

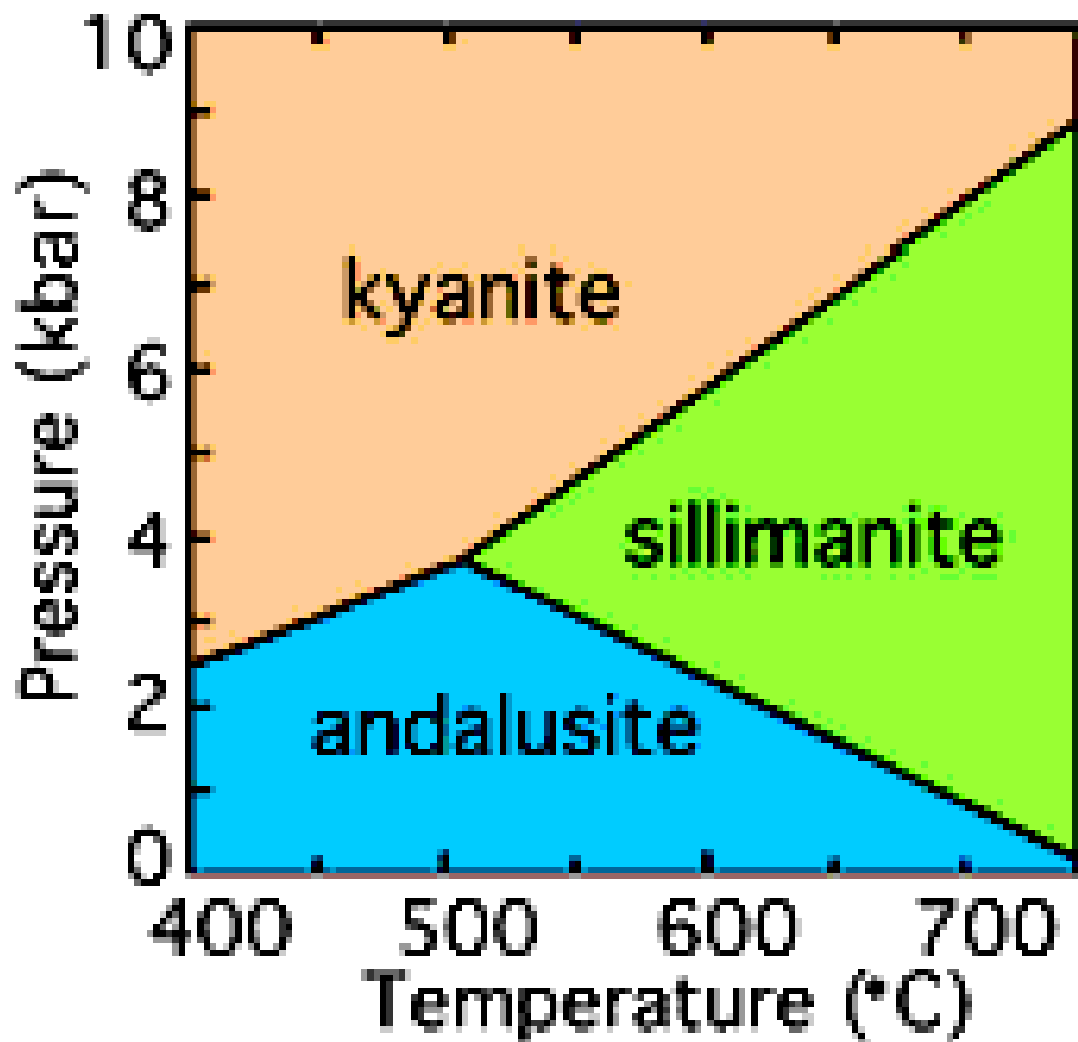
Environments of Mineral Formation

**Unary, Binary, and Ternary Mineral
Stability Diagrams**

Minerals of differing composition (or polymorphs of the same mineral) that coexist at a set of pressure (P) temperature (T) or composition (X) can be represented by their equilibrium conditions

In any rock (igneous, metamorphic, or sedimentary) is composed of a series of minerals that can be represented in PT or X space as
MINERAL STABILITY DIAGRAMS

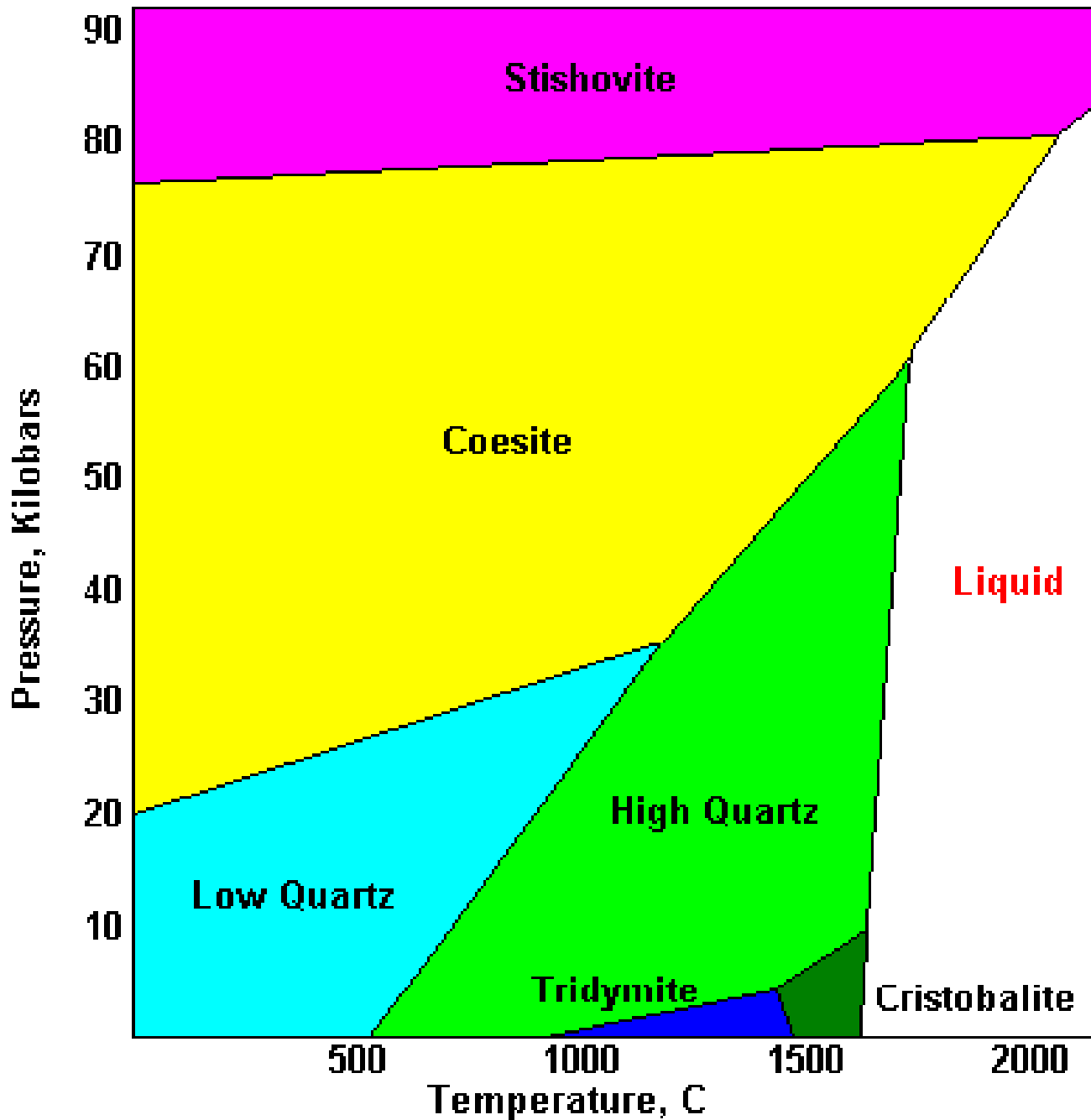
Diagrams can be set-up to represent different P, T, or X spaces where phases may or may not coexist to represent the conditions under which a set of minerals might form



In the Al₂SiO₅ phase diagram, lines represent **univariant curves** (divisions between PT stability field along which both minerals can coexist).

The three phases can all coexist where the univariant curves intersect, a fixed position called the **invariant point**.

The relationships of these phases in PT space can also be used to understand the **chemical equilibrium** for a system (the lowest possible energy configuration for any specific composition).



Likewise, the quartz polymorphs represent a set of equilibrium structural conditions for any given PT configuration.

Each polymorph is a unique phase that exists as the most stable form for a specific set of conditions.

The concept of the phase diagram is based on the **Phase Rule**, which must be defined in terms of a few concepts:

System: some arbitrary yet specific part of the universe we want to investigate

isolated: no mass or energy exchange between the system of interest and the environment that surrounds it

closed: no mass exchange between the system of interest and the environment, but energy transfer is permitted

open: free transfer of mass and energy between the system and the surrounding environment

Component (C): any chemical constituent that is part of the system

Phase (P): any mechanically separable part of the system with distinct chemical and physical properties

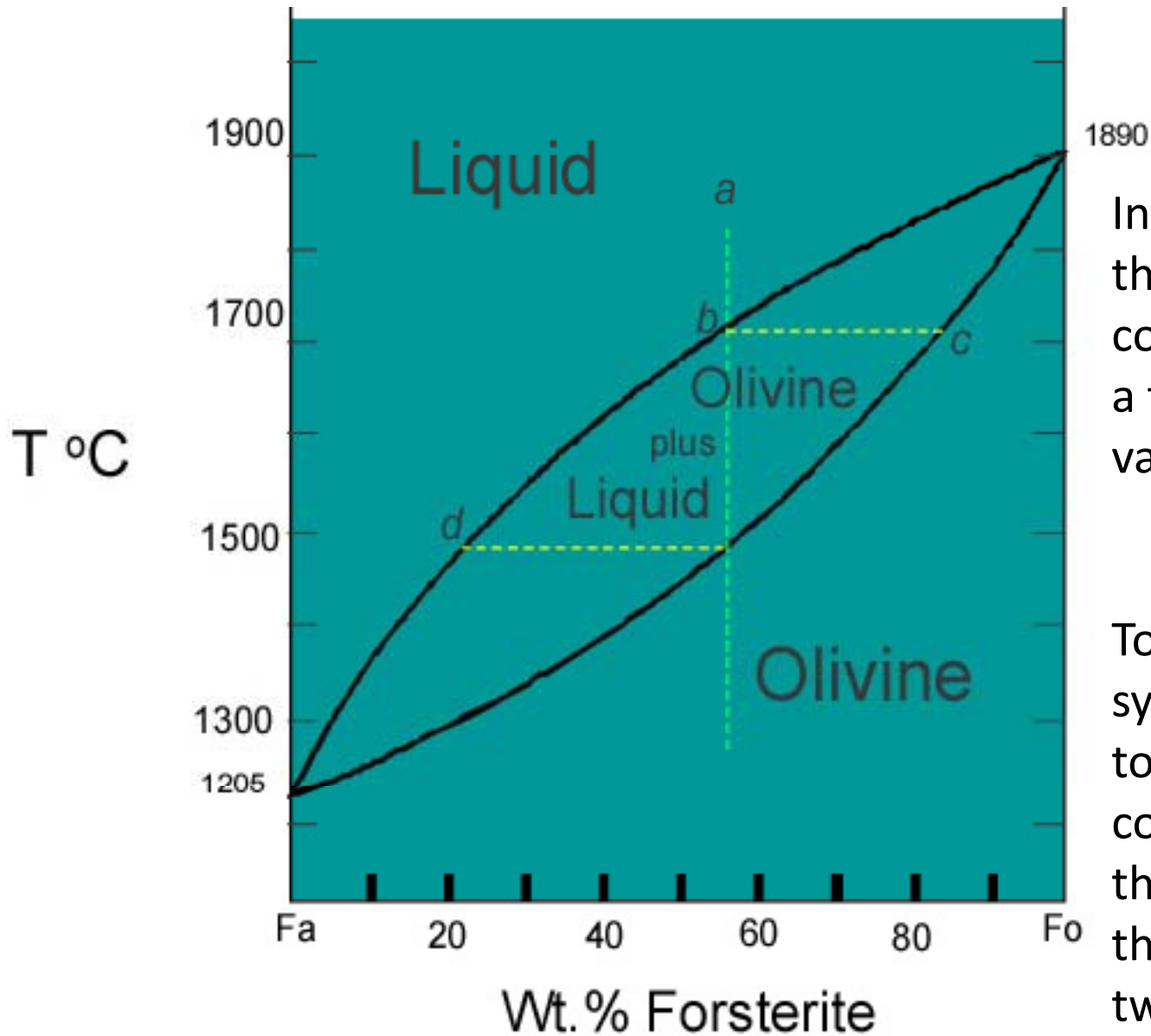
The **Phase Rule** (after Gibbs, 1876) is a way of describing any system in equilibrium in terms of quantified differences in the thermodynamic variables in a system (and the constraints on those variables)

For the most part (at least in geologic systems), the first order variables of greatest concern are P, T, and X.

These factors can be quantified as the **Degrees of Freedom:**

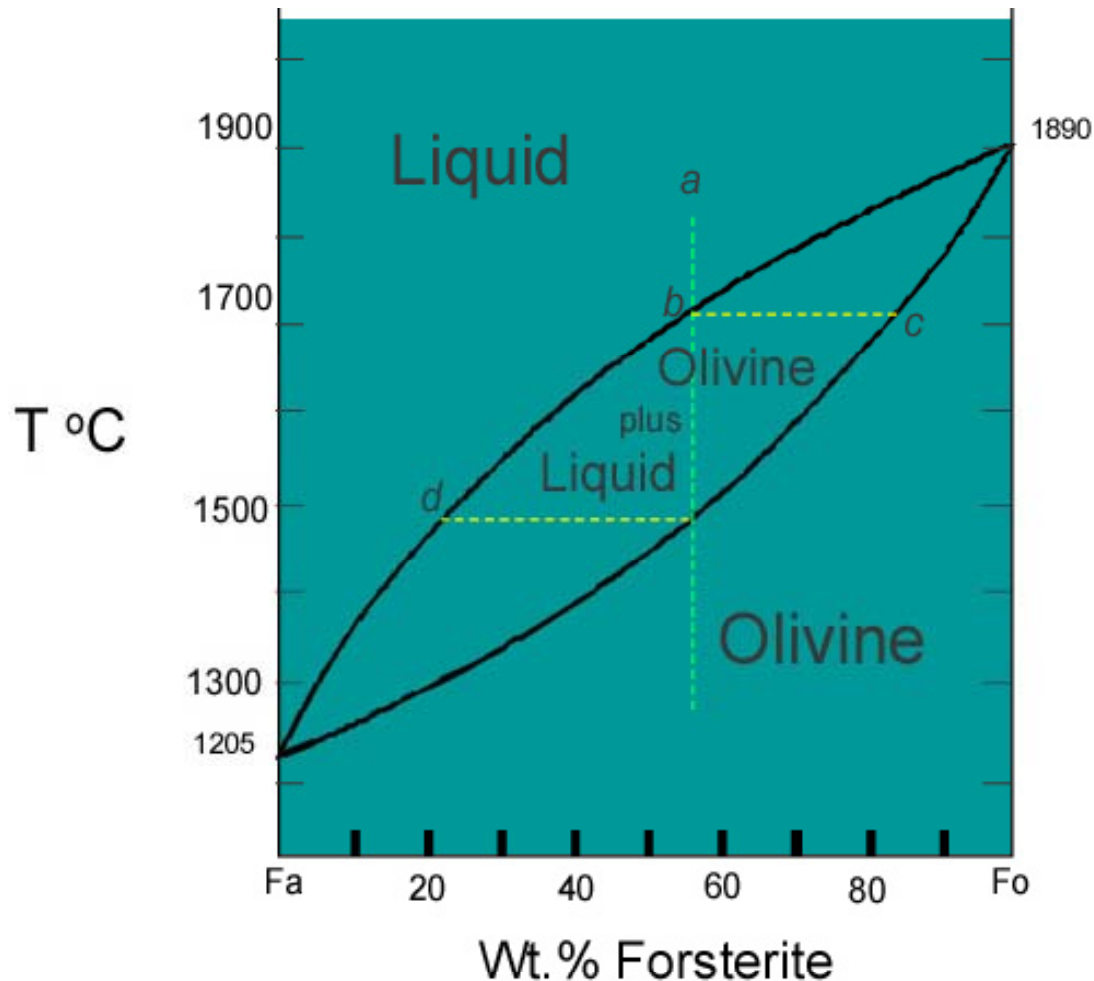
$$F = C - P + 2$$

Phase diagrams are based on this principle as any point can be represented by a unique P, T, X condition that can be constrained based on our knowledge of other variables in the system



In a binary system, there are two components leading to a total of three variables.

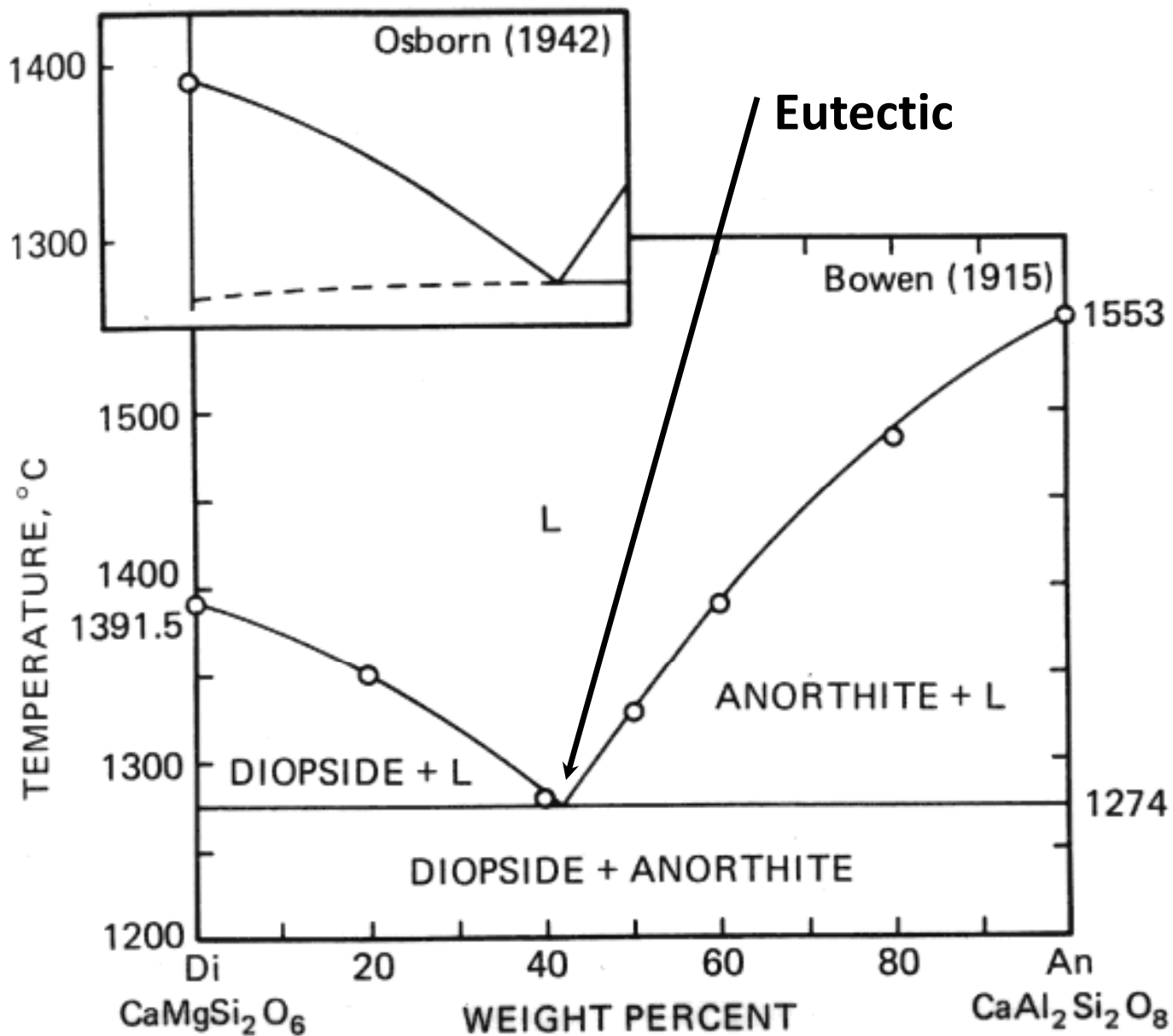
To study these systems, it is possible to hold on variable constant to simplify the system to study the interaction of only two variables.



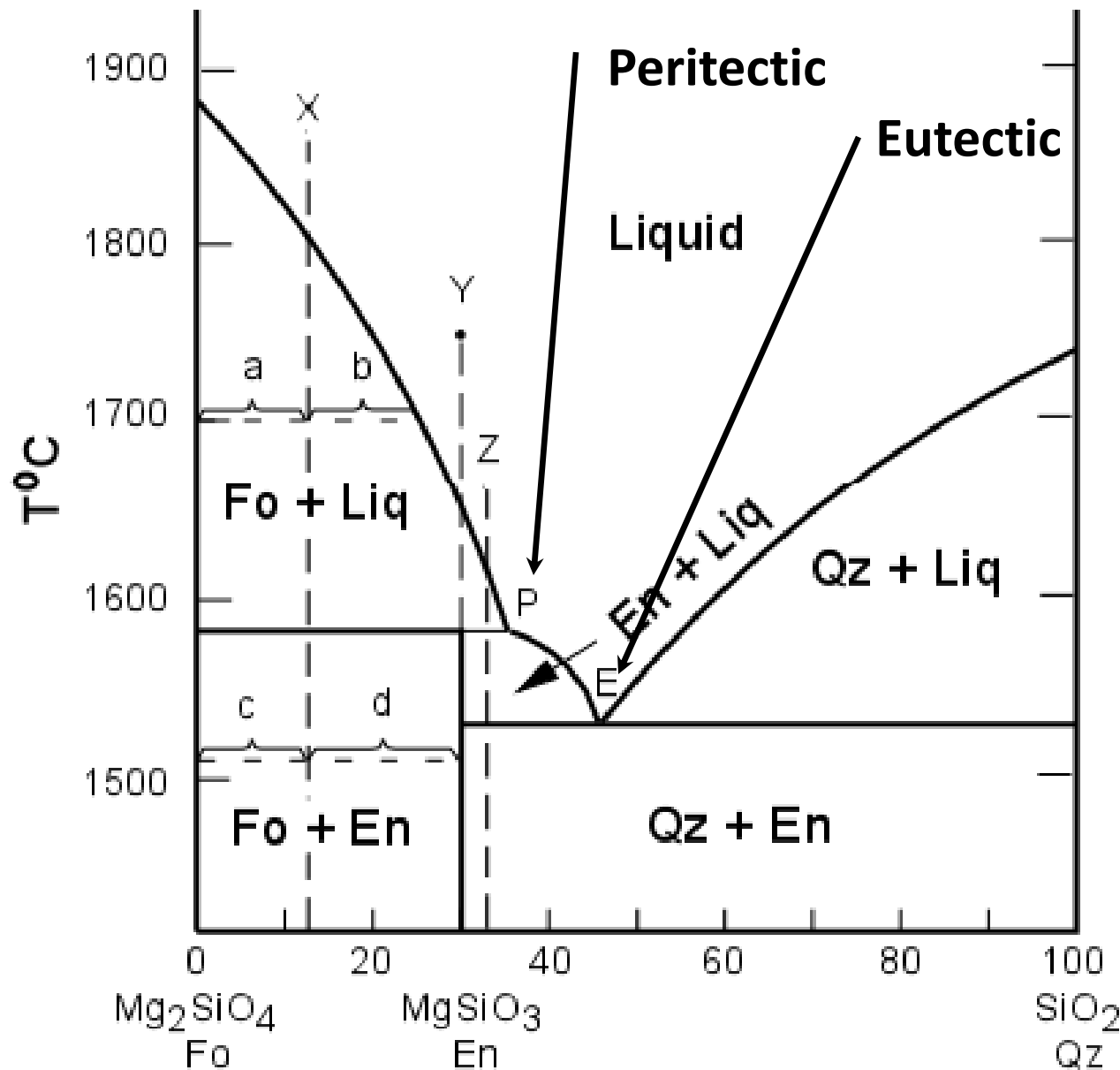
In the case of Olivine composition vs. temperature (relationship of T with the SSS between Fayalite (Fe_2SiO_4) and Forsterite (Mg_2SiO_4)) there are three fields: Liquid, Olivine, and Olivine+Liquid.

Liquidus: the line that divides the liquid *only* field from the liquid + crystals field (along this line crystal form as temperature drops)

Solidus: the line that divides the liquid + crystal field from the solid field

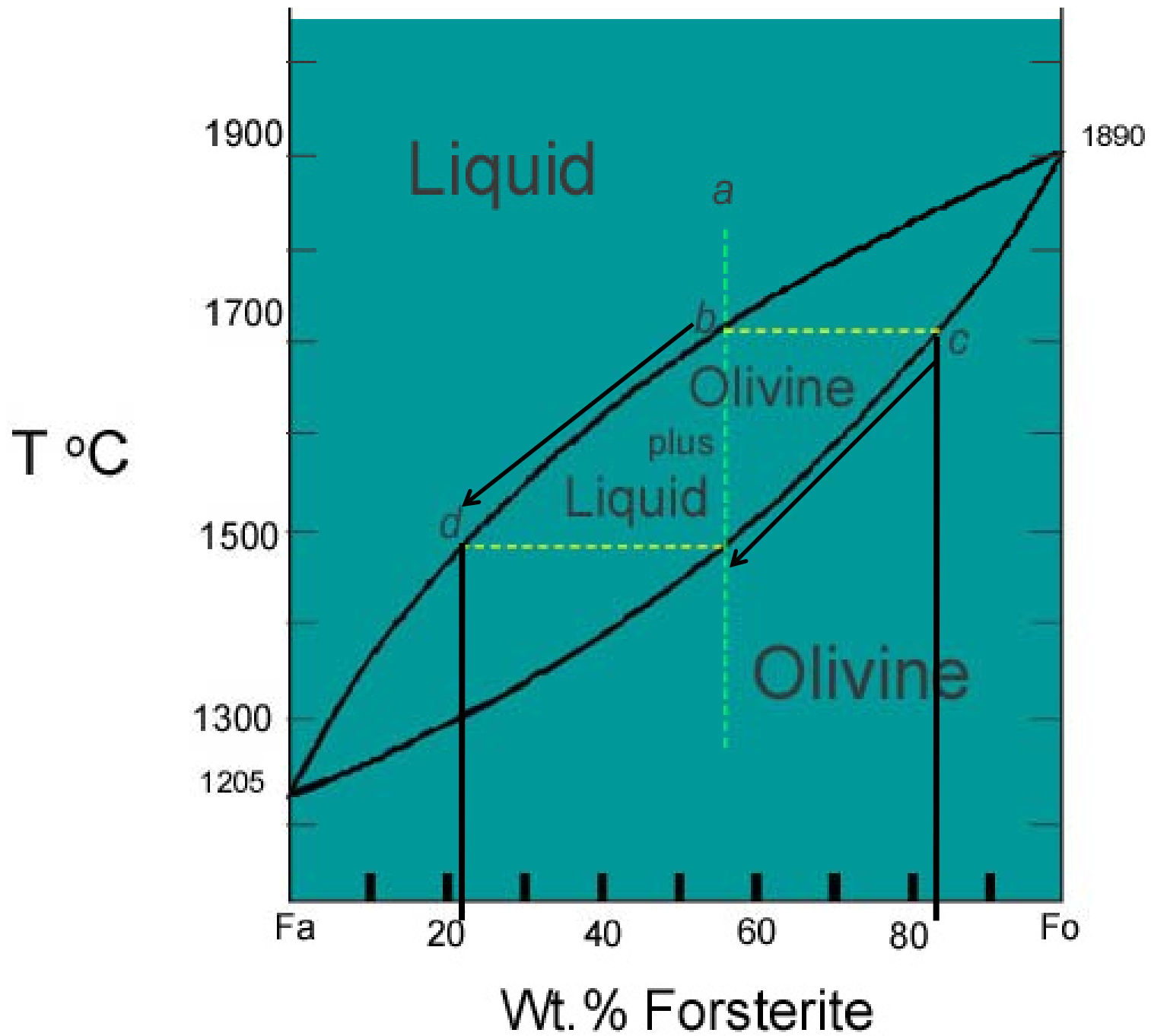


Eutectic point: intersection between the line representing the liquidus and the solidus. At this single unique location, the liquid is in equilibrium with all solid phases stable in the system



Peritectic point: reaction point between two previously precipitated phases (with liquid present) that results in the formation of a new solid phase.

As with a eutectic position, the temperature must remain stable until the reaction goes to completion and one of the reactants is exhausted in making the new phase.

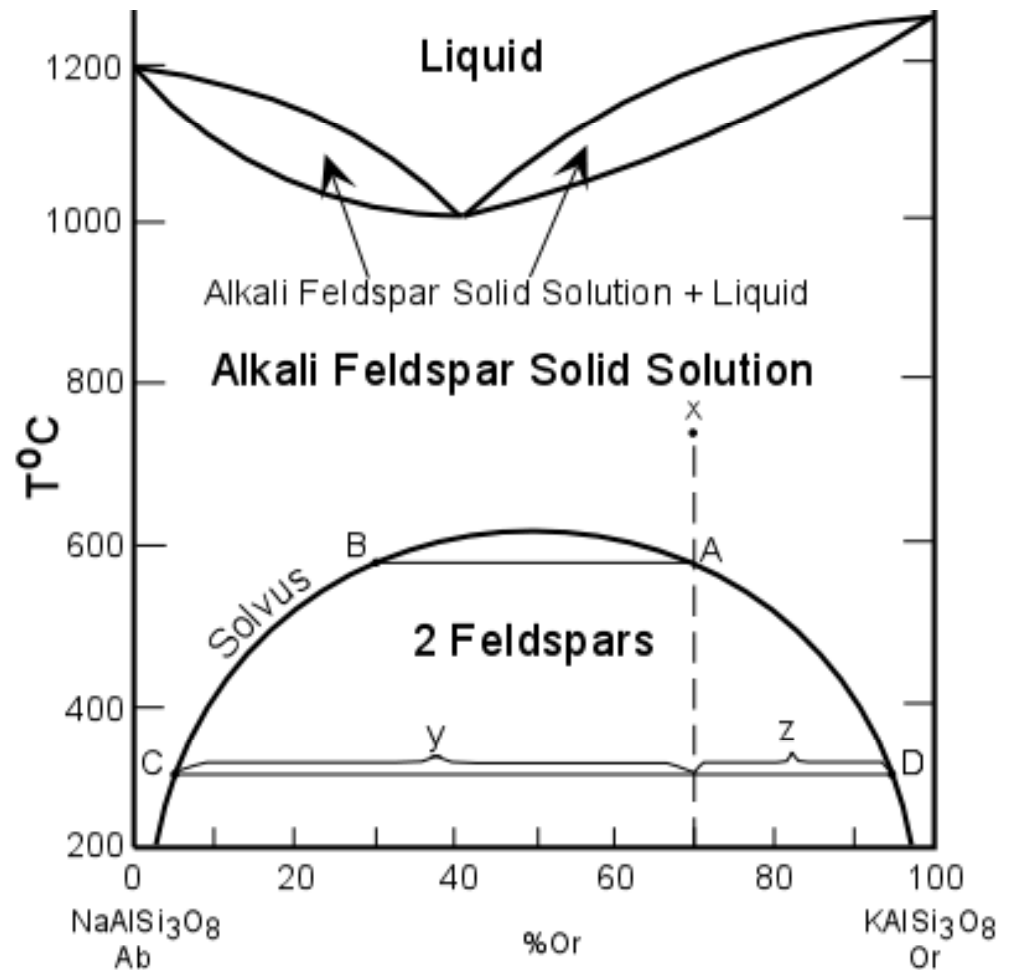


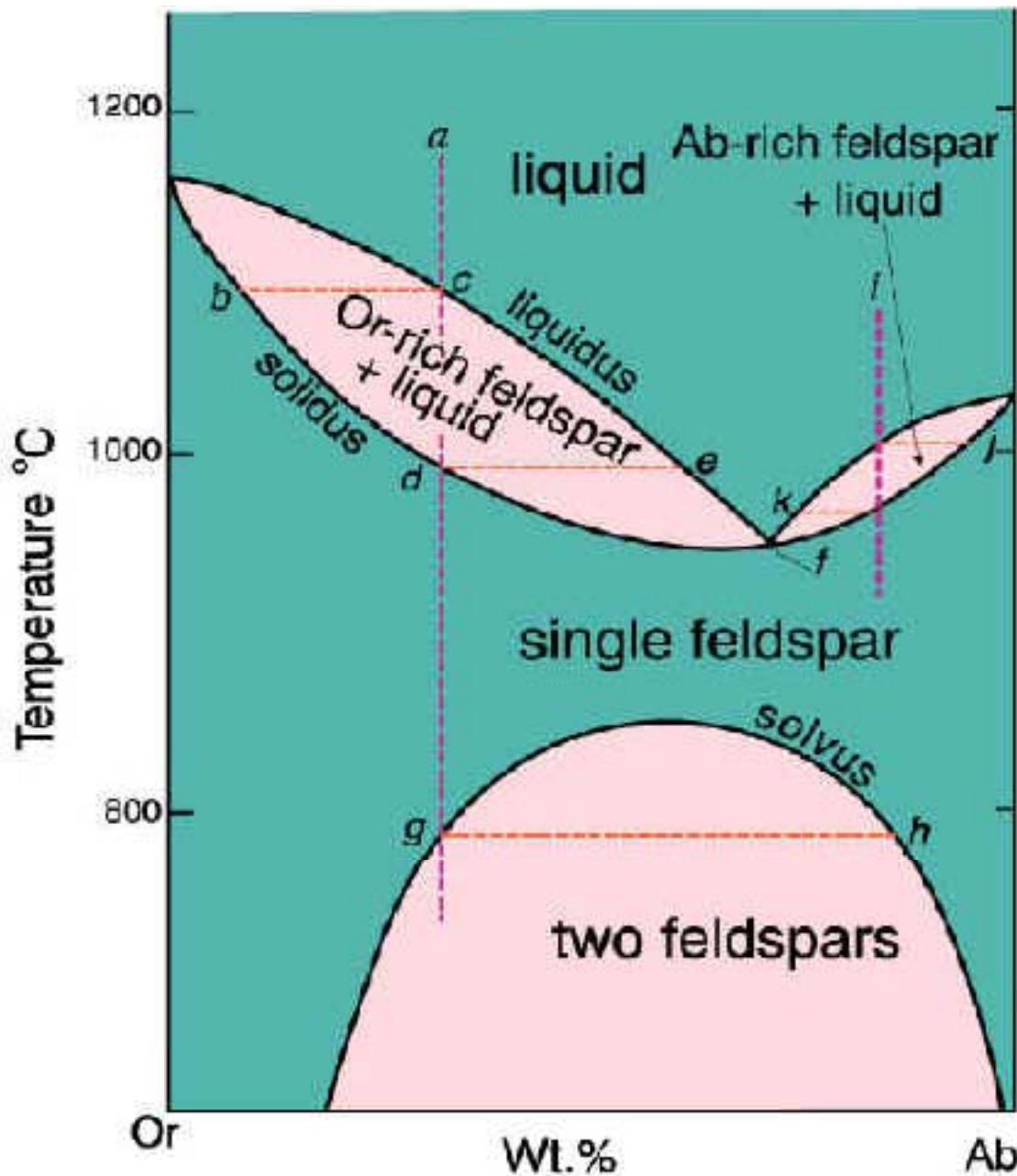
Composition of Alkali Feldspars

The alkali feldspars, consist of two end-members, $\text{NaAlSi}_3\text{O}_8$ – KAlSi_3O_8 . However complete solid solution only occurs at high temperatures.

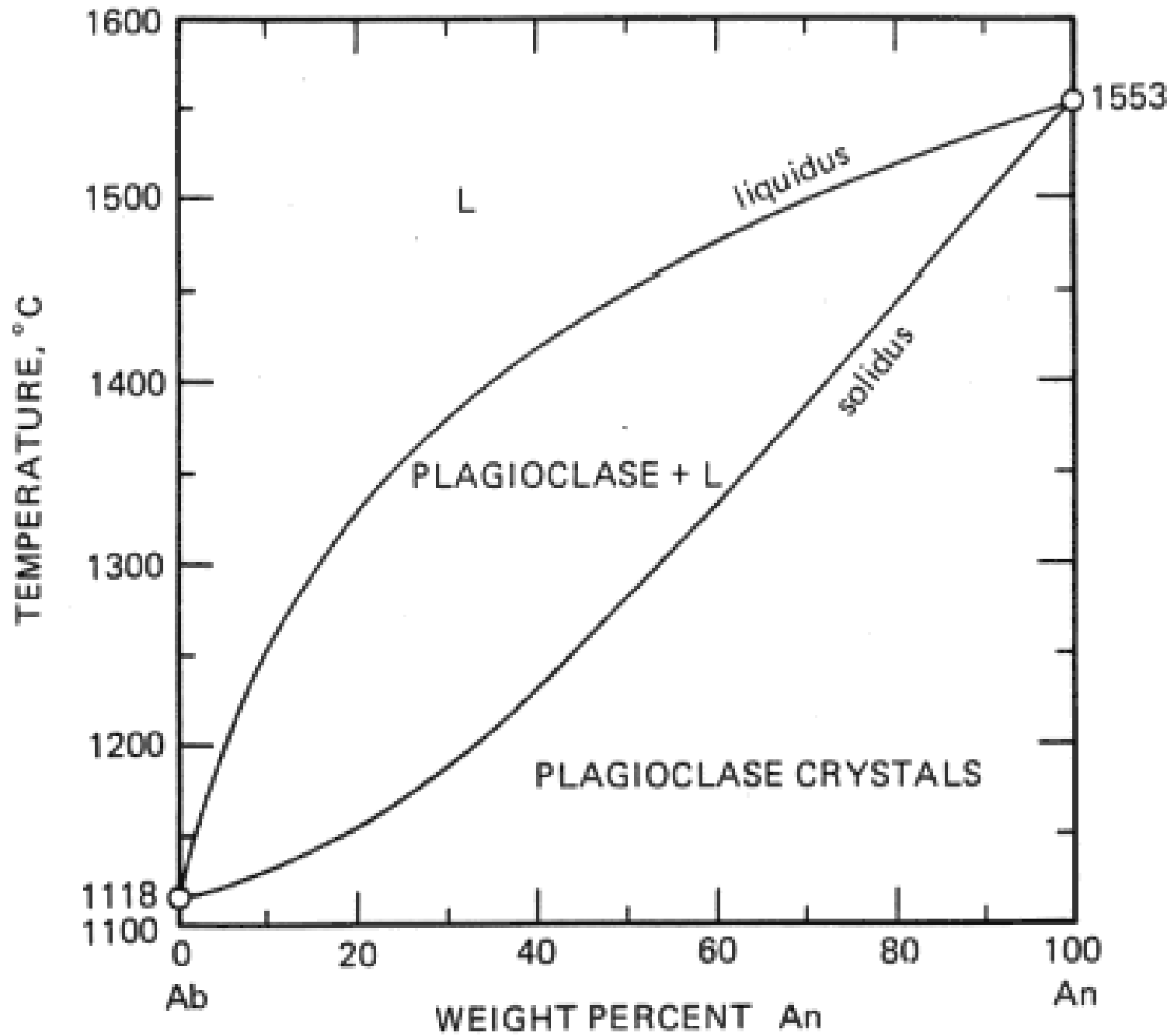
Areas of importance on this diagram include:

- 1)The Liquid Field
- 2)Liquid + Solid
- 3)Single Solid Phase
- 4)Miscibility Gap (immiscibility)
- 5)Unmixed Phases





- a:** initial composition
- b:** composition of first crystals to form
- c:** equivalent thermal position on the liquidus
- d:** composition of last crystals from initial composition **a**
- e:** equivalent liquid composition for last crystals to form
- g:** single crystal feldspar begins to exsolve into 2 feldspars of distinct compositions



Clinopyroxenes

Wollastonite $\text{Ca}_2\text{Si}_2\text{O}_6$

Magnesium-iron pyroxenes in which Ca cations occupy 50% of octahedral sites. (All of the M_2 sites).

The grey areas represent miscibility gaps.

50 mol % $\text{CaMgSi}_2\text{O}_6$

Diopside Hedenbergite
Augite

55 mol % $\text{CaFeSi}_2\text{O}_6$

5 mol %

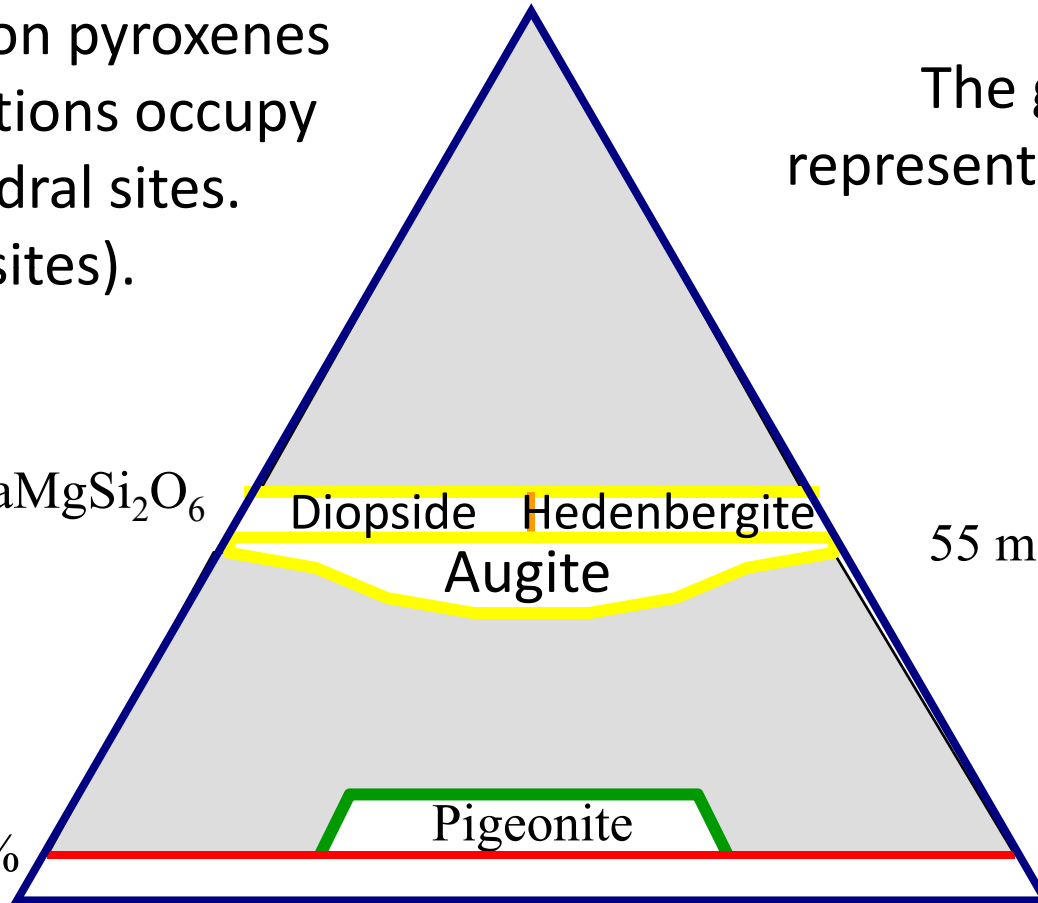
Pigeonite

10 mol %

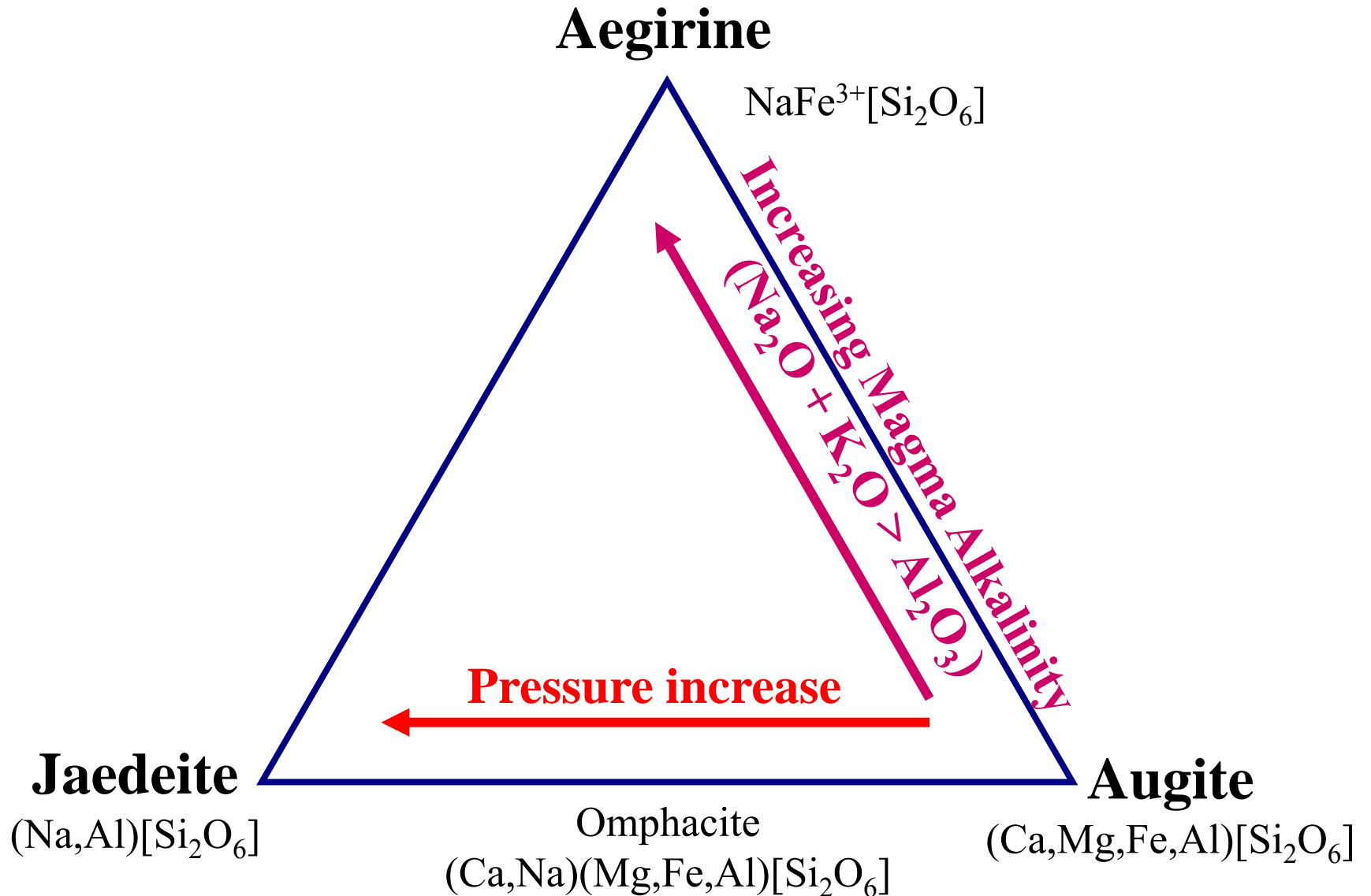
$\text{Mg}_2\text{Si}_2\text{O}_6$

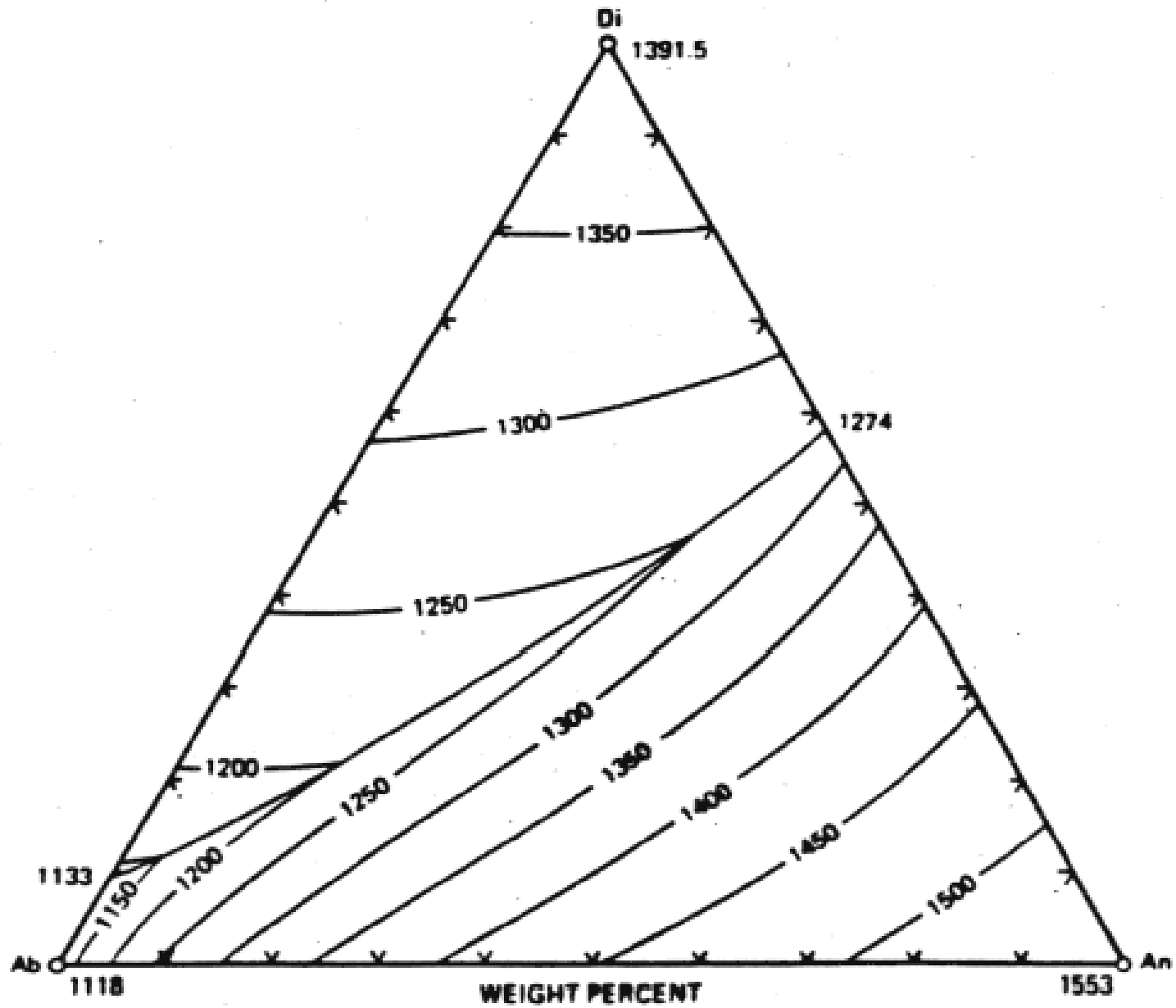
50 mol %

$\text{Fe}_2\text{Si}_2\text{O}_6$

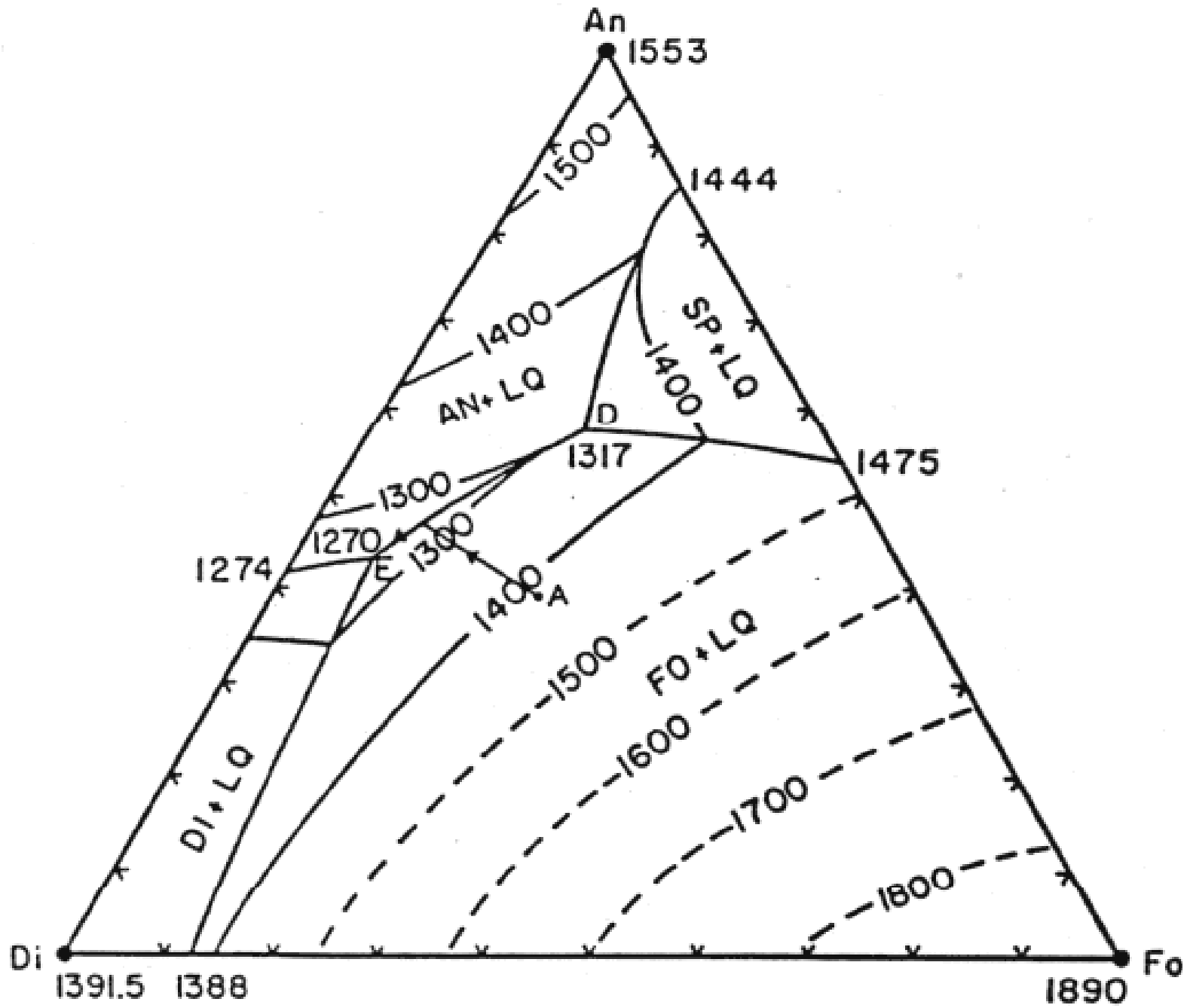


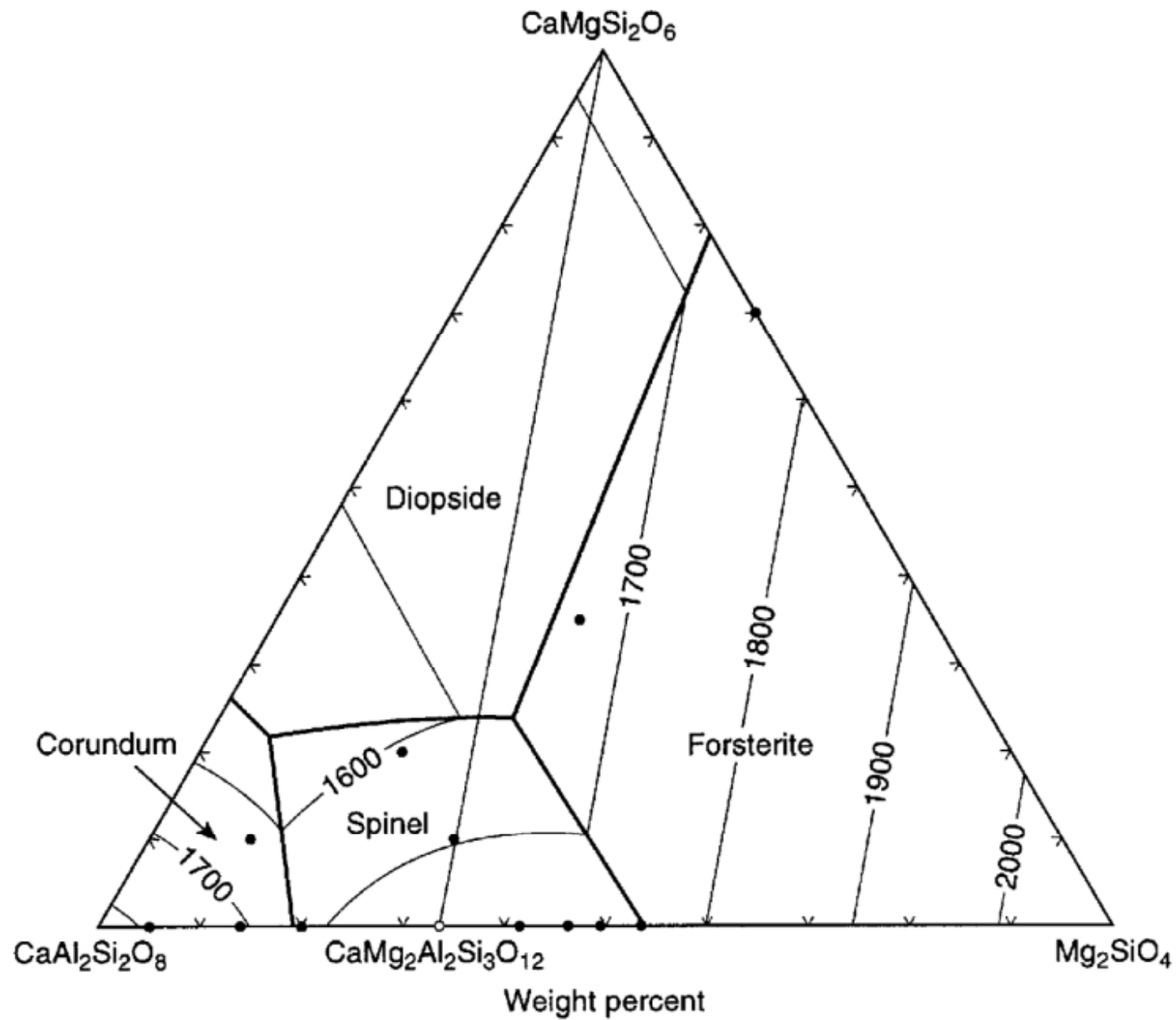
In special circumstances a complex coupled substitution involving both of the M-sites will occur.





[Anorthite \(\$\text{CaAl}_2\text{Si}_2\text{O}_8\$ \)-Wollastonite\(\$\text{Ca}_2\text{Si}_2\text{O}_6\$ \)-Titanite\(\$\text{CaTiSiO}_5\$ \)](#)

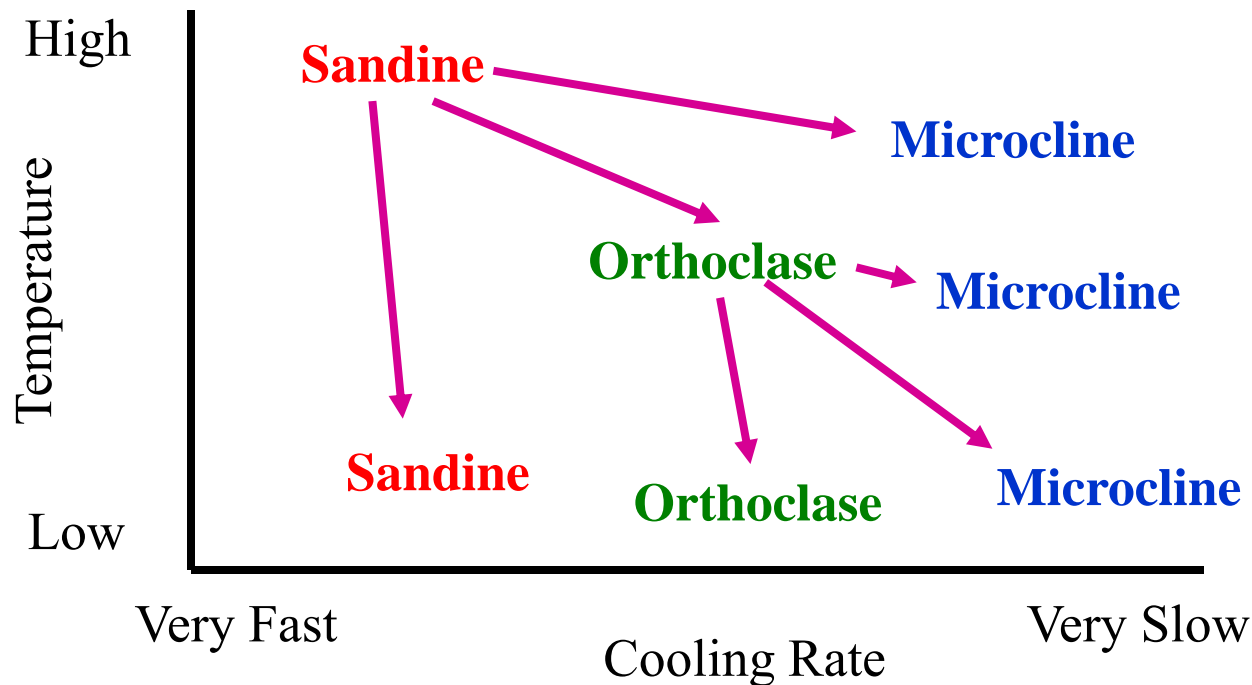




[Anorthite \(\$\text{CaAl}_2\text{Si}_2\text{O}_8\$ \)-Diopside\(\$\text{CaMgSi}_2\text{O}_6\$ \)-Forsterite\(\$\text{Mg}_2\text{SiO}_4\$ \)](#)

Feldspars are a classic example of the Al avoidance principle.

Which, itself, is measure of order in the lattice.



How does ordering vary in this diagram?

How does crystallographic structure vary with ordering?

What induces change in the structural symmetry?

Twinning

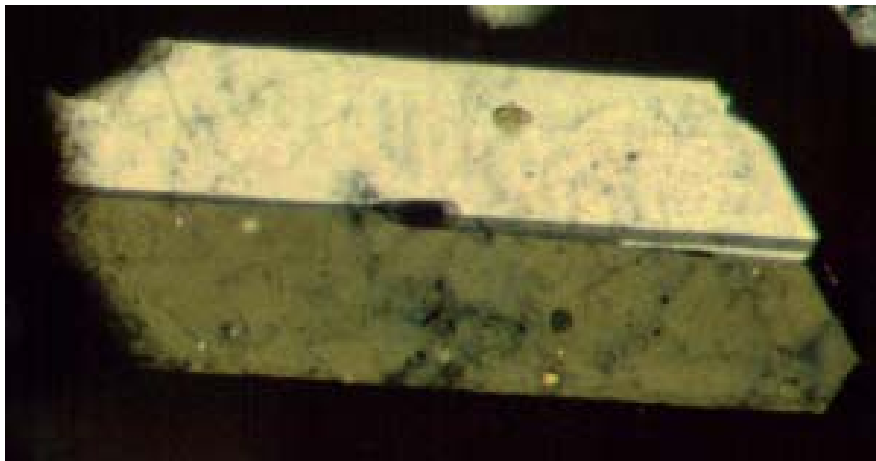
Twins result when different domains of a single crystal have different atomic orientations. The domains share atoms along a common surface.

They are observed in cross polarised light only.

Twins are NOT intergrowths – twin planes are continuous.

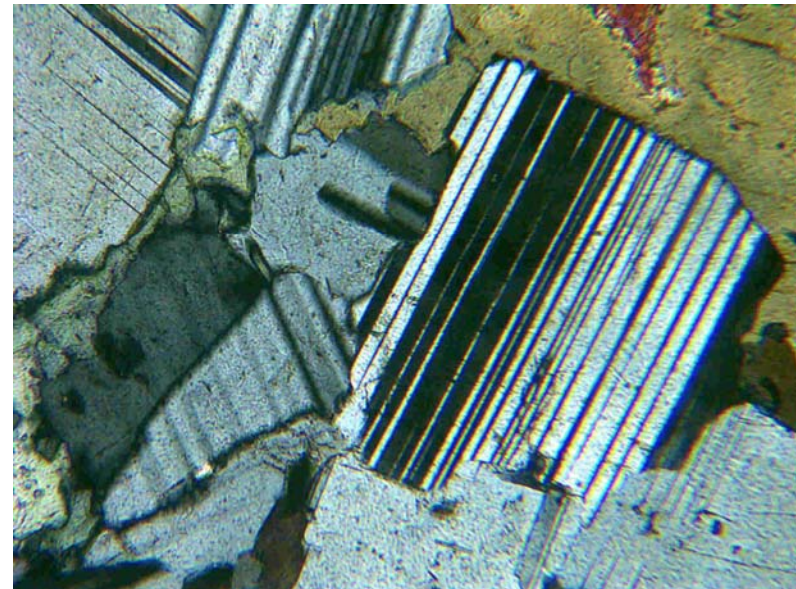
Simple Twins

2 domains with a
common plane of atoms.

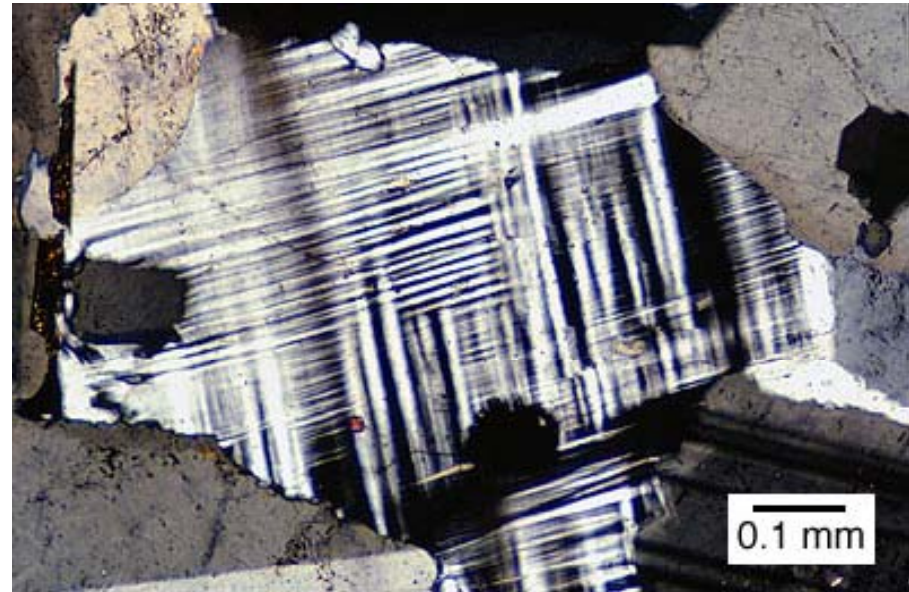


Complex Twins

>2 individual domains
(polysynthetic twinning)



A more complex polysynthetic twinning is observed in the triclinic forms of K-feldspar – so called “tartan twinning”.

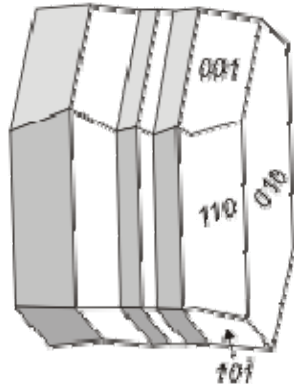


The different types of twins observed in different minerals are known by their various twin laws.

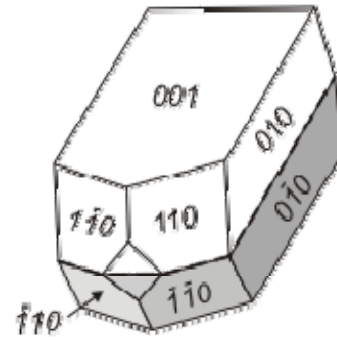
K-Fsp contain simple twins related by Carlsbad, Baveno, albite or pericline laws, which are defined by orientation to crystallographic lattice.

Combining albite and pericline, results in tartan.

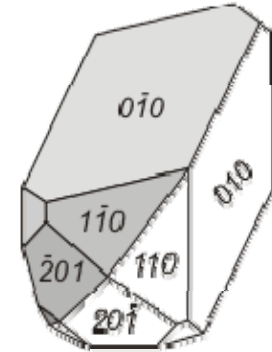
Twinning is not restricted to the feldspars. It is also seen in some pyroxenes, calcite, and the feldspathoids, leucite and nepheline.



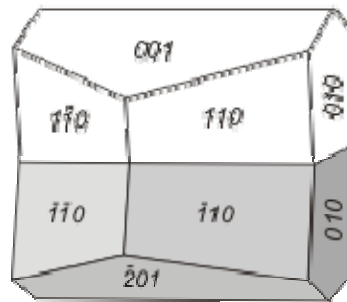
Albite



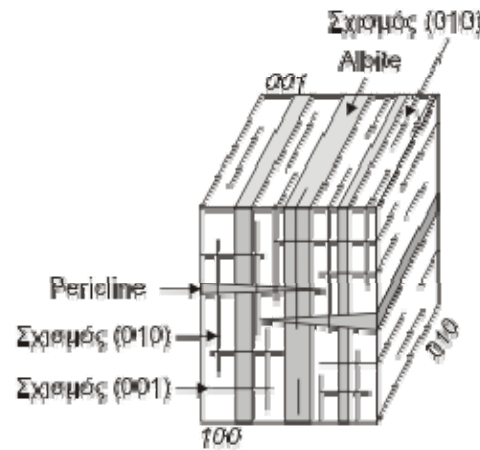
Manebach



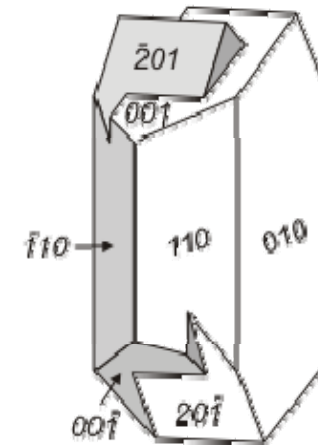
Baveno



Pericline



Albite-Pericline



Carlsbad

Leucite and Nepheline

The feldspathoid group minerals are also anhydrous tectosilicates.

Chemically, they are similar to feldspars, but contain less SiO_2 . Subsequently they tend to form from melts rich in alkalis (Na and K), and poor in SiO_2 .

Leucite (KAlSi_2O_6) is tetragonal, with K^+ accommodated in large 12 coordinated cavities in the structure.

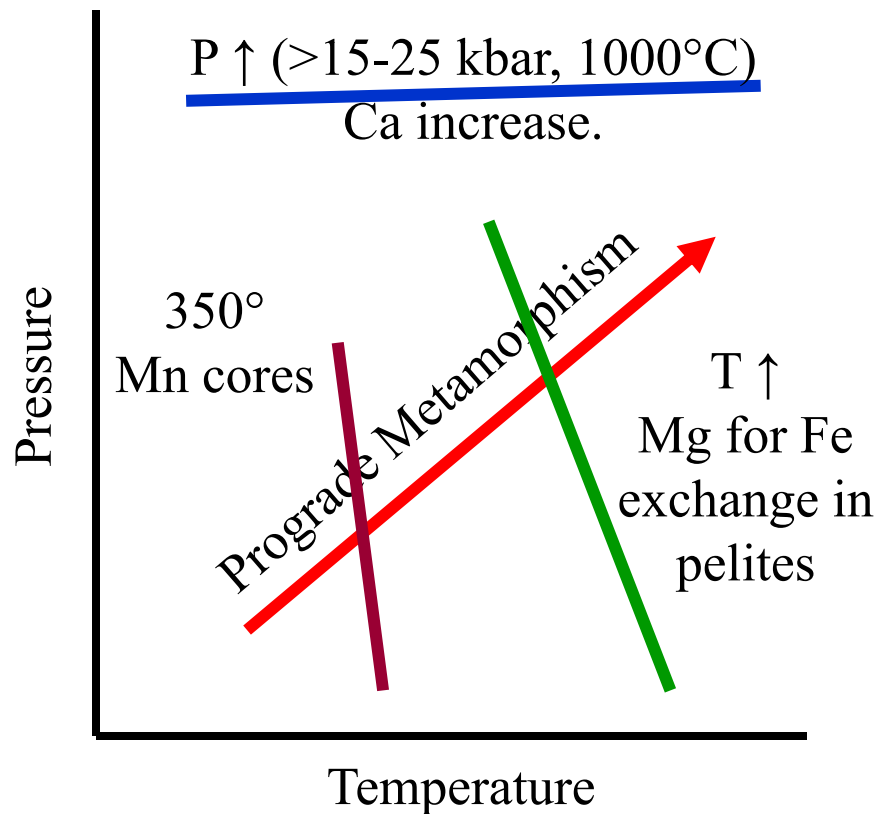
Nepheline ($(\text{Na},\text{K})\text{AlSi}_3\text{O}_8$) is hexagonal.

While leucite is not particularly common, nepheline is found in many alkaline rocks. Care must be taken because its optical properties are similar to those of quartz – the one exception is that it is optically negative!

N.B. Neither mineral is ever found in the presence of quartz.

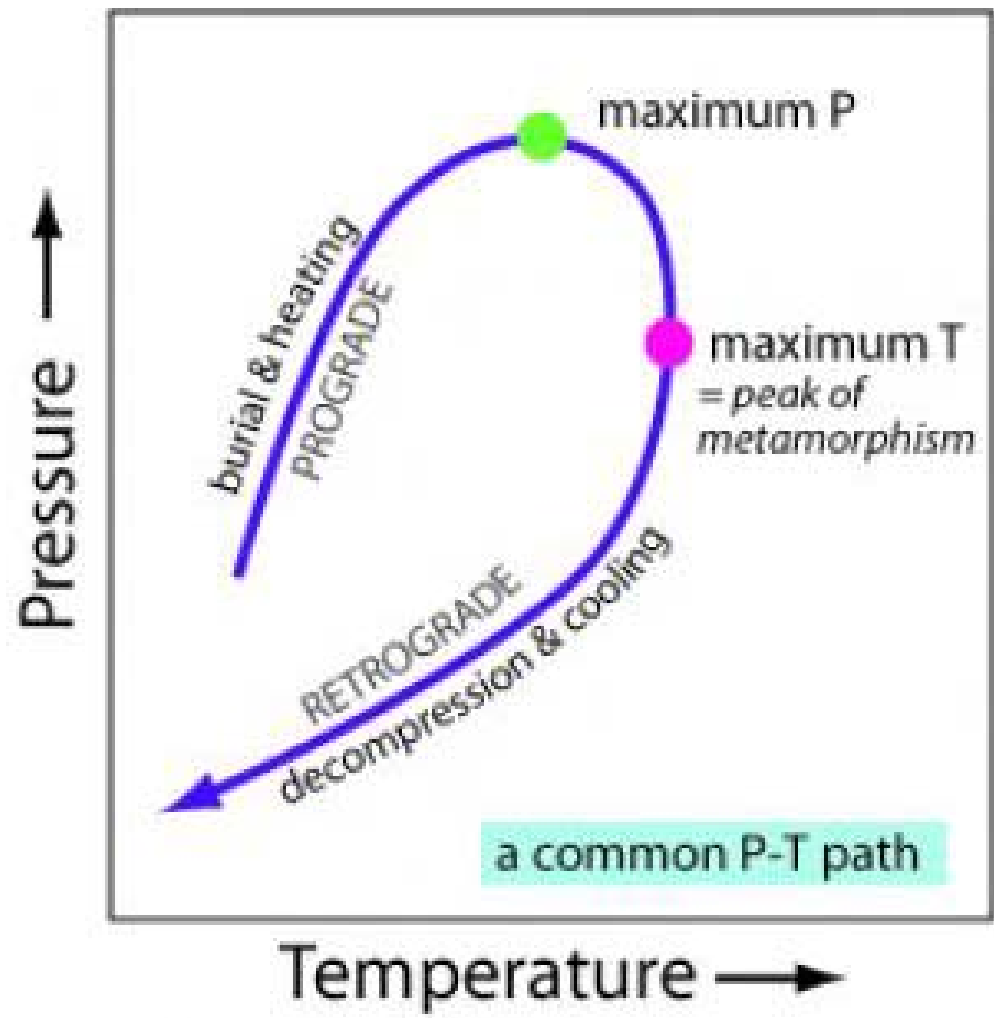
Paragenesis and Composition, ex. GARNET

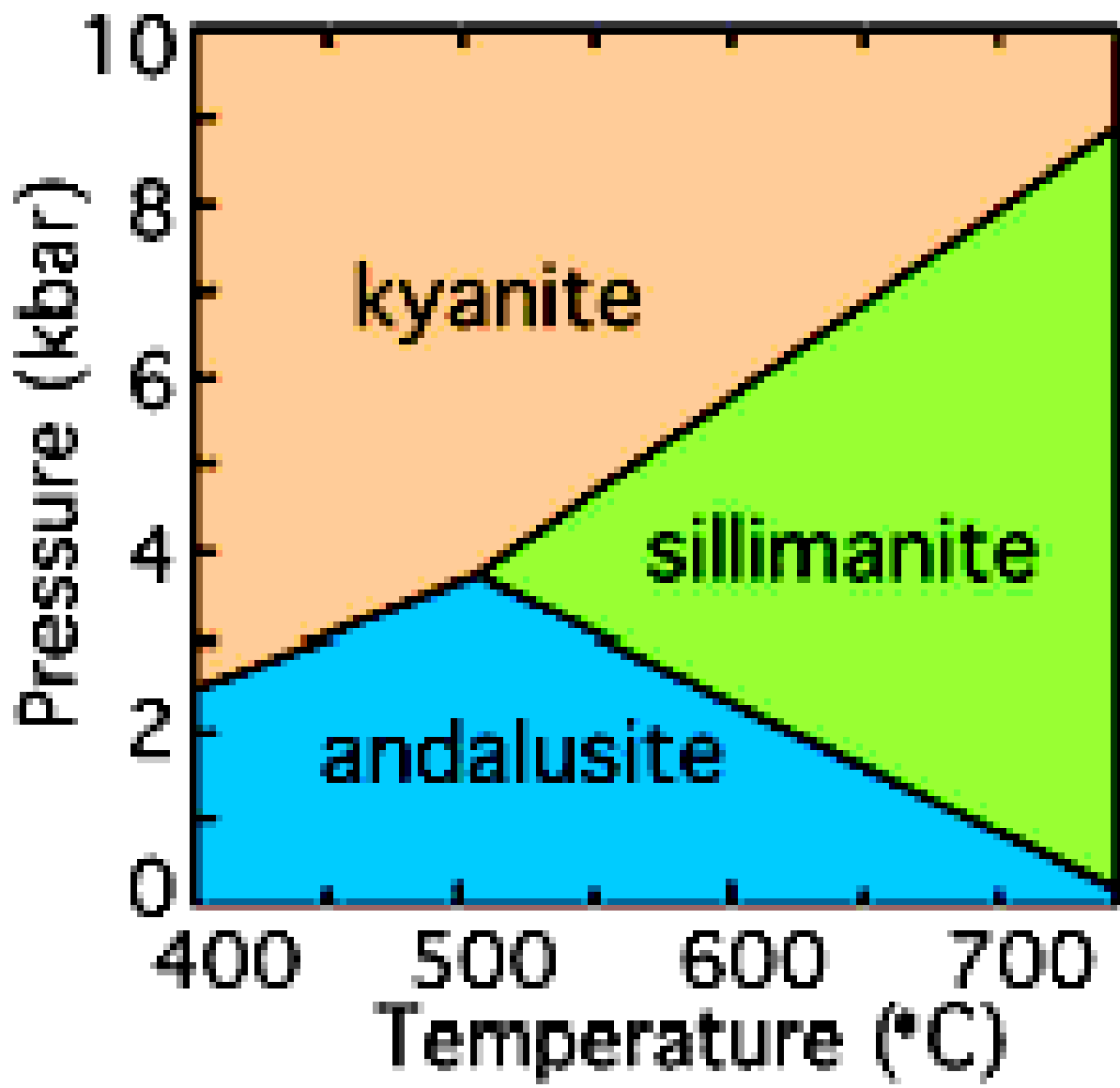
Pure end-member compositions of garnet are rare. The majority are some intermediate composition, which is determined by a combination of factors.

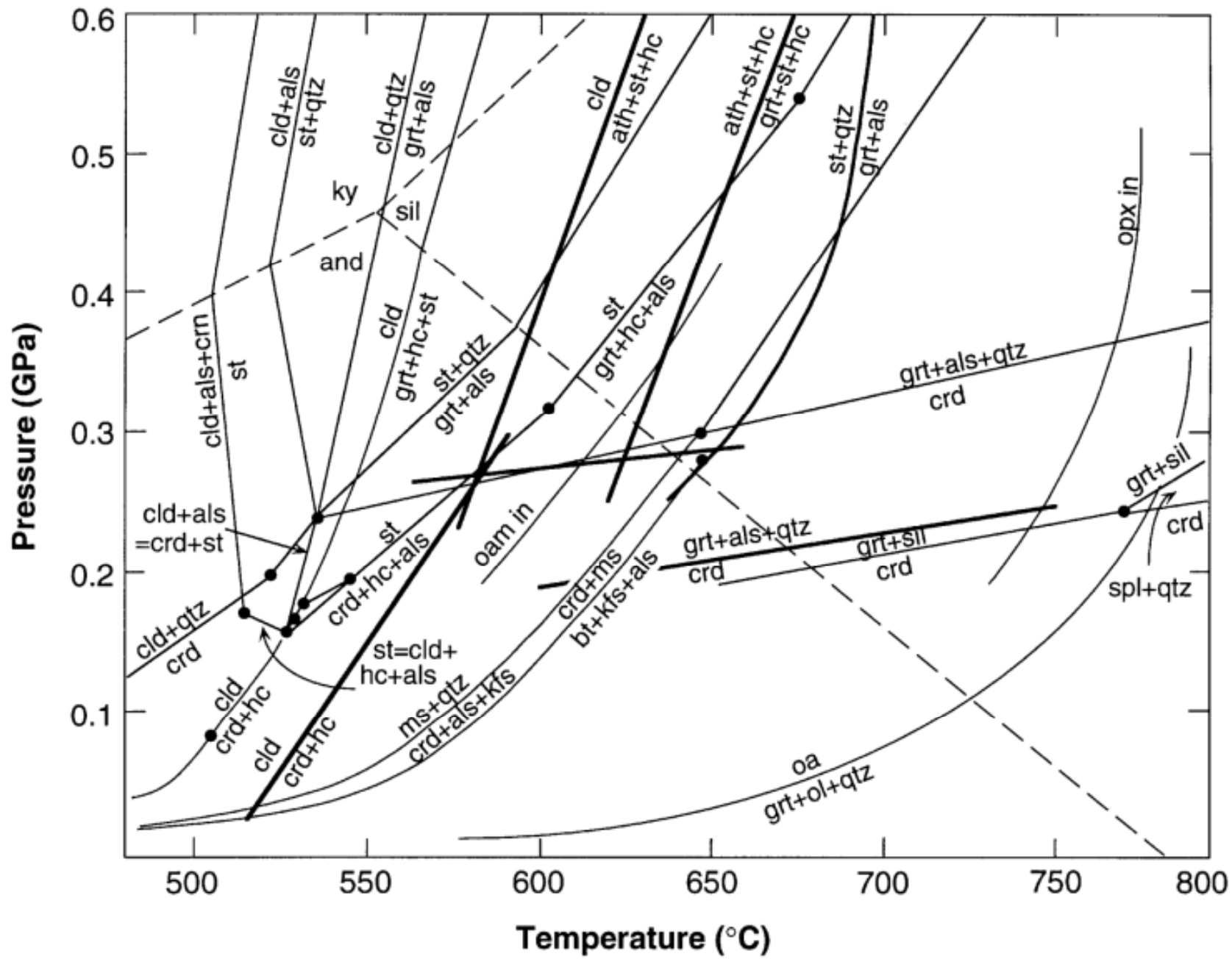


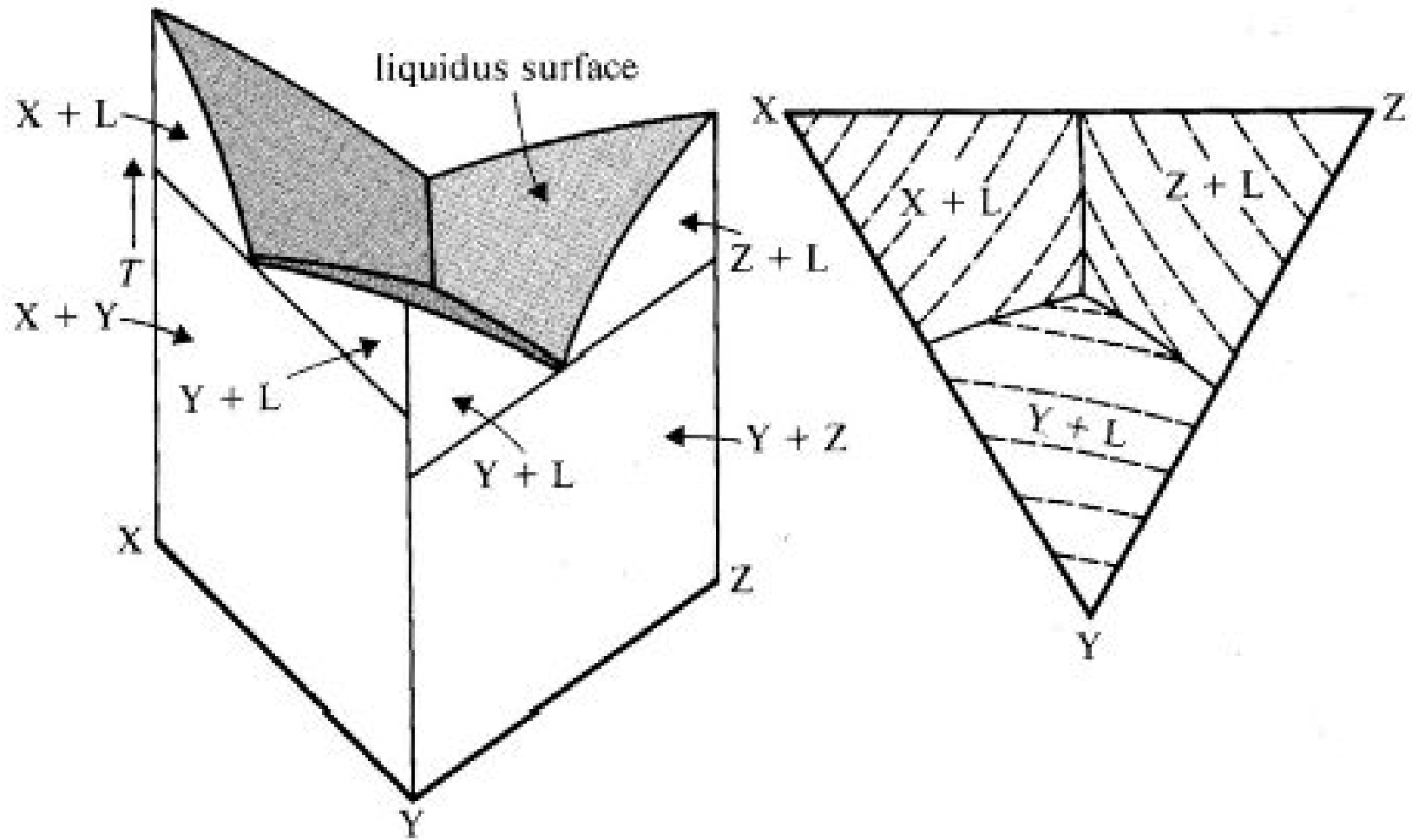
This reaction is a classic thermometer.

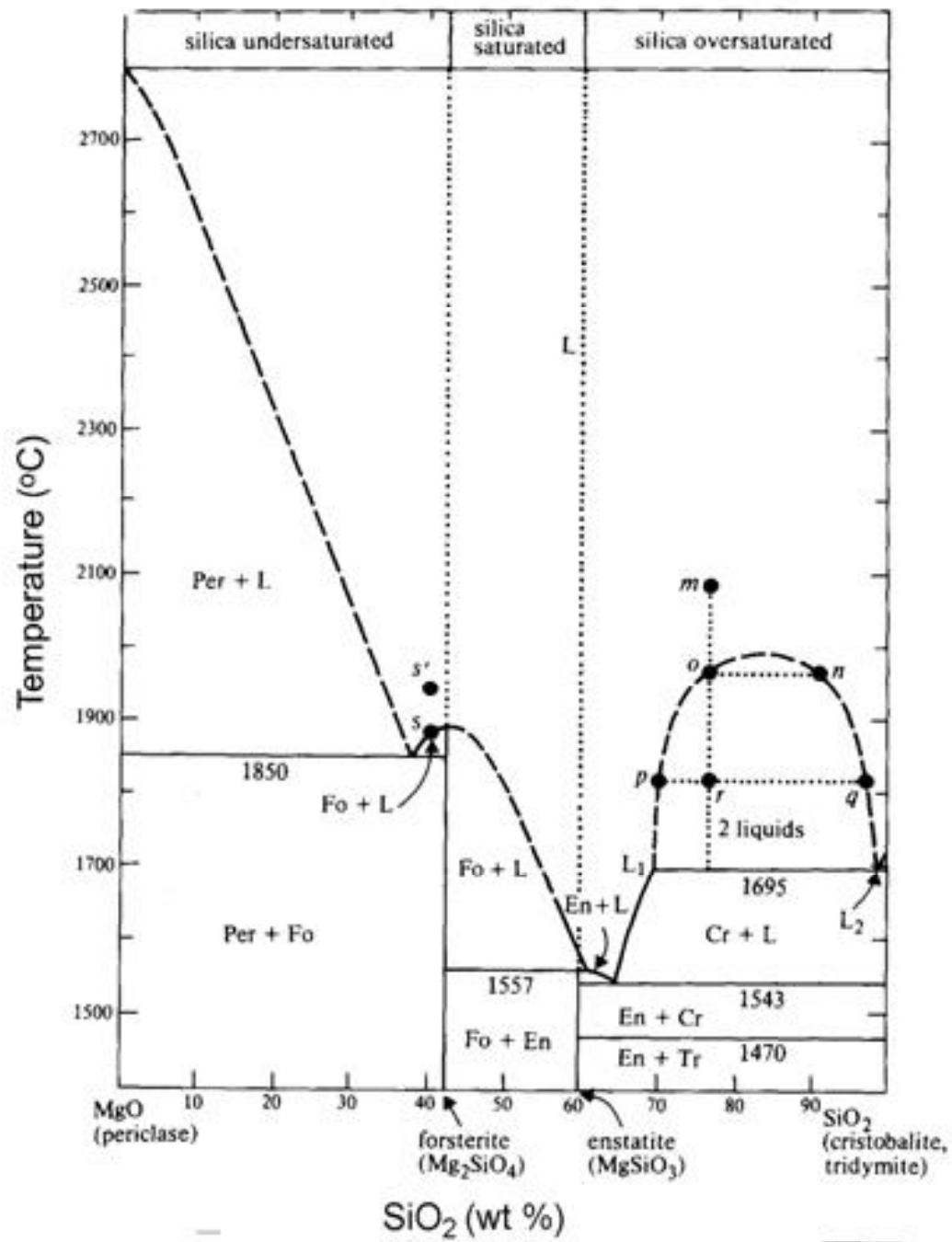
Exchange between Mg, Fe, Ca and Mn is favourable because of similarities in ionic radii and same charge.











**$\text{CaAl}_2\text{Si}_2\text{O}_8$
Anorthite (An)**

Plagioclase

**$\text{NaAlSi}_3\text{O}_8$
Albite (Ab)**

Alkali Fsp

**KAlSi_3O_8
Orthoclase (Or)**

Or₃₇₋₁₀₀ = Sanidine
Or₁₀₋₃₇ = Anorthoclase
Ab₉₀₋₇₀ = Oligoclase
Ab₇₀₋₅₀ = Andesine
Ab₅₀₋₃₀ = Labradorite
Ab₅₀₋₁₀ = Bytownite

