I ♥ Petrology!

Sarah Lambart - 2016

LECTURES 6-9: TWO-COMPONENT SYSTEMS

Recap Lecture 5

- Gibbs-Duhem equation: $dG = -SdT + VdP$

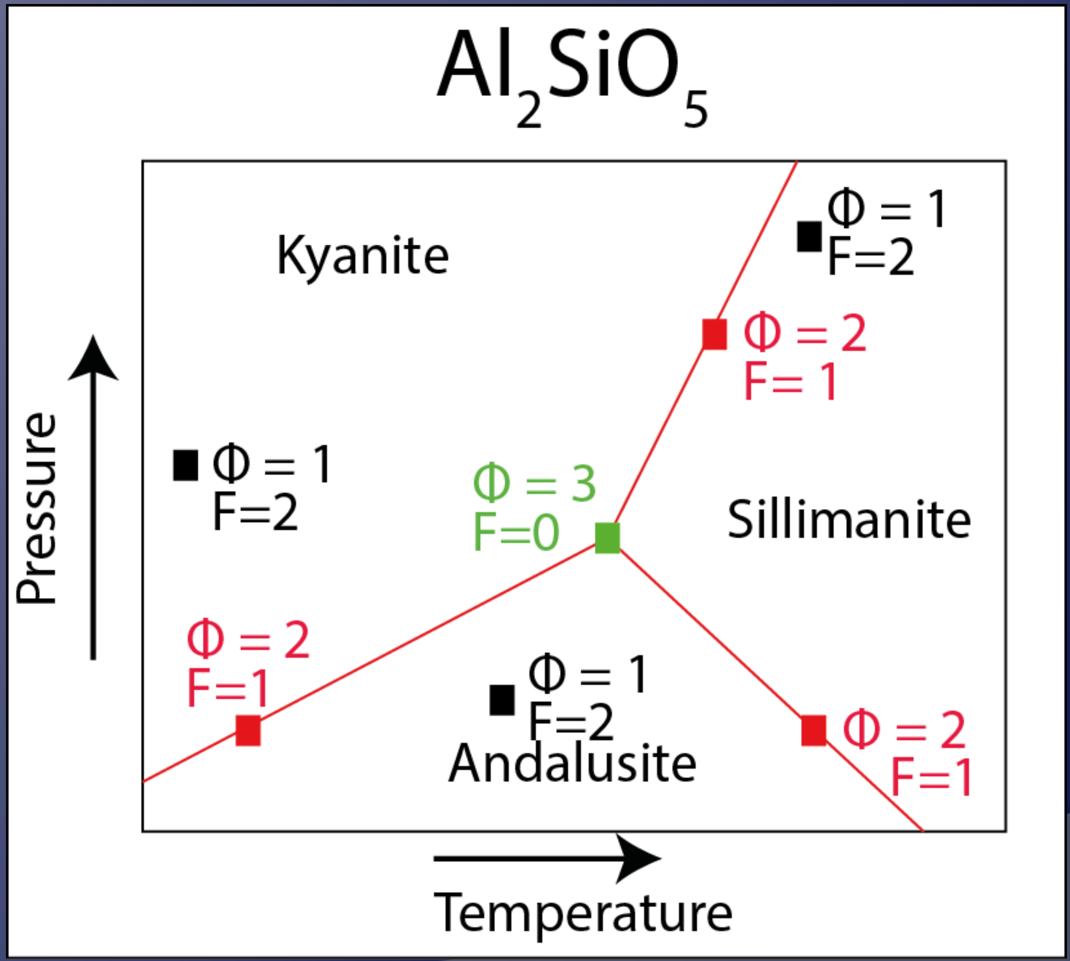
- Clapeyron equation: $dP/dT = \Delta S_R/\Delta V_R$

- Gibbs phase rule: $f = c + 2 - \Phi$

Recap Lecture 5

PHASE RULE

$$f = c + 2 - \Phi$$



Composition as a variable

- Constant X: one component diagram
- Constant T: isothermal diagram
- Constant P: isobaric diagram

$f = c + 1 - \Phi$: "reduced" phase rule

Binary systems: $f = 2 + 1 - \Phi$

- $\Phi_{max} = 3$
- 2 different cases:
  - System with eutectic
  - System with solid solution

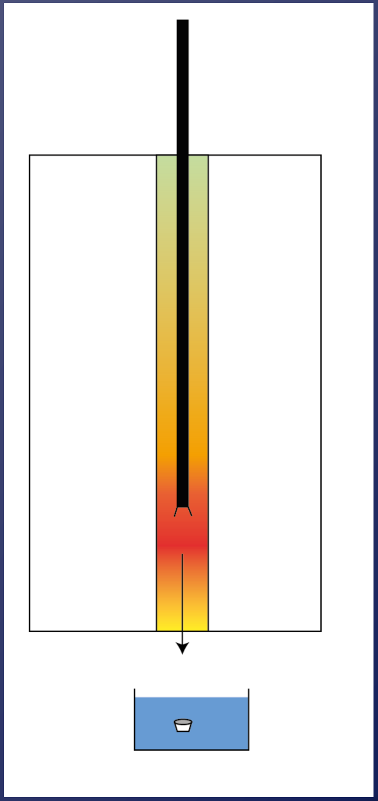
Binary systems: $f = 2 + 1 - \Phi$

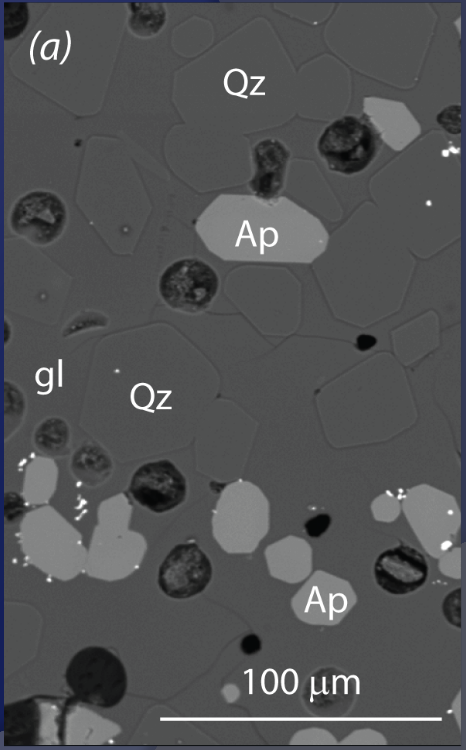
- $\Phi_{max} = 3$

- 2 different cases:
  - System with eutectic
    - System with a simple eutectic
    - System with an intermediate stable phase
    - System with an intermediate unstable phase
  - System with solid solution
    - Simple system
    - System with solubility gap

Construction of a binary phase diagram

One atmosphere furnace



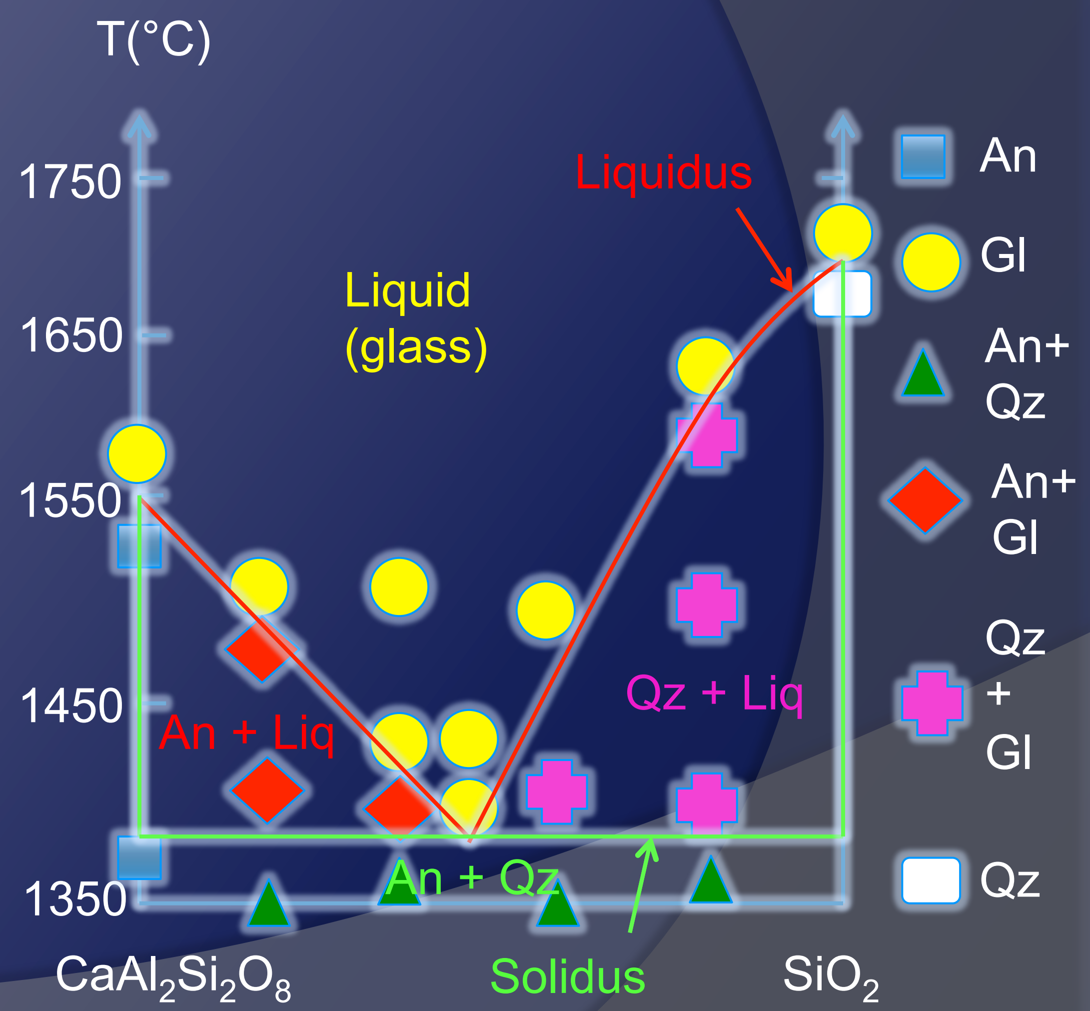


http://nai.nasa.gov/annual-reports/2011/rpi/project-6-the-environment-of-the-early-earth/

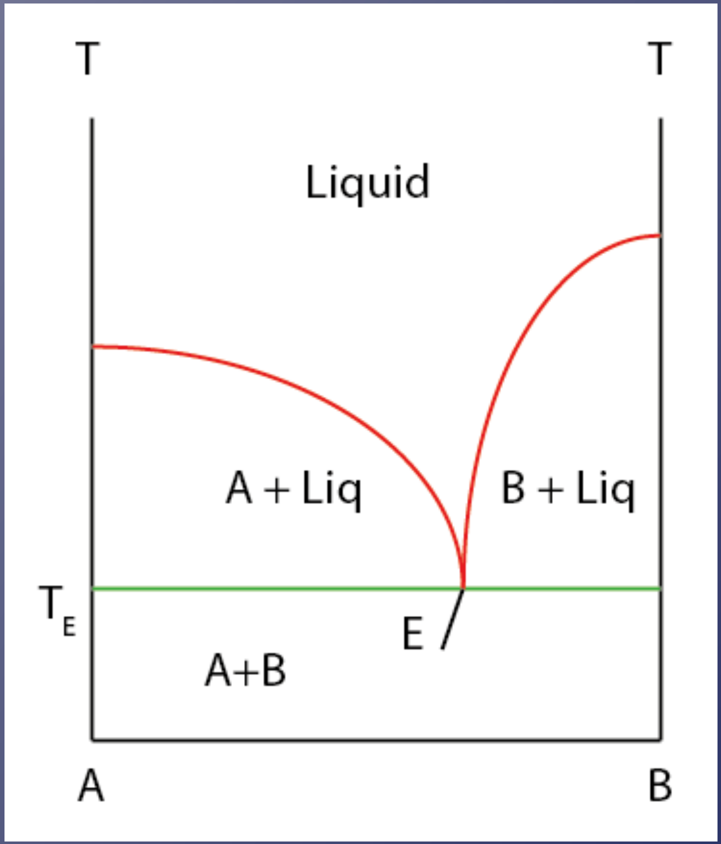
Construction of a binary phase diagram

$CaAl_2Si_2O_8$ - SiO_2

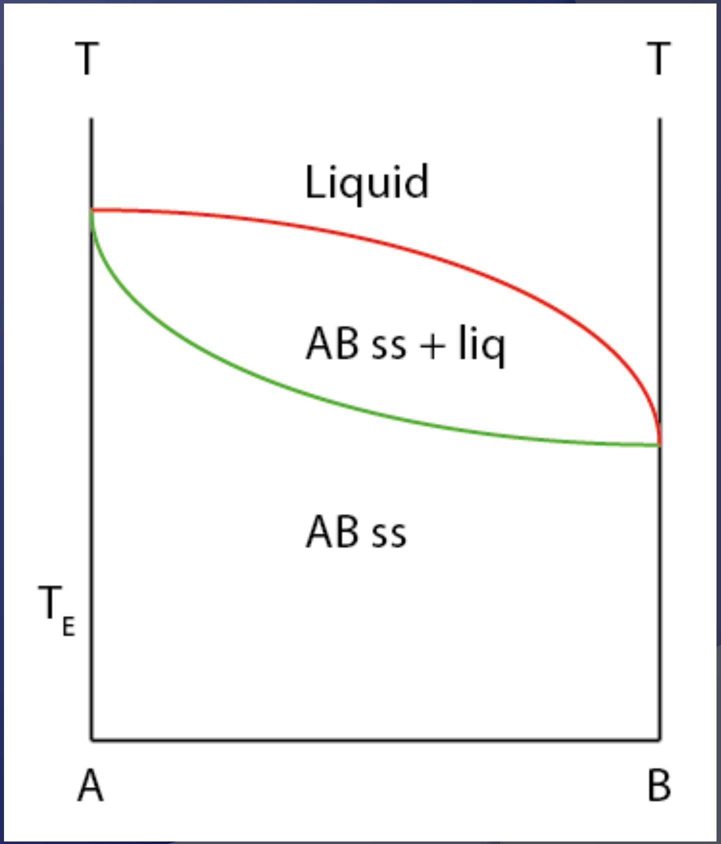
T (°C)	% SiO2	Product
1360	0	An
1540	0	An
1560	0	Gl.
1350	20	An + Qz
1400	20	An+Gl
1520	20	Gl
1350	60	An+Qz
1400	60	Qz+Gl
1700	100	Qz
1720	100	Gl
…	…	…



Syst. With Eutectic



Syst. With Solid solution



Case of a simple eutectic

Liquidus: separate the field with only liquid from the other fields

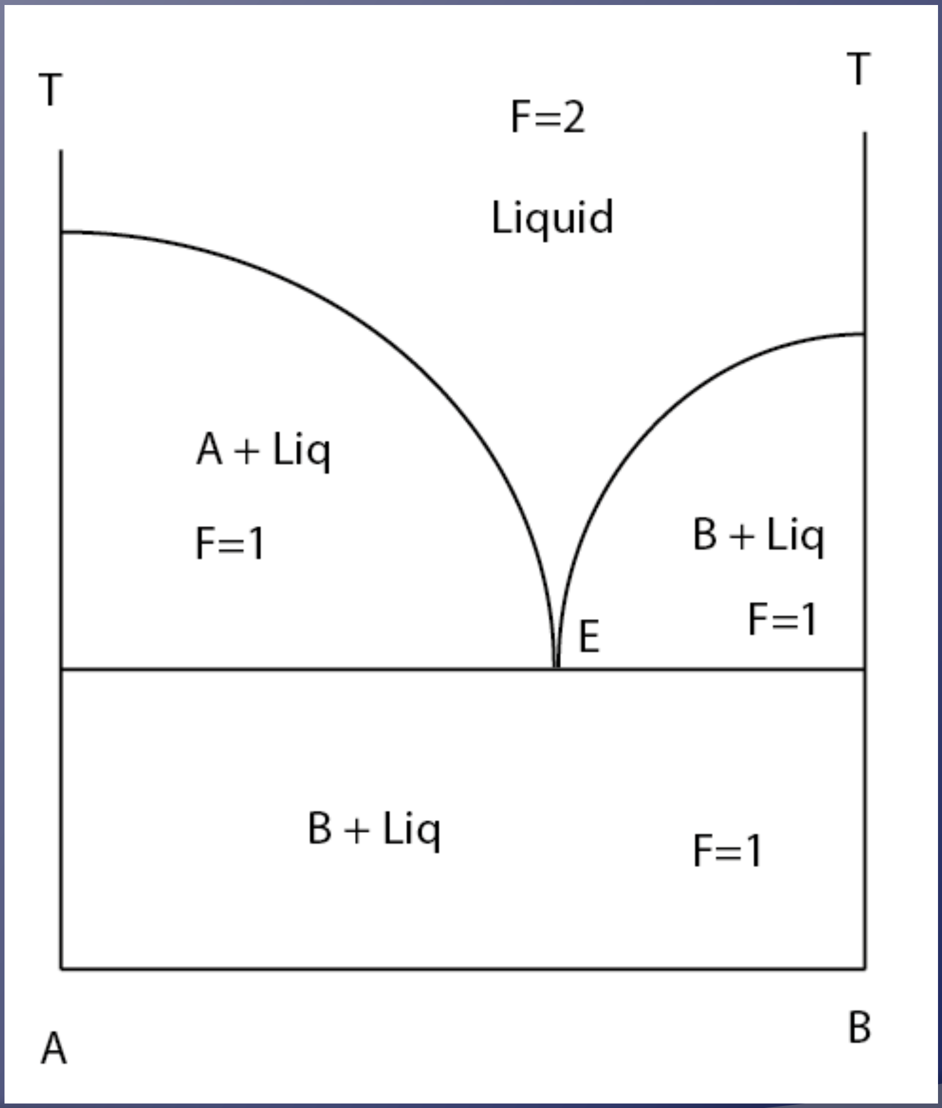
Solidus: separate the field with only solid phase(s) form the other fields

Eutectic point:

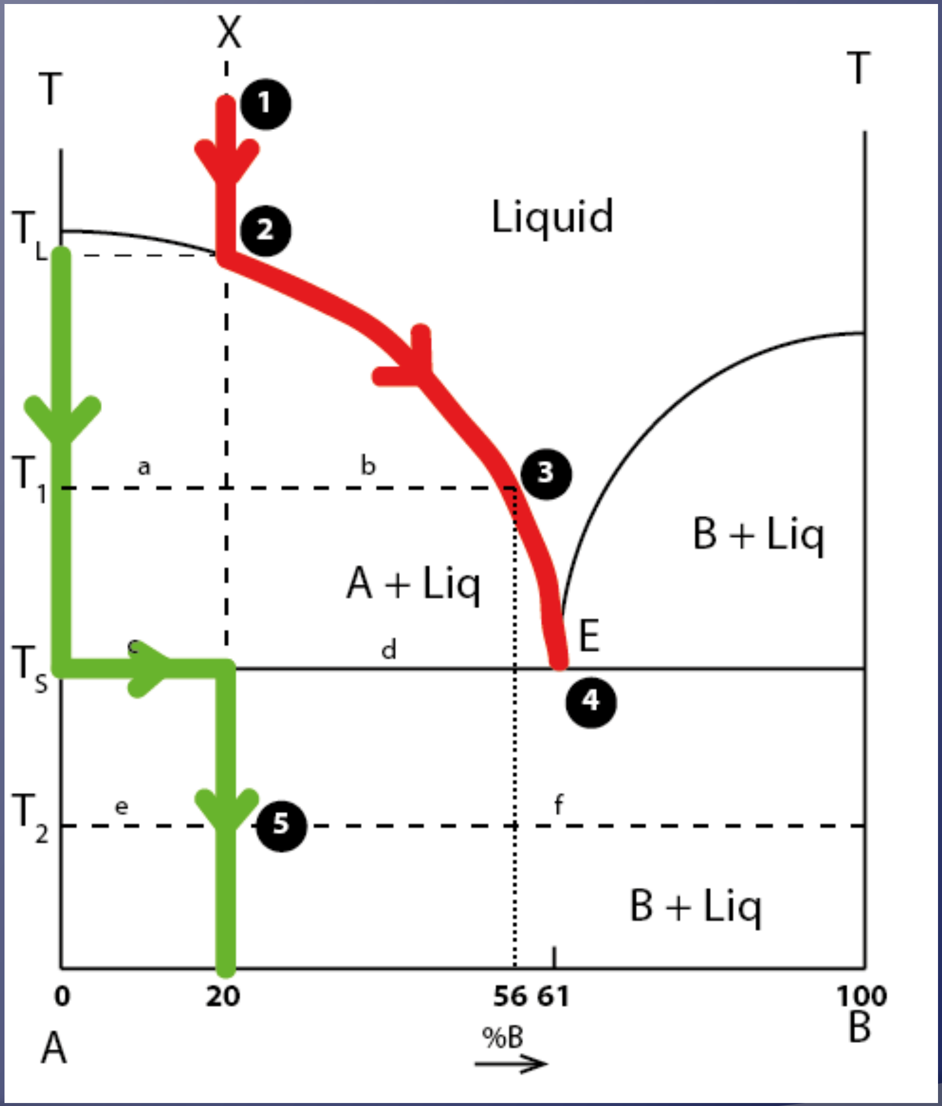
- separate the field with only solid phase(s) form the other fields
- lowest T at which liquid is stable
- Φ_{max}

Lever rule: phase proportions

Case of a simple eutectic



Case of a simple eutectic



Equilibrium crystallization of composition X *(T decreases)*

(1) 100% Liquid with composition X = 20%B

(2) Liquidus: first crystal of A appears

(3) T1: Mnl A + liquid

- Liquid composition: 56%B
- Liquid proportion: a/(a+b)=20/56=35.7%
- Mnl A proportion: 1-a/(a+b)=b/(a+b)

(4) Eutectic point:

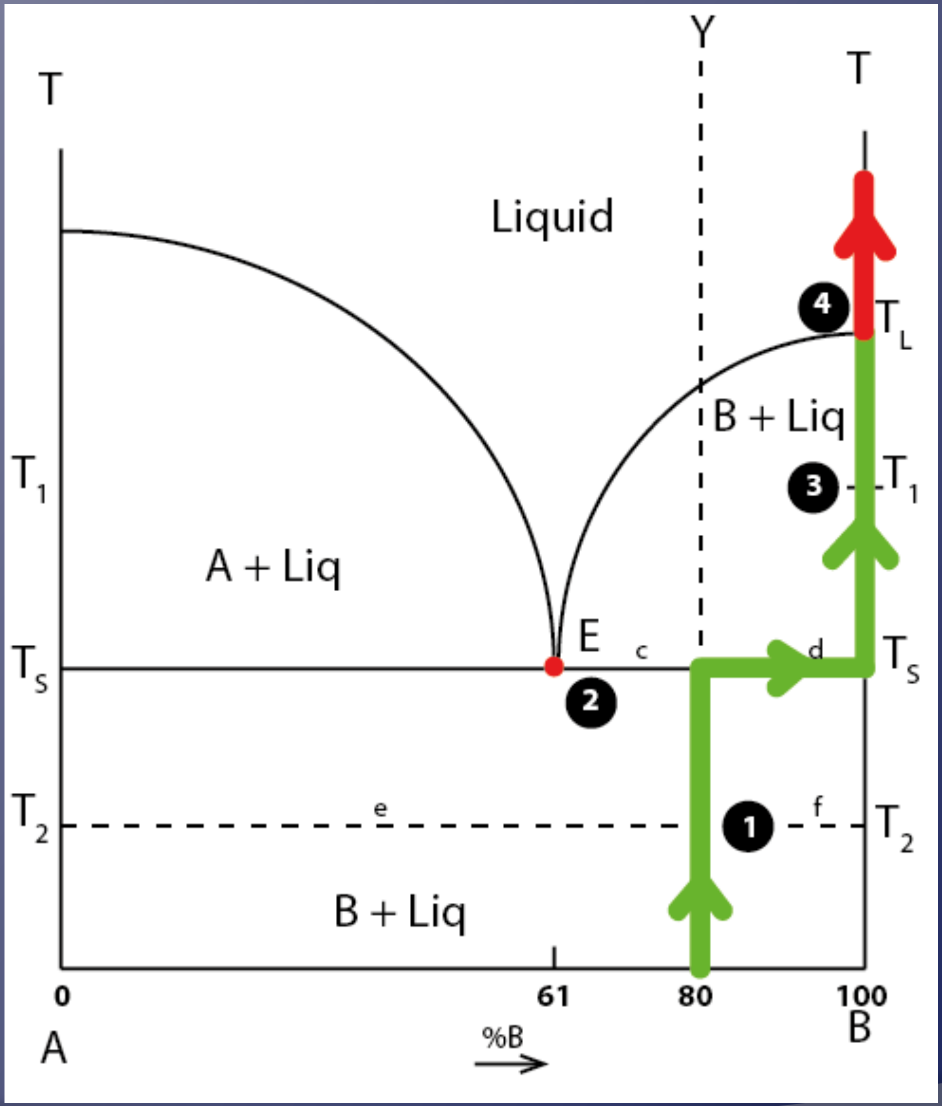
- Phase proportion when it reaches T_S:
  - % liq = 20/61 = 32.8%
  - % A = 1 - 20/61 = 67.2%
  - %B = 0%
- Crystallization of the liquid in the proportion of the eutectic:

Liq → 39% A + 61% B

- Liquid proportion when it leaves T_S: 0%

(5) Solid state: mix between crystals of A and B: % A: f/(e+f)=(100-20)/100=80%

Case of a simple eutectic



Fractional melting of composition Y

(T increases and melt is extracted at each step)

(1) 100% solid: mix of A and B
A%=f/(e+f) = (100-80)/100=20%

(2) Eutectic point: first melt appears

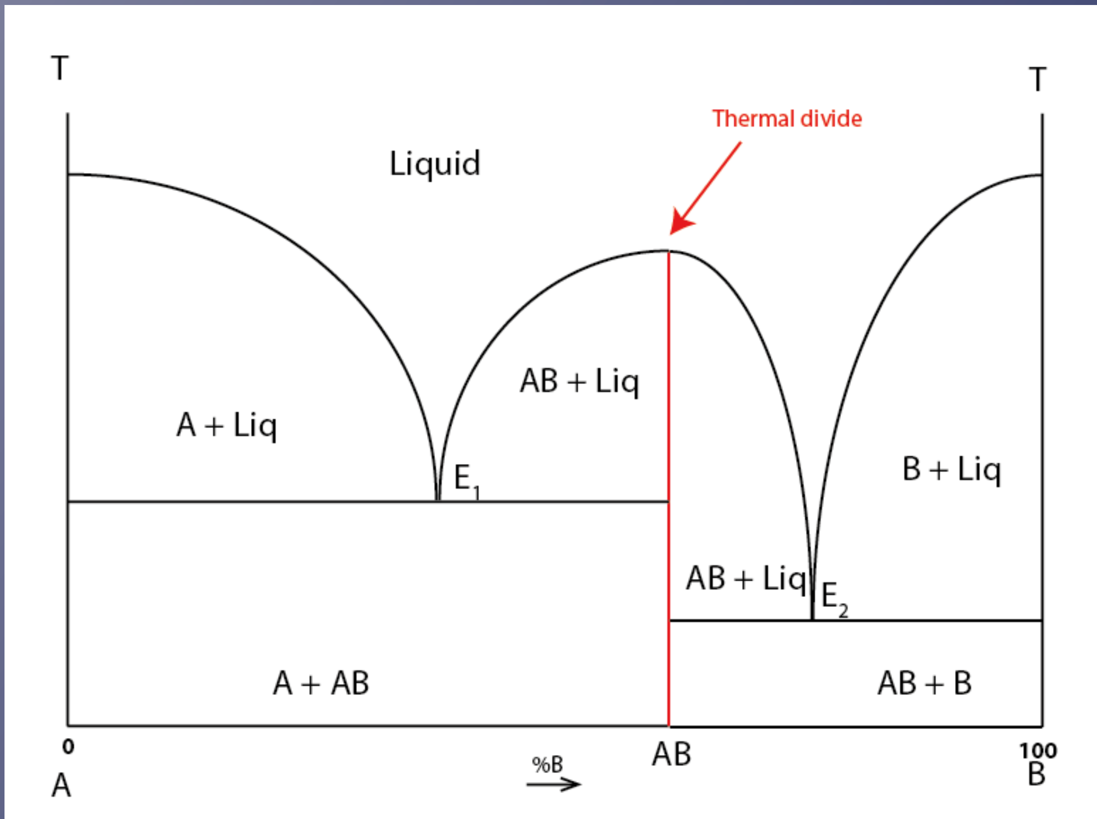
- Melting of the solid in the eutectic proportions: 61% B + 39% A → Liq
- Liquid composition: 61% B
- Phase proportions when it leaves T_S:
  - % A = 0%
  - % Liq = 0% (all the liquid is instantaneously extracted)
  - % B = 100%

(3) T1: 100% Mnl B

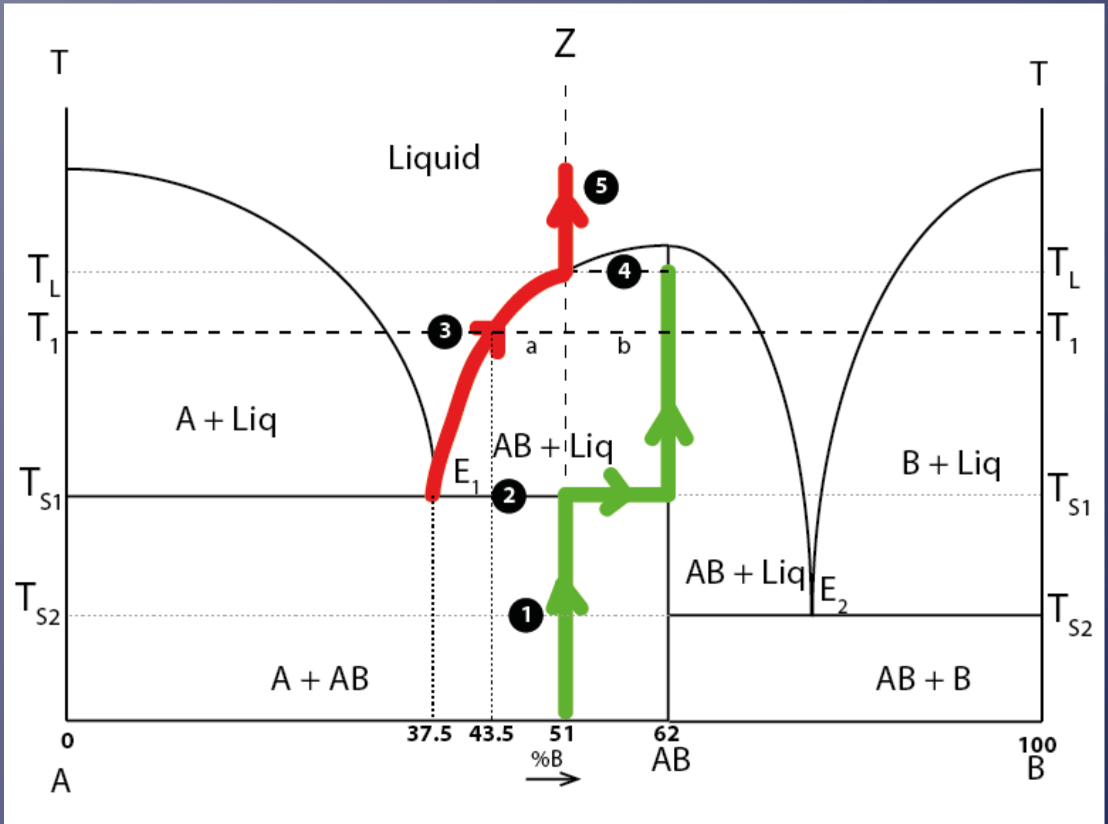
(4) Liquidus: $B_{solid} \rightarrow B_{liquid}$

Note: unlike during the equilibrium melting, the last melt to be formed doesn't have the same composition than the initial solid.

System with an intermediate stable phase



System with an intermediate stable phase



Equilibrium melting of composition Z *(T increases)*

(1) 100% solid: mix of A and AB
A% = (62-51)/62 = 17.7%

(2) Eutectic point: first melt appears

- Melting of the solid in the eutectic proportions: ((62-37.5)/62=) 39.5% A + 60.5% AB → Liq
- Liquid composition: 37.5% B
- Phase proportions when it leaves T_S:
  - % A = 0%
  - % Liq = (62-51)/(62-37.5) = 45%
  - % B = 55%

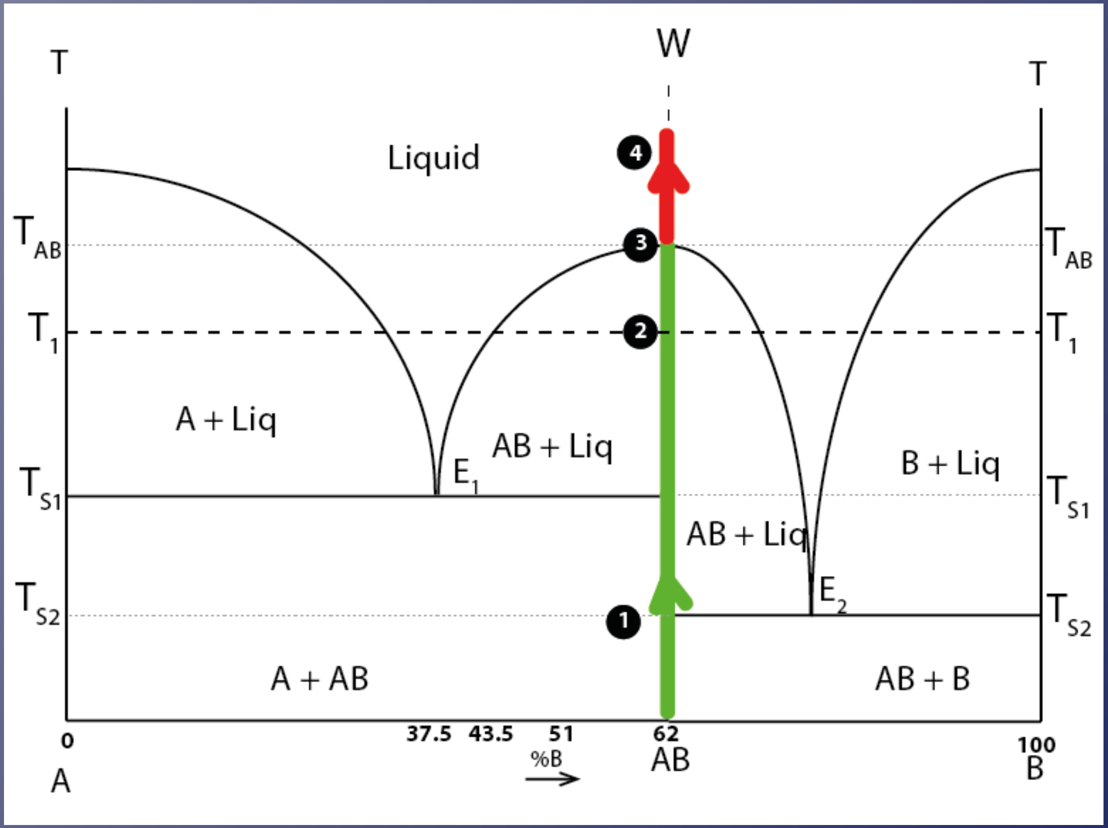
(3) T1: Mnl AB + Liquid

- Liquid composition: 43.5% B
- Liquid proportion: b/(a+b) = (62-51)/(62-43.5) = 59.4%

(4) Liquidus: the last crystal of AB melts

(5) 100% liquid – Liquid composition: Z = 51% B

System with an intermediate stable phase



Equilibrium melting of composition W *(T increases)*

(1) 100% mnl AB

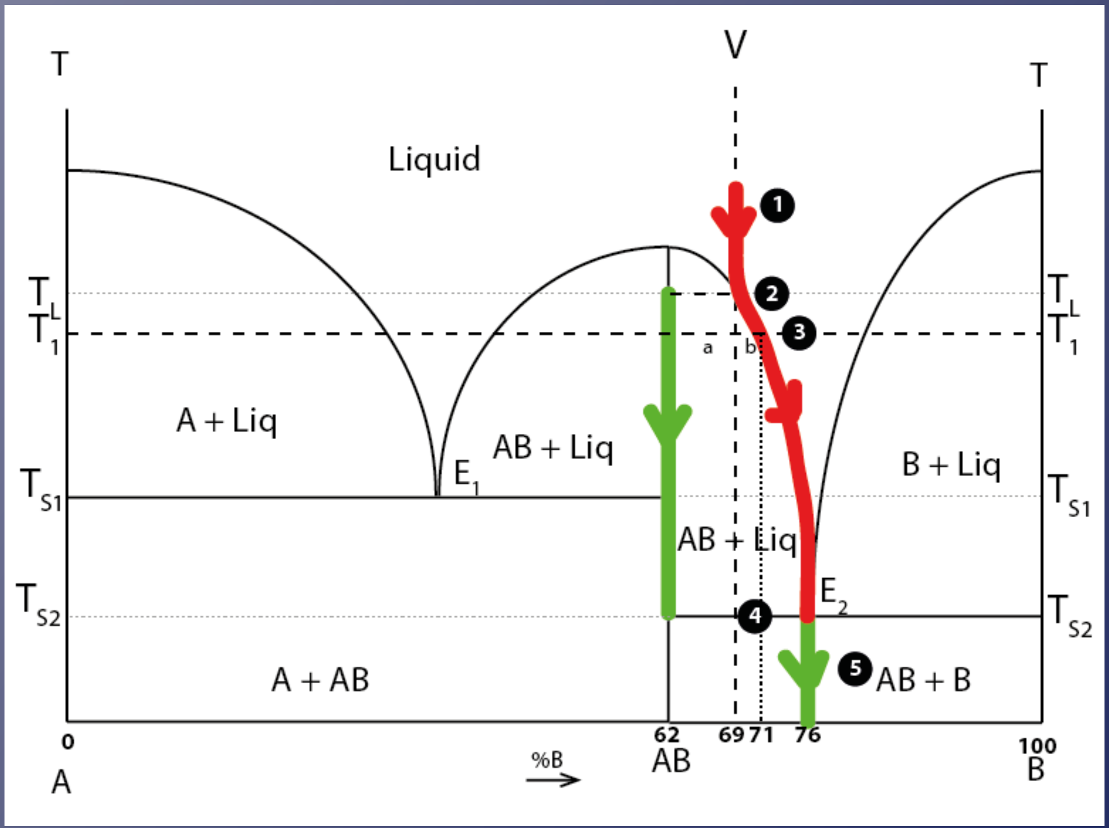
(2) T_1: 100% mnl AB

(3) T_{AB}: Congruent melting: $AB_{solid} \rightarrow AB_{liquid}$

(4) 100% liquid AB – Liquid composition: 62%B

Note: Composition W behaves as a one component system (such as composition 100% A and composition 100% B

System with an intermediate stable phase



Fractional crystallization of composition V *(T decreases and crystals are separated at each step)*

Note: at each step you form a new melt composition ⇒ Formation of magmatic series

(1) 100% liquid
Liquid composition: V = 69% B

(2) Liquidus: first crystal of AB appears and is instantaneously separated.

(3) T_1: New bulk composition = 71% B – Crystals of AB continue to be formed and separated

(4) Eutectic point: first crystal of B appears

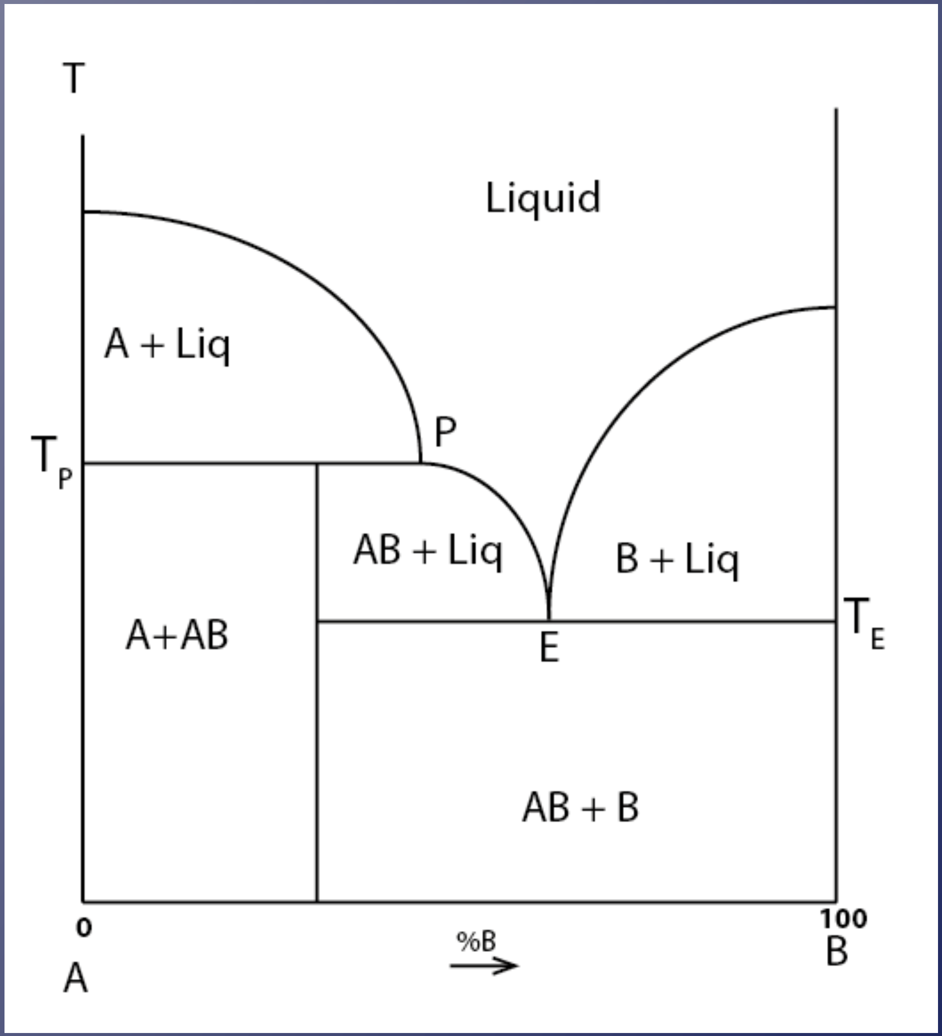
- Phase proportion when it reaches T_{S2}: 0%AB (all crystal separated), 100% Liq, 0%B
- Liquid crystallizes to form AB and B in eutectic proportions:

 Liq → ((100-76)/(100-62)=) 63% AB + 37% B

- Last solid to be formed: mix of 63% AB – 37%B

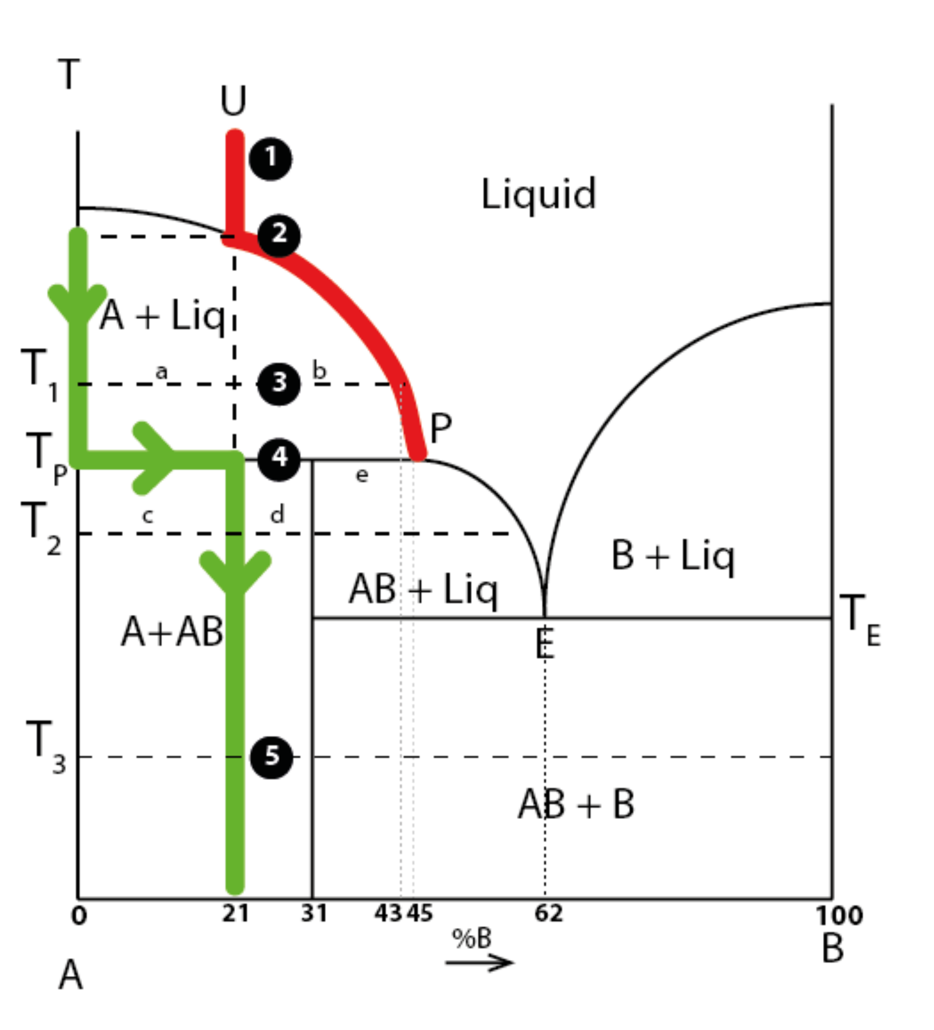
(5) 100% solid: 63% AB + 37% B – solid composition: 76%

System with an intermediate unstable phase



System with an intermediate unstable phase

Equilibrium crystallization of composition U *(T decreases)*



(1) 100% Liquid with composition X = 21%B

(2) Liquidus: first crystal of A appears

(3) T1: Mnl A + liquid

- Liquid composition: 43%B
- Liquid proportion: a/(a+b)=21/43=48.8%
- Mnl A proportion: 51.2%

(4) Peritectic point:

- Phase proportion when it reaches T_P:
  - % liq = 21/45 = 46.7%
  - % A = 1 – 21/45 = 53.3%
  - %AB = 0%
- Incongruent crystallization of AB in the proportion of the peritectic:

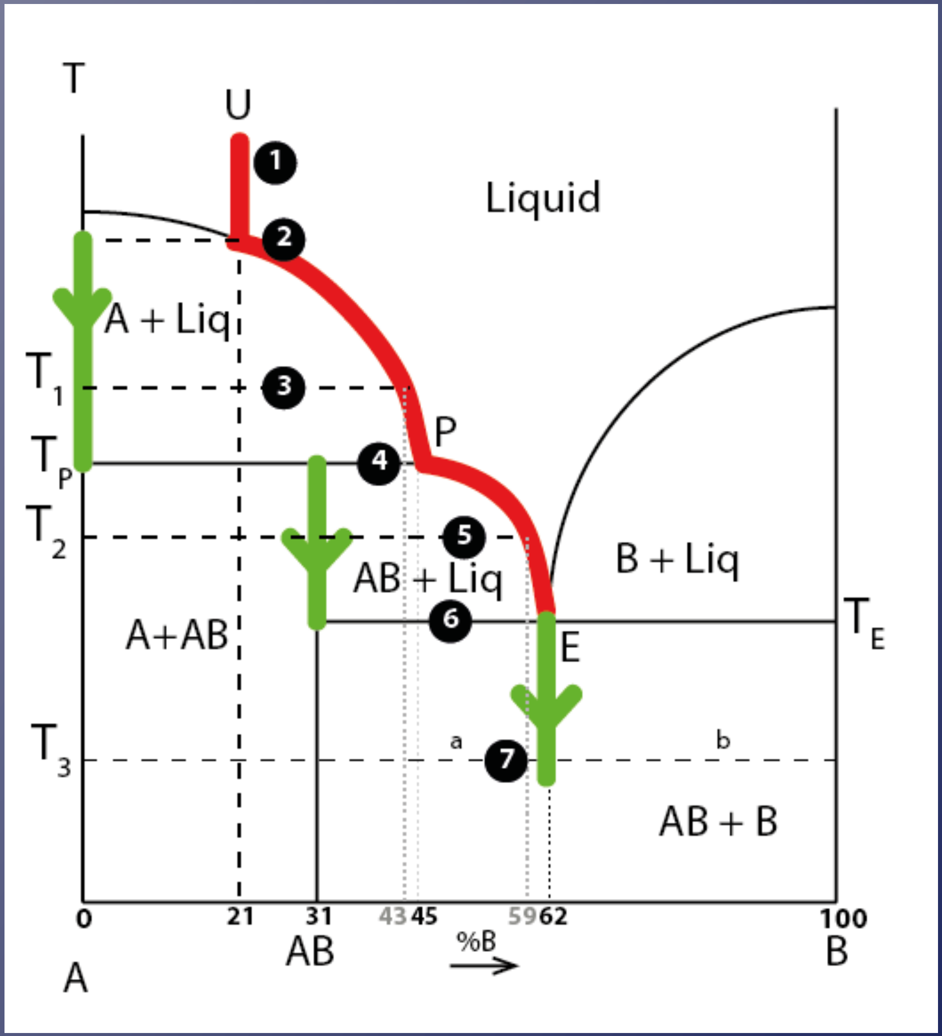
(31/45=) 68.9%Liq + 31.1% A → AB

- Liquid proportion when it leaves T_P: 0%

(5) Solid state: mix between crystals of A and AB: % A: d/(c+d)=(31-21)/31=32%

System with an intermediate unstable phase

Fractional crystallization of composition U *(T decreases and minerals separated)*



(1) 100% Liquid with composition U = 21%B

(2) Liquidus: first crystal of A appears and is instantaneously separated from the melt

(3) T_1: New bulk composition = 43% B – Crystals of A continue to be formed and separated

(4) Peritectic point:

- Phases when it <u>reaches</u> T_P: 100% Liq (compo 45% B): no crystals A to react with.
- Phases when it <u>leaves</u> T_P: 100% Liq

(5) AB + liquid (with AB separated instantaneously)

(6) Eutectic point

- first crystal of B appears
- Liquid crystallizes to form AB and B in eutectic proportions:

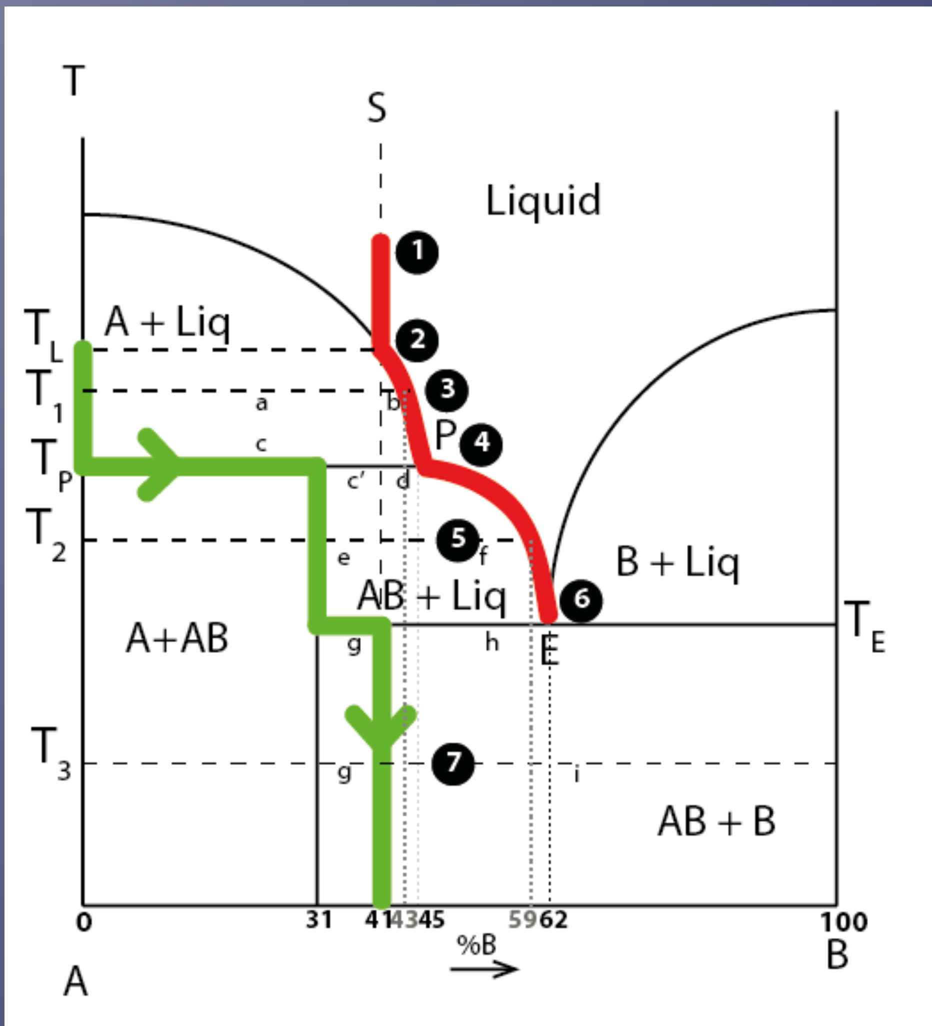
 Liq → ((100-62)/(100-31)=) 55% AB + 45% B

- Last solid to be formed: mix of 55% AB – 45% B

(7) 100% solid: 55% AB + 45% B – solid composition: 62% B

System with an intermediate unstable phase

Equilibrium crystallization of composition S *(T decreases)*



(1) 100% Liquid with composition S = 41%B

(2) Liquidus: first crystal of A appears

(3) T_1: Mnl A + liquid

- Liquid compo.: 43%B
- % Liq: a/(a+b)=41/43=95.3%

(4) Peritectic point:

- Phases when it reaches T_P: Liq + A
    - % Liq = 41/45 = 91.1%
    - % A = 1 – 41/45 = 8.9%
- Incongruent crystallization of AB in the proportion of the peritectic:

(31/45=) 68.9%Liq + 31.1% A → AB

- Phases when it leaves T_P: Liq + AB

% Liq: c'/(c'+d) = (41-31)/(45-31) = 71.4%

(5) AB + liquid

- % Liq: e/(f+e) = (41-31)/(59-31) = 35.7%
- Liq comp: 59%B

(6) Eutectic point:

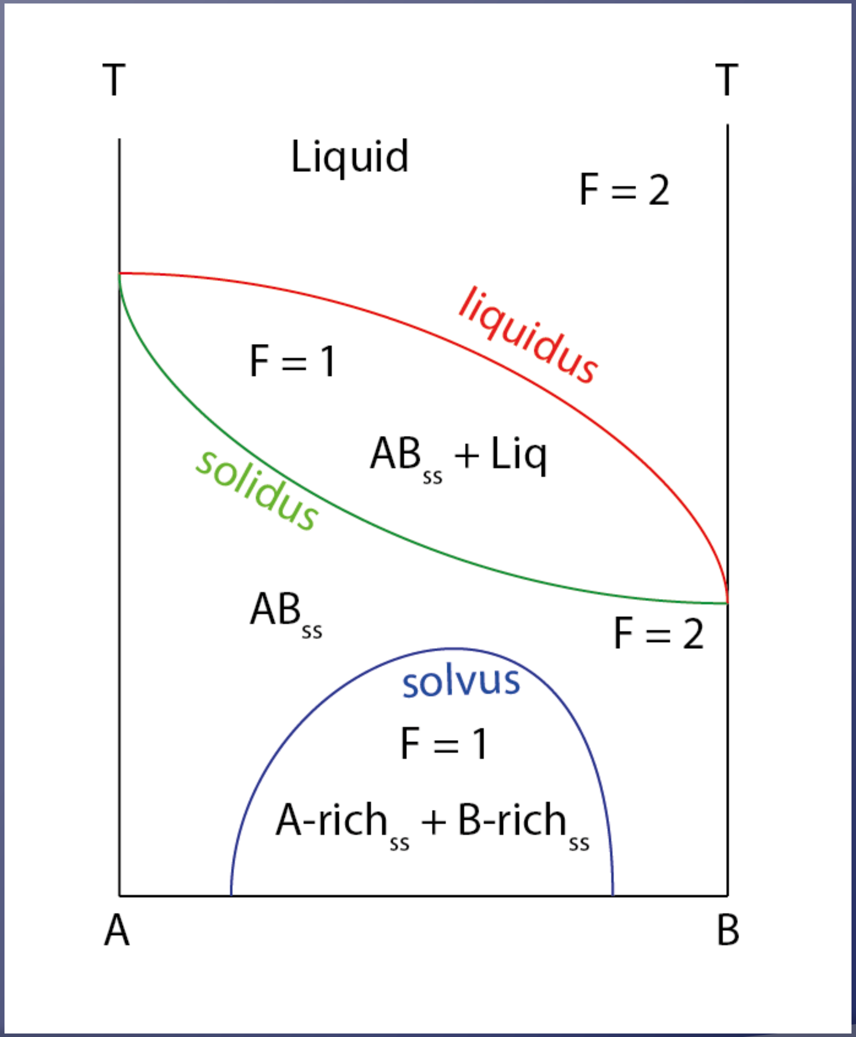
- Phases when it reaches T_E: Liq + AB
    - % liq = g/(g+h) = (41-31)/(62-31) = 32.2%
    - liq compo: 62% B
- Crystallization of the liquid in the proportion of the eutectic:

Liq → ((100-62)/(100-31)=)55% AB + 45% B

(7) Solid state: mix between crystals of AB and B:

- % AB: i/(g+i)=(100-41)/(100-31)=85.6%
- Solid compo: S: 41%B

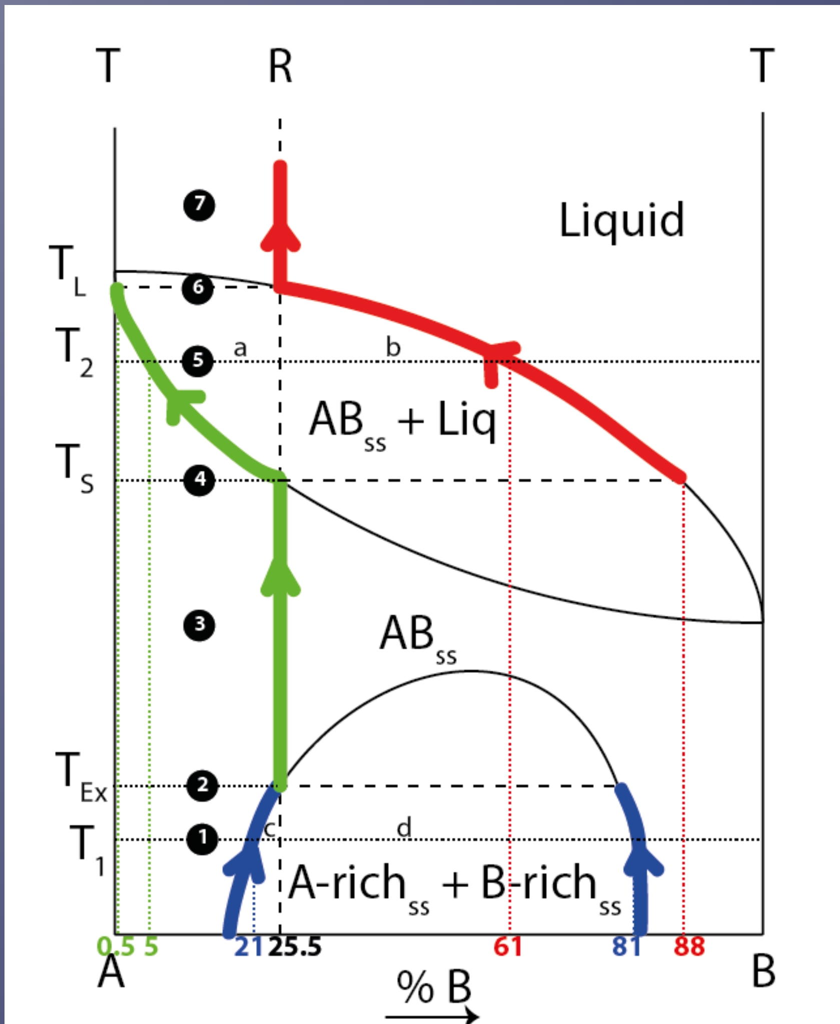
System with solid solution



Note: Mineral phases have intermediate compositions between pure end-members that evolve during the magmatic process

System with solid solution

Equilibrium melting of composition R
(T increases)



(1) T_1: 2 immiscible liquids: A-rich ss and B-rich ss

- A-rich ss compo: 21%B
- B-rich ss compo: 81%B
- %A-rich ss: d/(c+d) = (81-25.5)/(81-21) = 92.5%

(2) T_{ex}: end of the immiscibility: only one solid solution of compo 25.5% B

(3) One solid phase with compo 25.5%B

(4) Solidus: first melt appears

- Compo first melt: 88%B

(5) T_2: ABss +Liq

- Compo AB: 5%B
- Compo liq: 61%B
- % liq: a/(a+b) = (25.5-5)/(61-5) = 36.6%

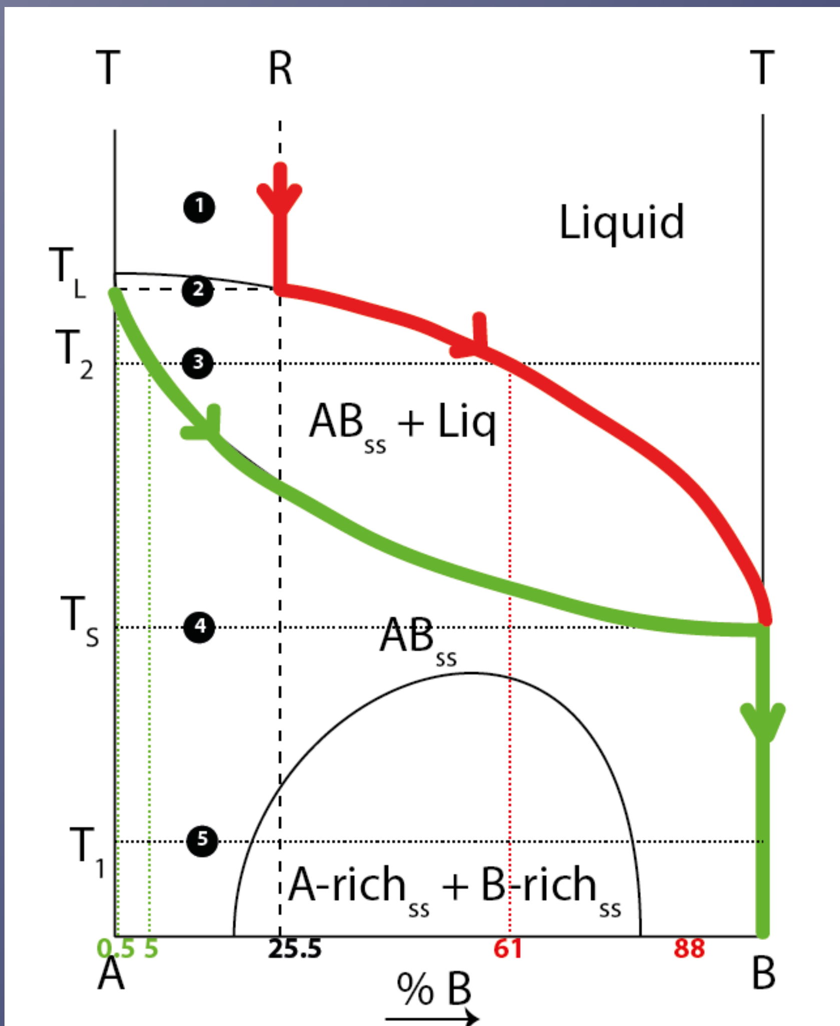
(6) Liquidus: last crystal of ABss to melt

Compo last crystal: 0.5%B

(7) 100% liquid – compo liq: 25.5% B

System with solid solution

Fractional crystallization of R



(1) 100% liquid of compo 25.5% B

(2) Liquidus: first crystal of Abss to crystallize.

- compo first crystal: 0.5% B (almost pure A)

(3) New bulk composition: 61%B

Compo crystal in equilibrium: 5%B

(4) $B_{liquid} \rightarrow B_{solid}$

(5) 100% B_{solid}

Note: As in systems with eutectic, during fractional crystallization, the final solid do not have the same composition than the initial liquid.

Between TL and TS, all the mnls composition along the solidus will be formed and separated from the liquid

NEXT TIME

Ternary diagrams

TO READ:

Chapters 3 Ehlers (smartsite)

FIGURE PRESENTATION