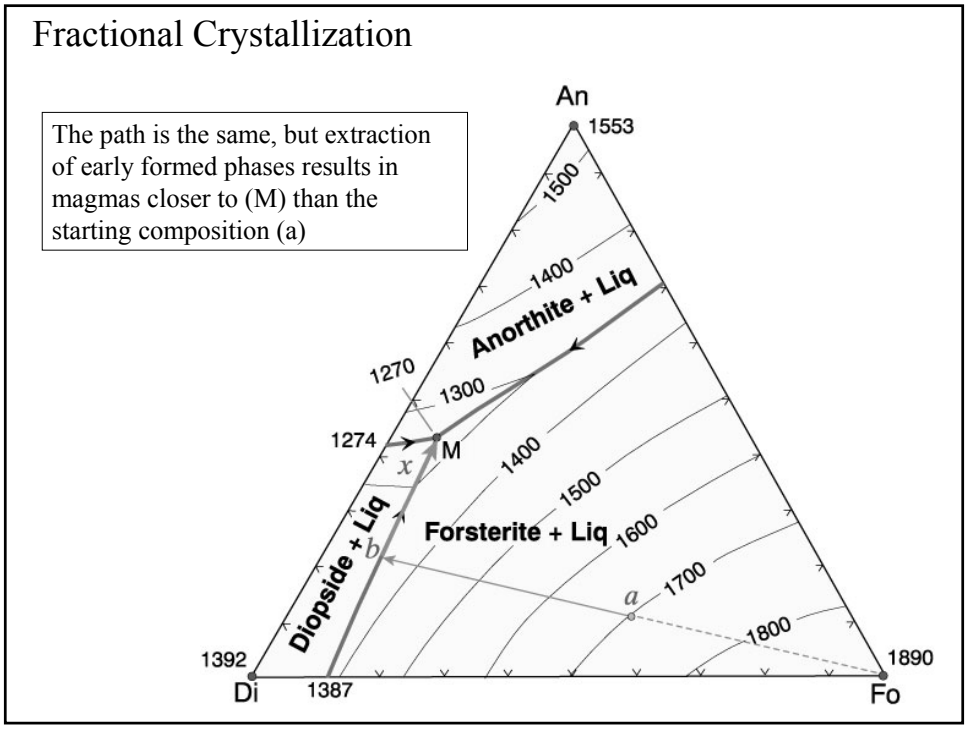
What happens next?

The path a → b → M is called a liquid line of descent

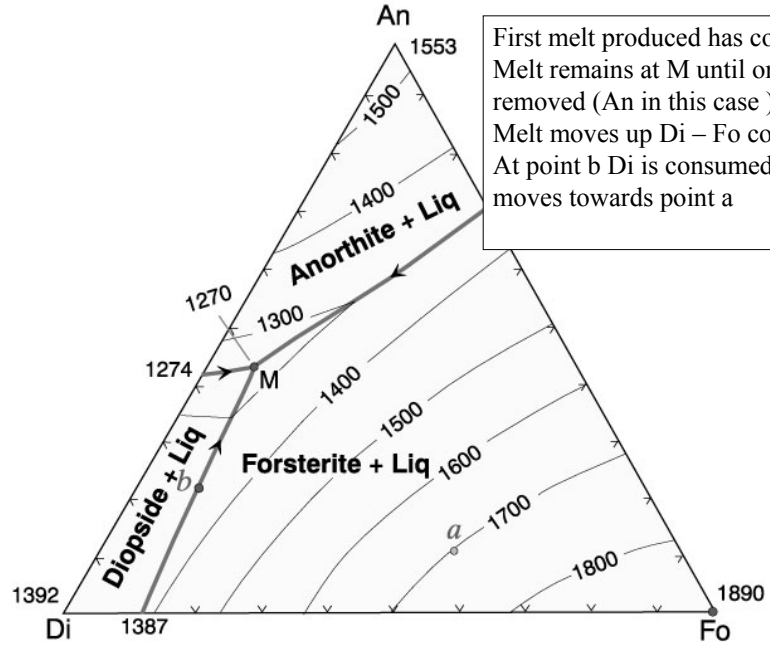





## Fractional Crystallization

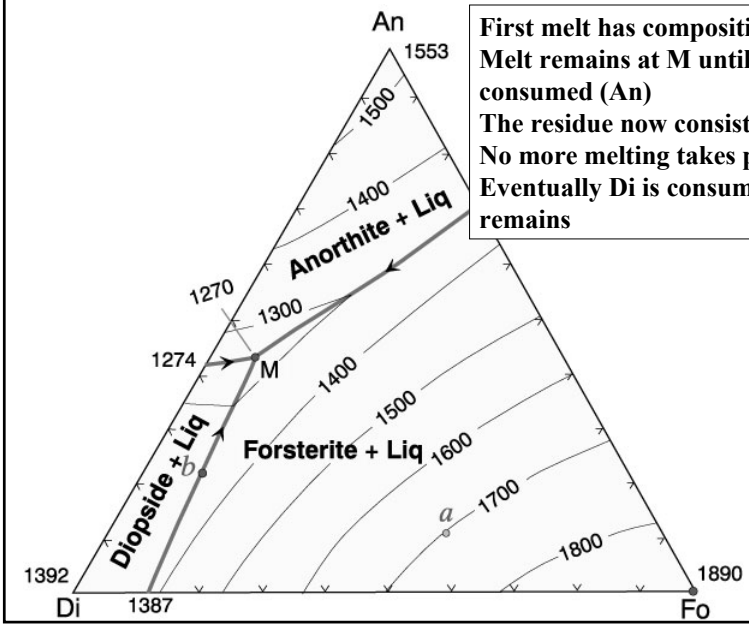


## Equilibrium Melting (melt reacts with residue)




First melt produced has composition M
Melt remains at M until one phase is removed (An in this case )
Melt moves up Di – Fo cotectic to b
At point b Di is consumed and melt moves towards point a

## Partial Melting (continuous removal of melt)



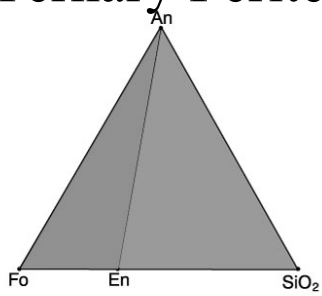

**First melt has composition M**
**Melt remains at M until first phase is consumed (An)**
**The residue now consists of Di and Fo**
**No more melting takes place until 1387$^0$C**
**Eventually Di is consumed and only Fo remains**

# Ternary Peritectic Systems:

(at 0.1 MPa)

3 binary systems:

Fo-An eutectic
An-$SiO_2$ eutectic
Fo-$SiO_2$ peritectic



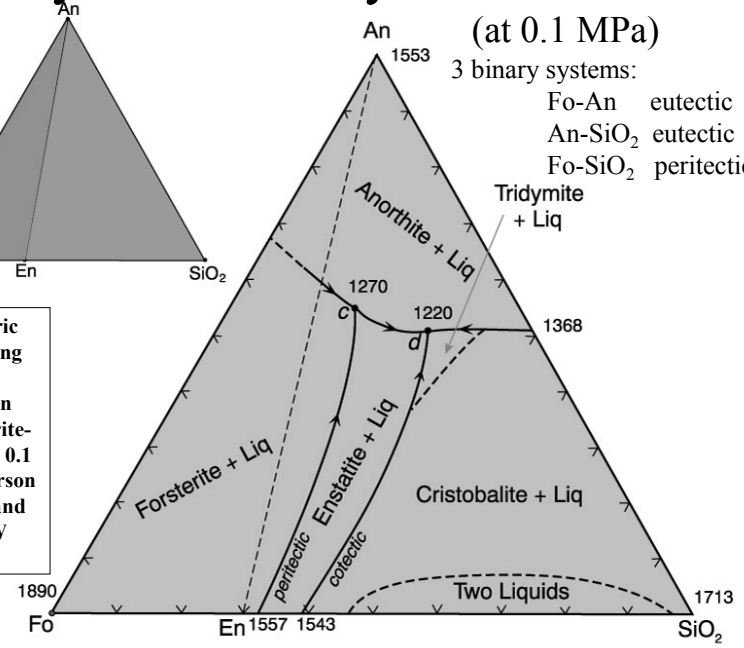



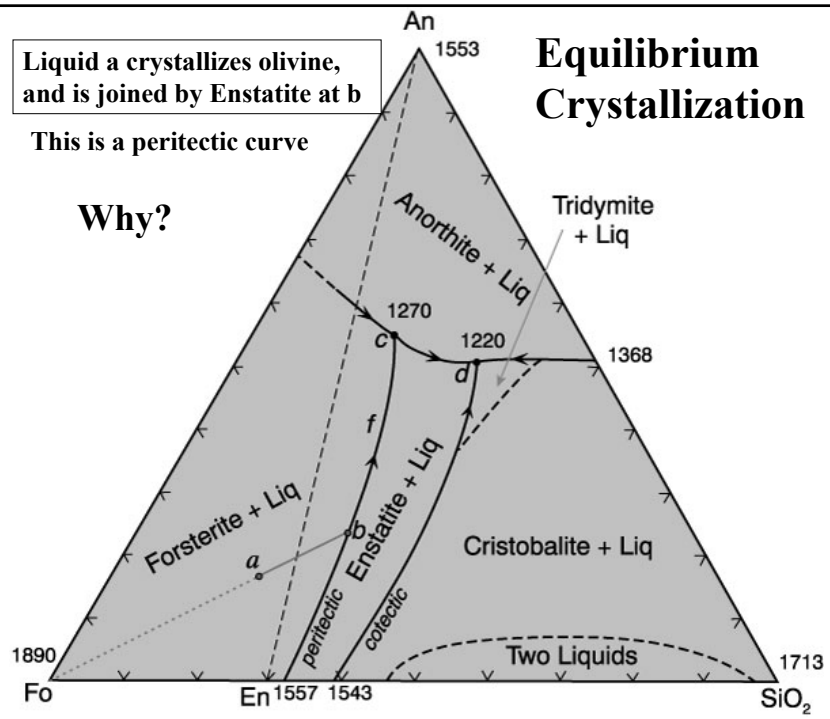

**Figure 7-4. Isobaric diagram illustrating the cotectic and peritectic curves in the system forsterite-anorthite-silica at 0.1 MPa. After Anderson (1915) A. J. Sci., and Irvine (1975) CIW Yearb. 74.**

**Liquid a crystallizes olivine, and is joined by Enstatite at b**

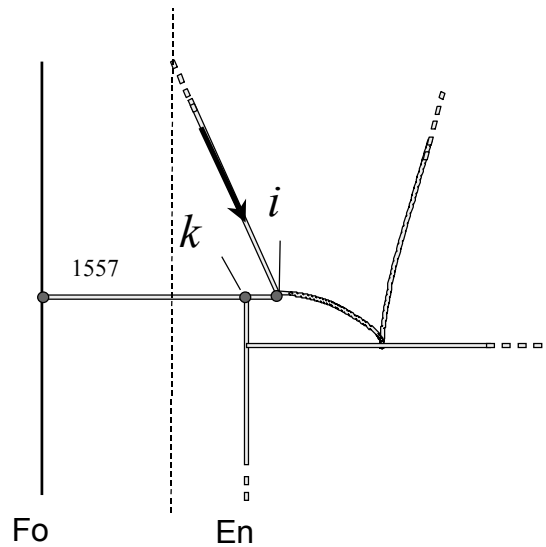
**This is a peritectic curve**

**Why?**

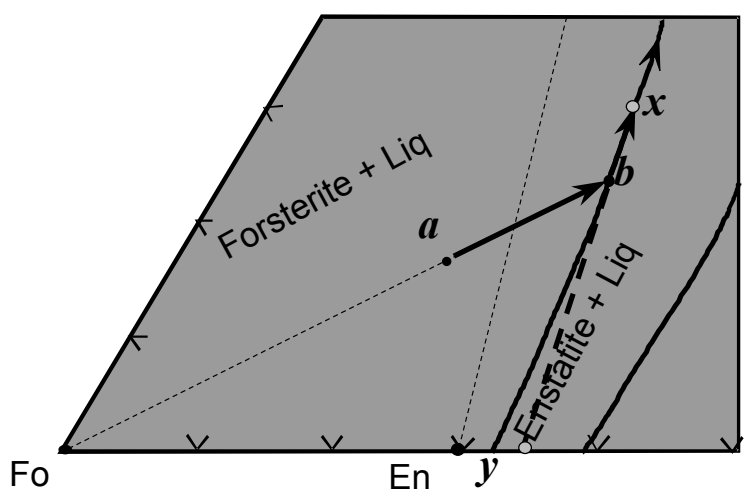
## Equilibrium Crystallization



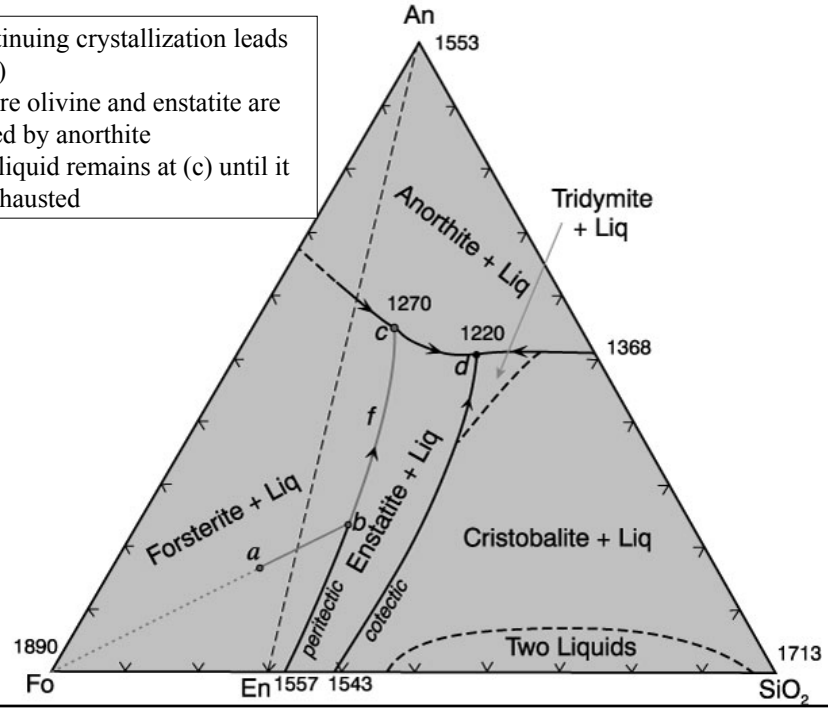
Works the same way as the Fo - En - $SiO_2$ binary




F = 1 therefore the liquid follows the curve (b) to (x)
The bulk composition of xtals being removed is given by the tangent to the curve (y) - only enstatite is available
So olivine is resorbed to produce enstatite

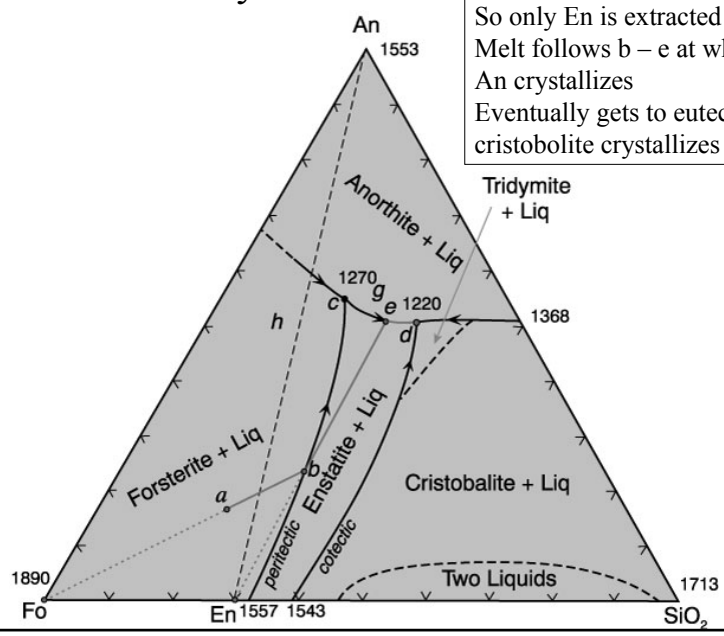


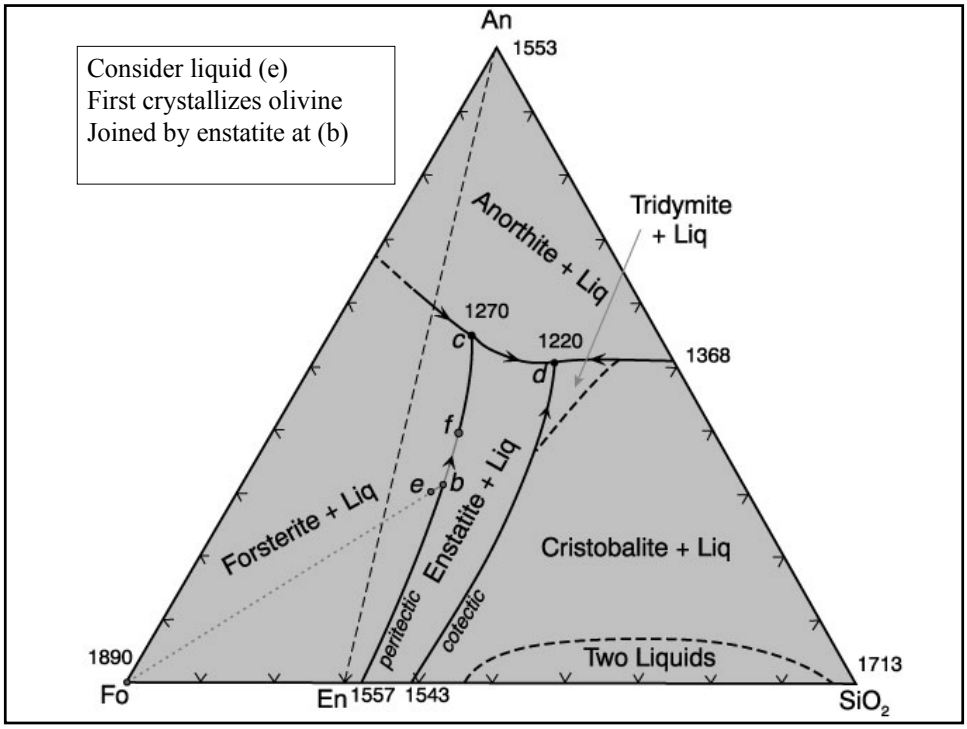
Continuing crystallization leads to (c)
Where olivine and enstatite are joined by anorthite
The liquid remains at (c) until it is exhausted



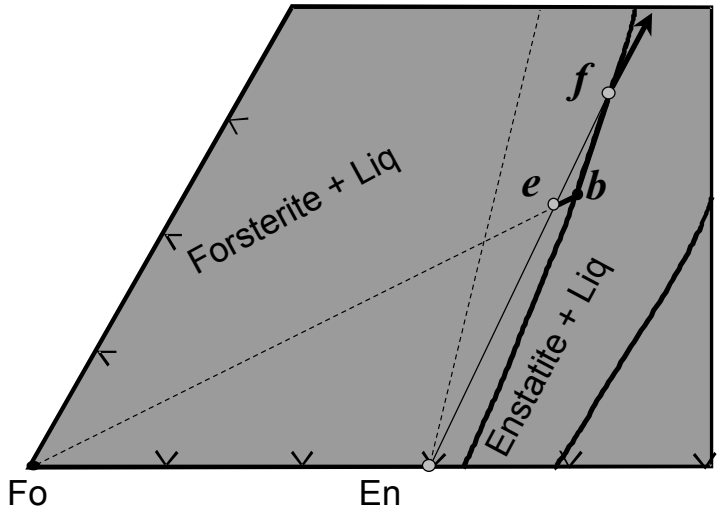

# Fractional Crystallization

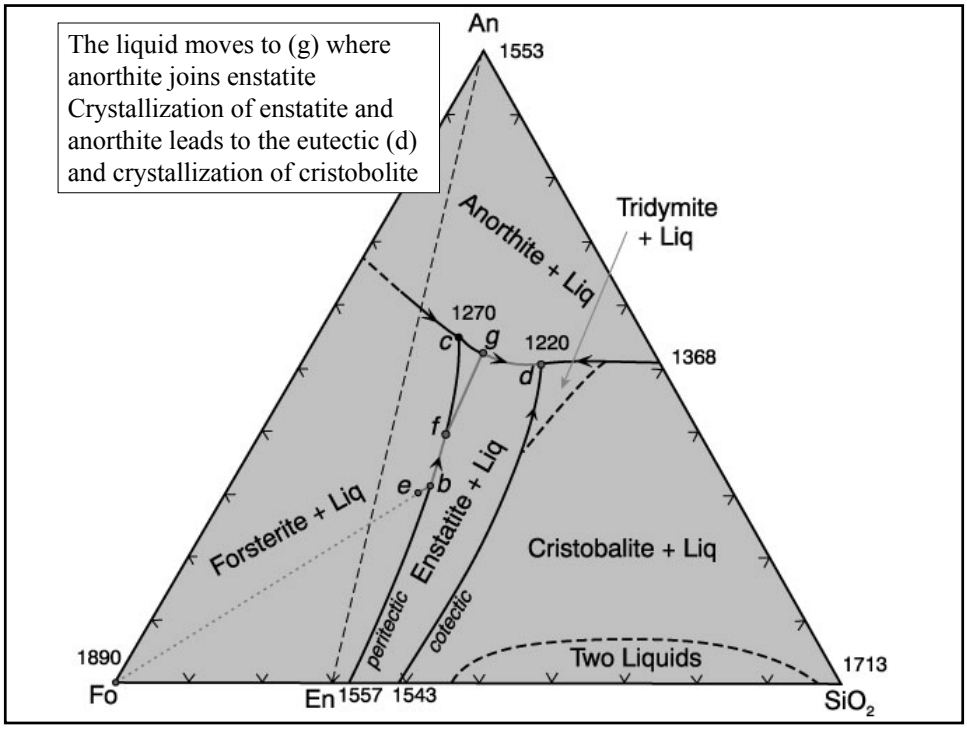
At b there is no Fo left (removed)
So only En is extracted
Melt follows b – e at which point An crystallizes
Eventually gets to eutectic d where cristobolite crystallizes

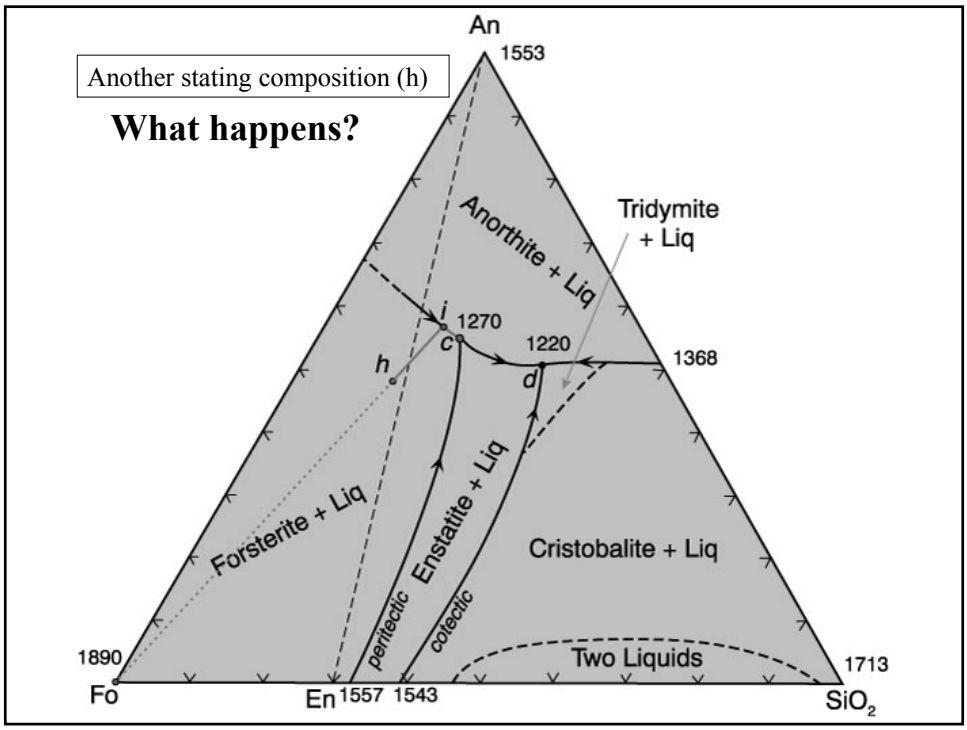





At (f) all olivine is resorbed and only enstatite is being removed
Consequently the melt moves off the curve at (f) away from enstatite




The liquid moves to (g) where anorthite joins enstatite
Crystallization of enstatite and anorthite leads to the eutectic (d) and crystallization of cristobolite
An
1553
Anorthite + Liq
Tridymite + Liq
1270
c
g
1220
1368
d
f
e
b
Forsterite + Liq
Enstatite + Liq
Cristobalite + Liq
peritectic
cotectic
Two Liquids
1890
1713
Fo
En
1557
1543
SiO2


Another stating composition (h)
What happens?
An
1553
Anorthite + Liq
Tridymite + Liq
i
1270
c
1220
1368
h
d
Forsterite + Liq
Enstatite + Liq
Cristobalite + Liq
peritectic
cotectic
Two Liquids
1890
1713
Fo
En
1557
1543
SiO2