Binary Systems

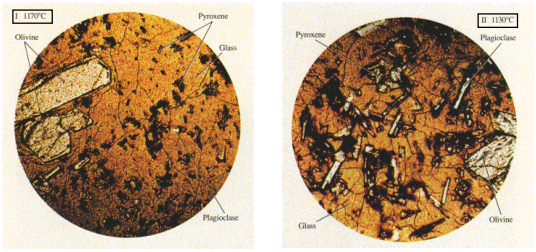
Readings:
Winter Chapter 6

Types of Relationships

- Solid Solution
  - Ab-An
  - Fo-Fa
- Eutectic
  - Di-An
- Reaction relation
  - Fo-Q

Makaopuhi Lava Lake

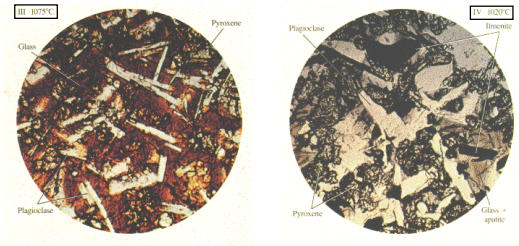
Magma samples recovered from various depths beneath solid crust



From Wright and Okamura, (1977) *USGS Prof. Paper*, **1004**.

Makaopuhi Lava Lake

Thermocouple attached to sampler to determine temperature



From Wright and Okamura, (1977) *USGS Prof. Paper*, **1004**.

Makaopuhi Lava Lake

Temperature of sample vs. Percent Glass

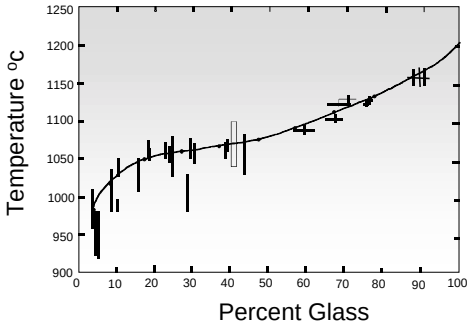


Fig. 6-1. From Wright and Okamura, (1977) *USGS Prof. Paper*, **1004**.

Crystallization Behavior of Melts

- Melts crystallize over a range of temperatures
- Several minerals crystallize together
- The number of minerals increases as T decreases
- The minerals form in sequence with overlap

Melt/Liquid Crystallization

- Minerals in solid solution change composition as cooling progresses
- The melt composition also changes during crystallization
- The minerals that crystallize depend on T and X of the melt
- Pressure also affects the types of minerals that form and the sequence
- The nature and pressure of the volatiles can also affect the minerals and their sequence

The Phase Rule

$$F = C - \phi + 2$$

F = # degrees of freedom

The number of intensive parameters that must be specified in order to completely determine the system

ϕ = # of phases

phases are mechanically separable constituents

C = minimum # of components (chemical constituents that must be specified in order to define all phases)

2 = 2 intensive parameters

Usually = temperature and pressure for us geologists

Two Component Systems

Systems with Complete Solid Solution

Plagioclase (Ab-An, $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$)

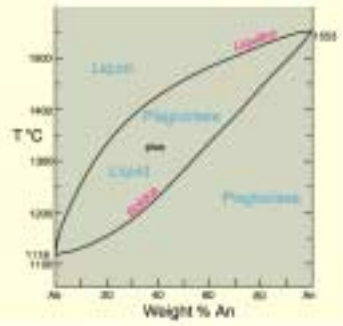
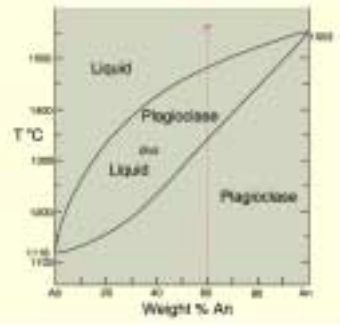


Fig. 6-8. Isobaric T-X phase diagram at atmospheric pressure. After Bowen (1913) Amer. J. Sci., **35**, 577-599.

Bulk composition *a* = An_{60}

= 60 g An + 40 g Ab

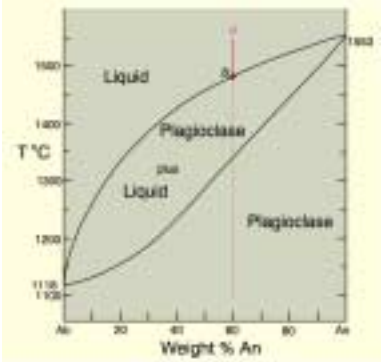
X_{An} = 60/(60+40) = 0.60



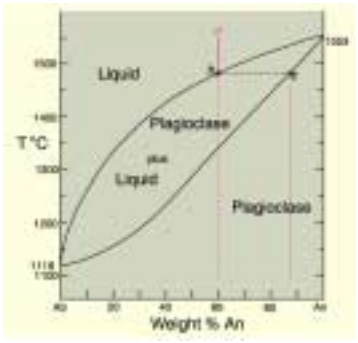
Two Degrees of Freedom

- Must specify 2 independent intensive variables in order to completely determine the system
- This is a divariant situation
- Two intensive variables can vary independently without changing ϕ, the number of phases

Must specify T and X_{An}^{liq} or can vary these without changing the number of phases



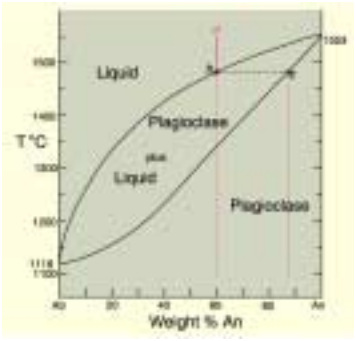
Get new phase joining liquid:
first crystals of plagioclase: $X_{An}^{plag} = 0.87$ (point *c*)



F = 2 - 2 + 1 = 1 ("univariant")
Must specify only one variable from among:
T X_{An}^{liq} X_{Ab}^{liq} X_{An}^{plag} X_{Ab}^{plag} **(P constant)**

X_{An}^{liq} and X_{An}^{plag} are dependent upon T

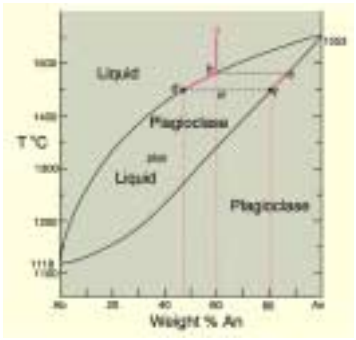
The slope of the solidus and liquidus are the expressions of this relationship



At 1450°C, liquid *d* and plagioclase *f* coexist at equilibrium

A continuous reaction of the type:

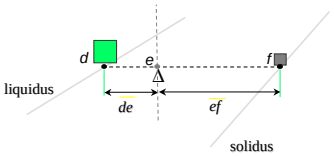
$liquid_A + solid_B = liquid_C + solid_D$



The lever principle:

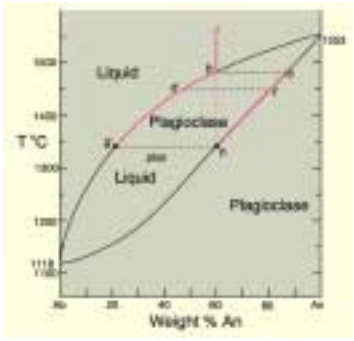
$$\frac{\text{Amount of liquid}}{\text{Amount of solid}} = \frac{\overline{ef}}{\overline{de}}$$

where *d* = the liquid composition, *f* = the solid composition and *e* = the bulk composition



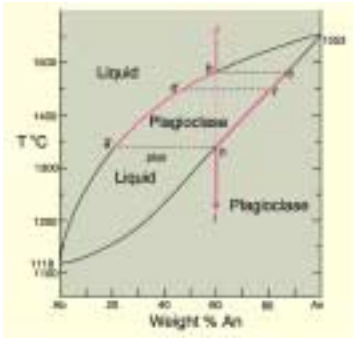
When $X_{plag} \rightarrow$ h, then $X_{plag} = X_{bulk}$ and, according to the lever principle, the amount of liquid $\rightarrow 0$

Thus g is the composition of the last liquid to crystallize at 1340°C for bulk X = 0.60

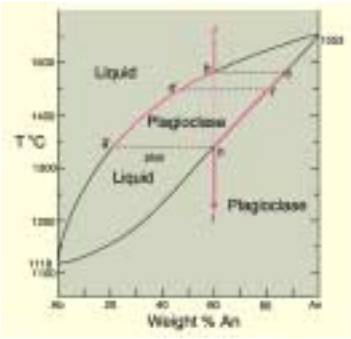


Final plagioclase to form is i when $X_{An}^{plag} = 0.60$

Now $\phi = 1$ so F = 2 - 1 + 1 = 2



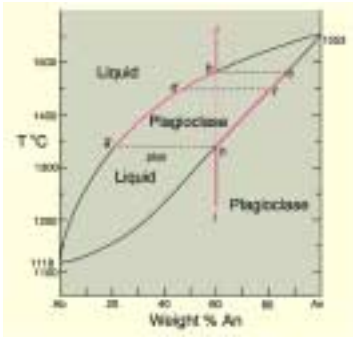
Note the following:
•The melt crystallized over a T range of 135ºC *
•The composition of the liquid changed from b to g
•The composition of the solid changed from c to h



Numbers refer to the "behavior of melts" observations

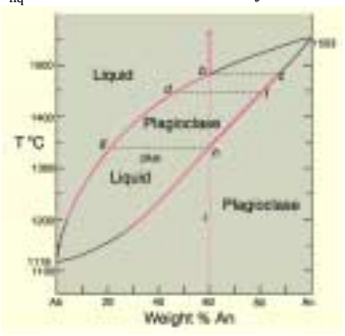
* The actual temperatures and the range depend on the bulk composition

Equilibrium melting is exactly the opposite
- Heat An_{60} and the first melt is g at An_{20} and 1340ºC
- Continue heating: both melt and plagioclase change X
- Last plagioclase to melt is c (An_{87}) at 1475ºC

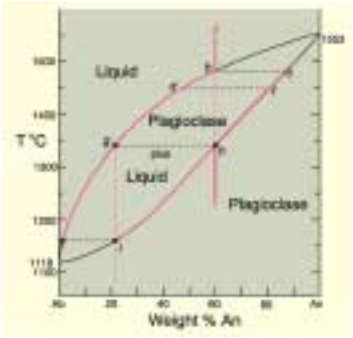


Fractional crystallization:
Remove crystals as they form so they can't undergo a continuous reaction with the melt

At any T $X_{bulk} = X_{liq}$ due to the removal of the crystals



Partial Melting:
Remove first melt as it forms
Melt X_{bulk} = 0.60 and the first liquid = *g*
remove and cool bulk = g → final plagioclase = *i*



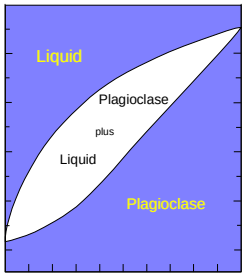
Note the difference between the two types of fields

The blue fields are one phase fields

Any point in these fields represents a true phase composition

The blank field is a two phase field

Any point in this field represents a bulk composition composed of two phases at the edge of the blue fields and connected by a horizontal tie-line



The Olivine System

Fo - Fa (Mg_2SiO_4 - Fe_2SiO_4)
also a solid-solution series

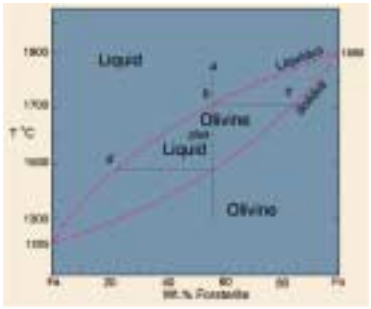


Fig. 6-10. Isobaric T-X phase diagram at atmospheric pressure After Bowen and Shairer (1932), Amer. J. Sci. 5th Ser., **24**, 177-213.