2015 Fall

"Phase Equilibria *in* Materials"

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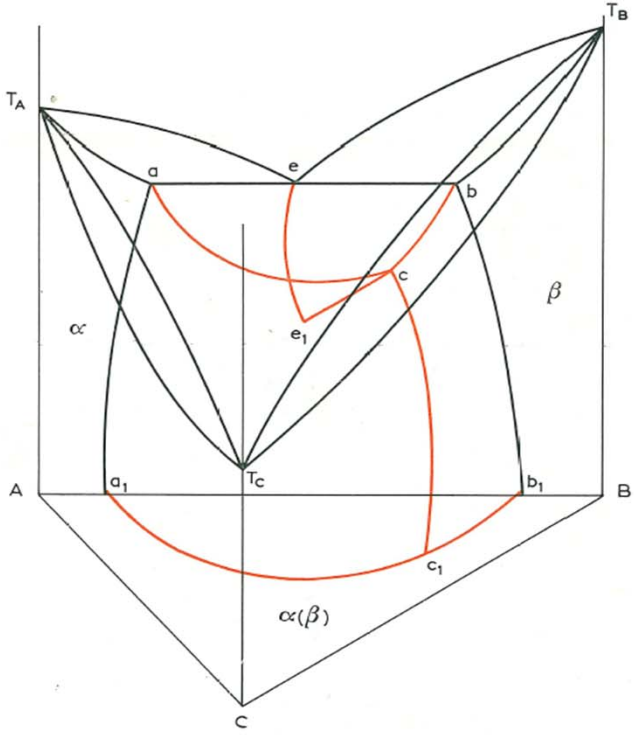
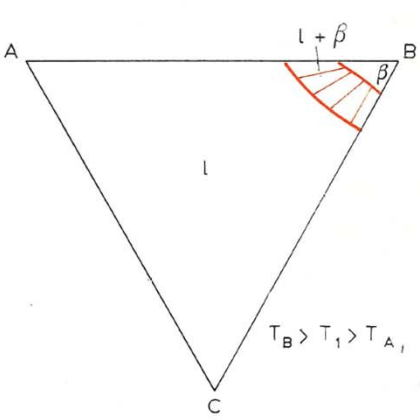
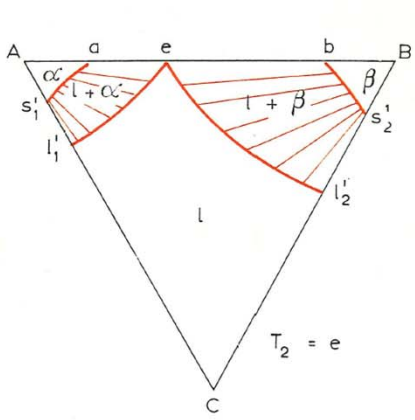
9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- **Isothermal section**

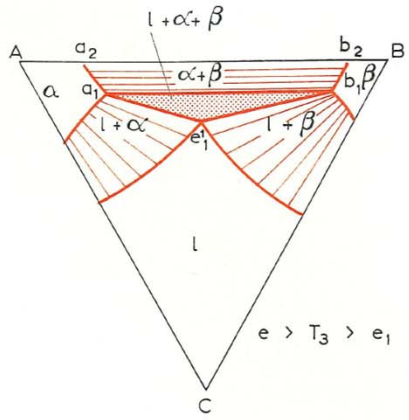




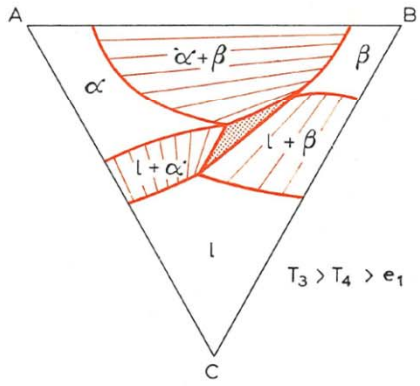
$T_B > T_1 > T_A$



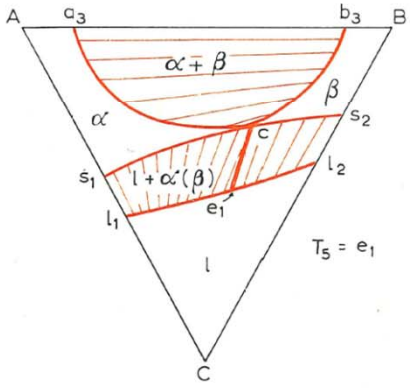
$T_2 = e$



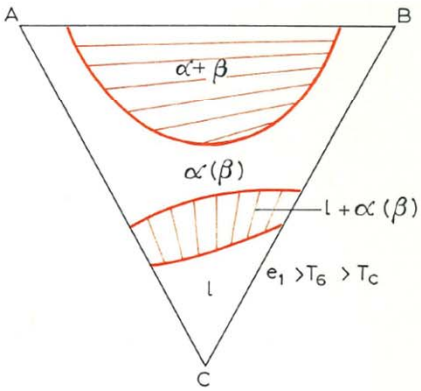
e > T_3 > e_1



$T_3 > T_4 > e_1$



$T_5 = e$

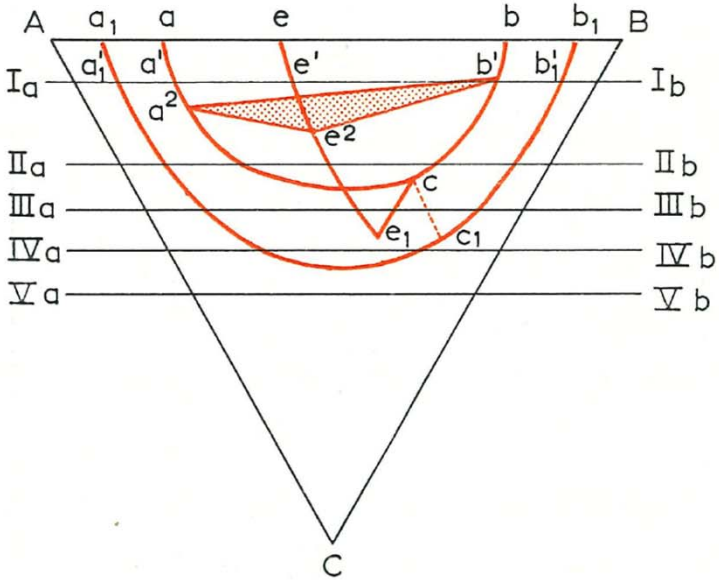


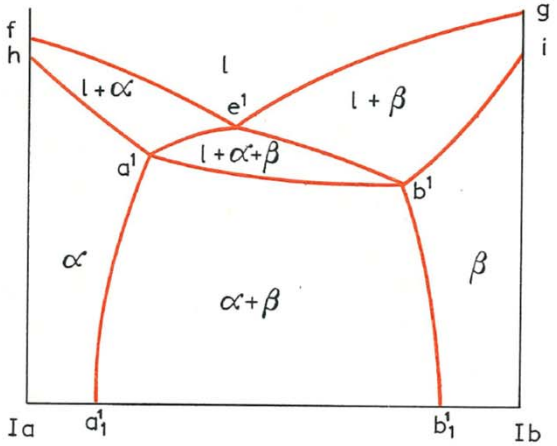
$e_1 > T_6 > T_c$

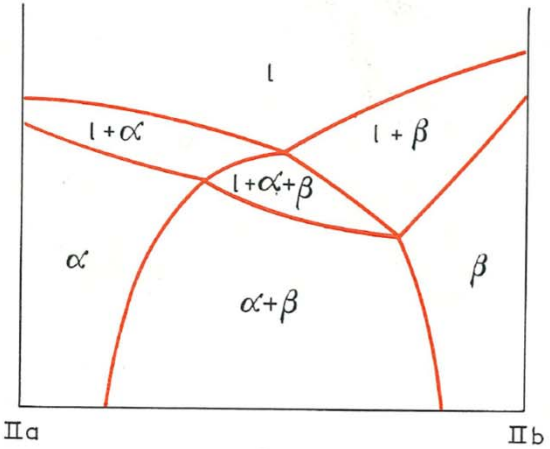
cf) Movie

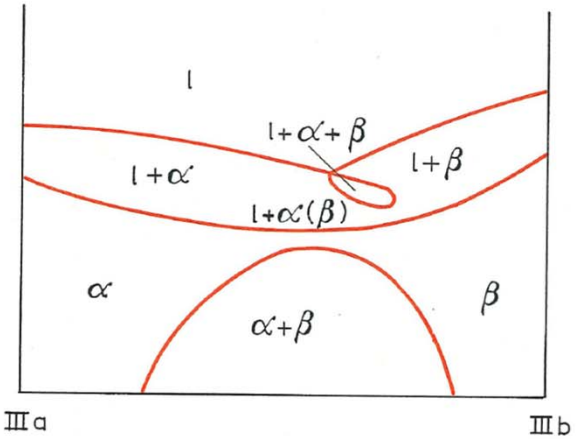
9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

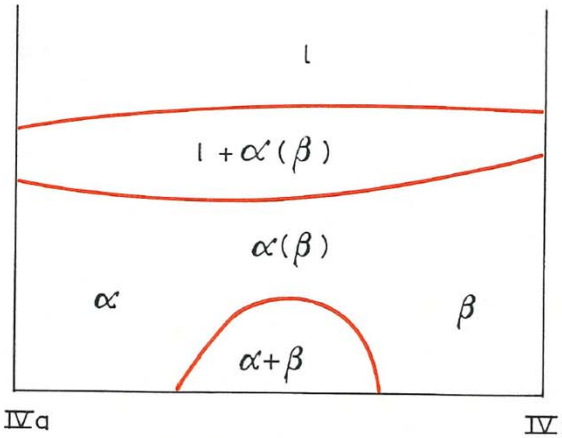
- **Vertical section**

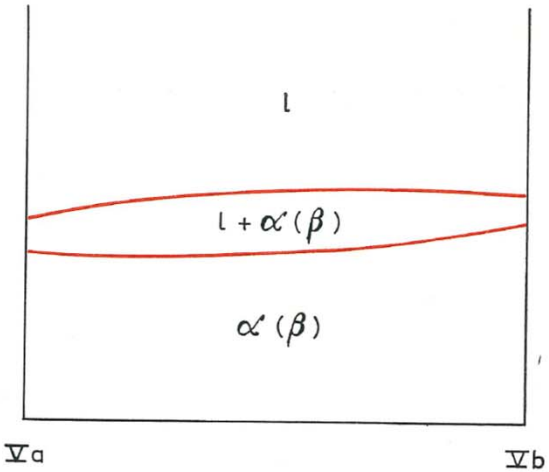












> Point 1: 4 on the α solidus surface

> Point 1- Point 2

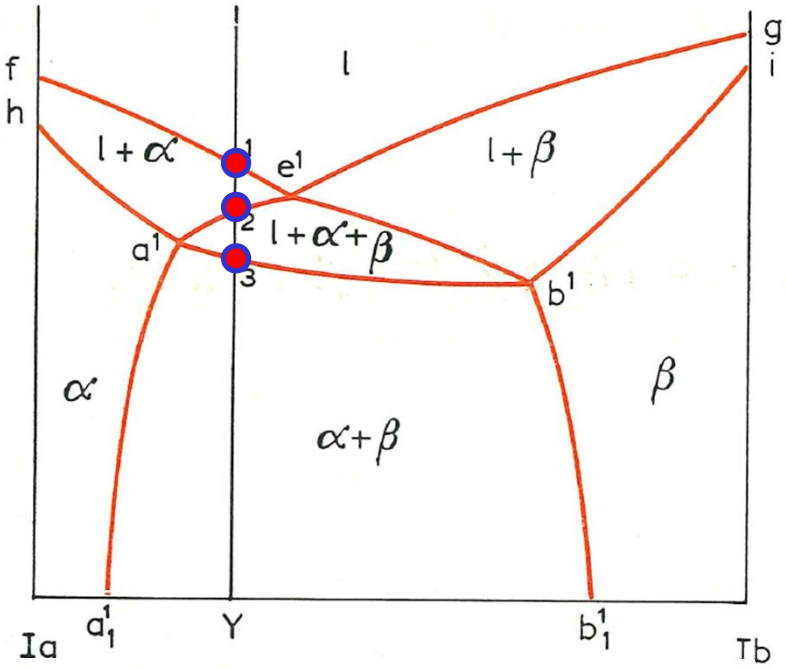
* 4→6 on the α solidus surface
* 1→5 on the α liquidus surface

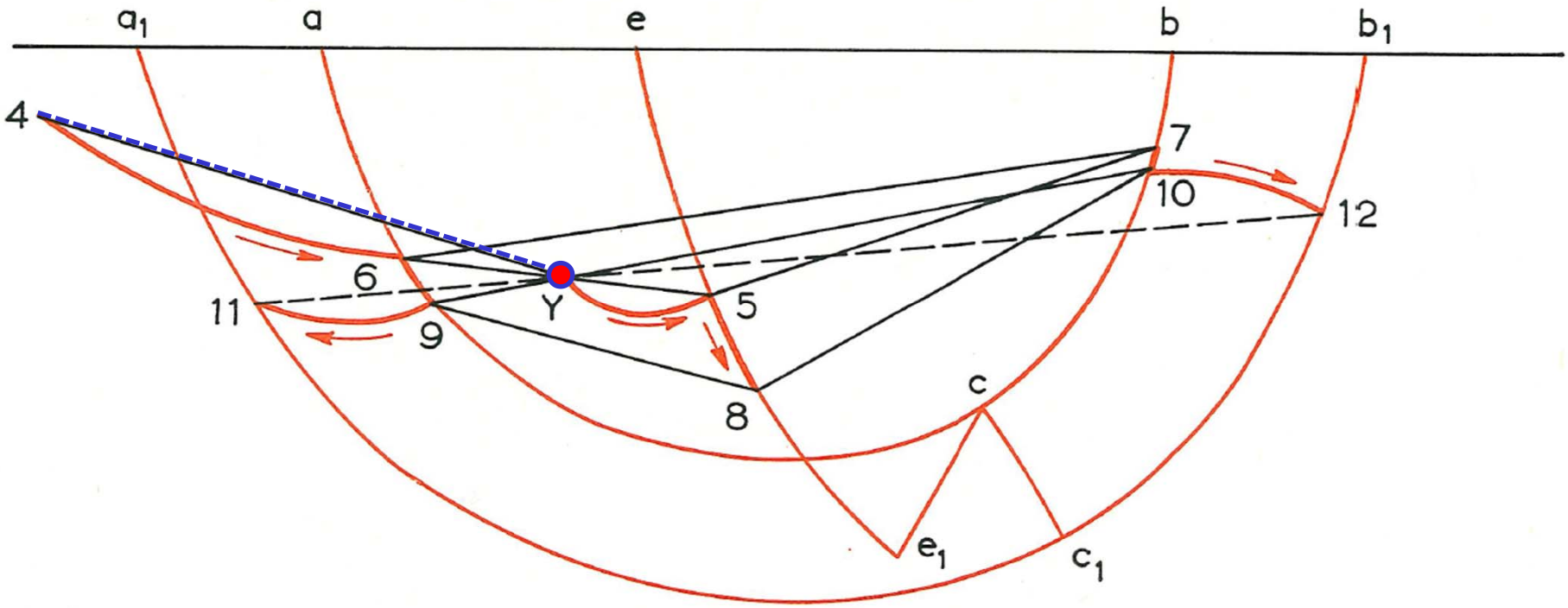
Three phase equilibrium l5, α6, β7

* α: 6→9, β: 7→10, l: 5→8

> Point 3: on the tie line 9-10

> Point 3-Y: α: 9→11, β: 10→12

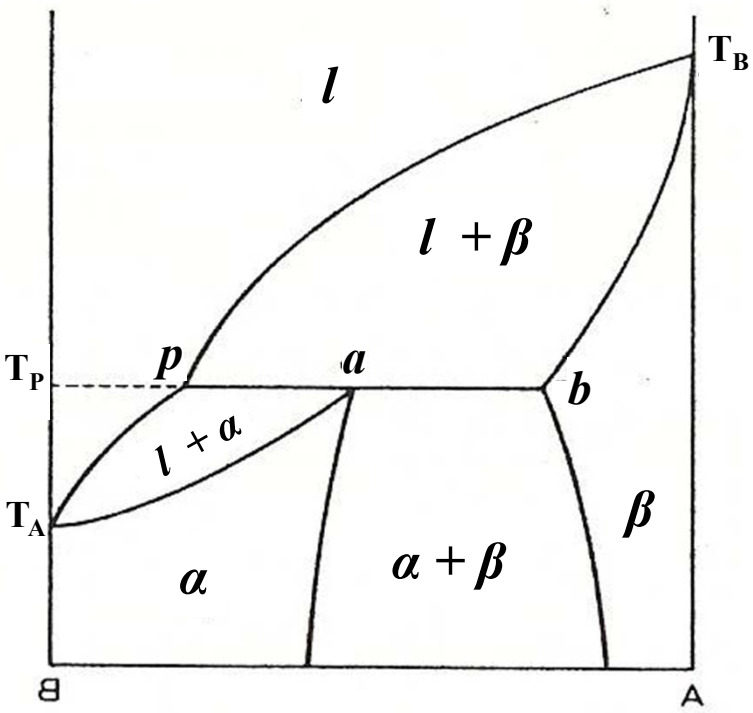


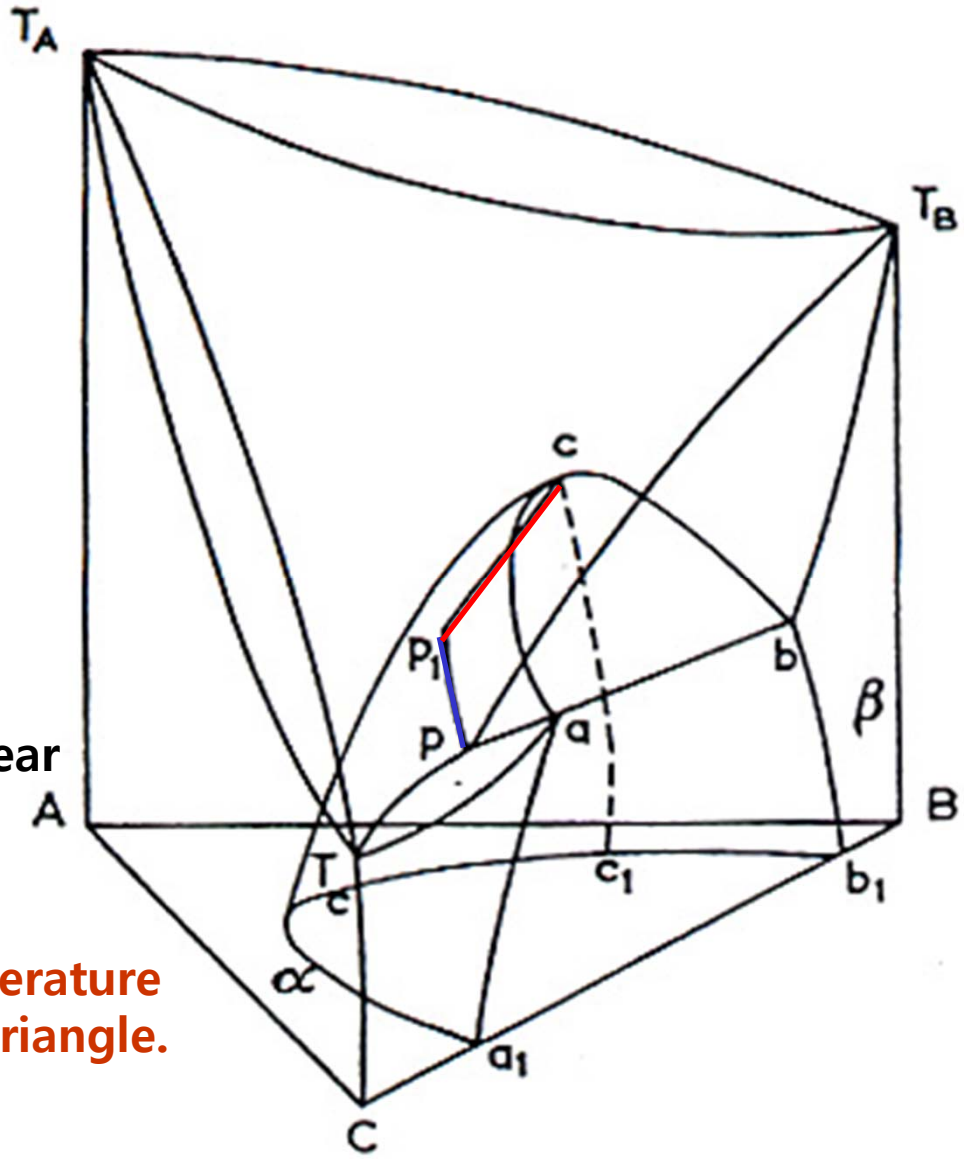


Projection of the solidification sequence for alloy Y on the concentration triangle

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- A peritectic solubility gap in one binary system





: A minimum or a maximum may appear in the monovariant liquid curve.

PP_1: monovariant curve for liquid

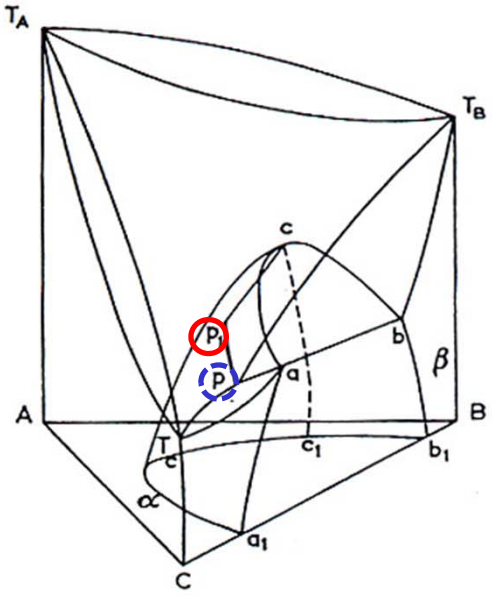
Points P_1 and c lie at the same temperature and the line P_1c is a degenerate tie triangle.

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

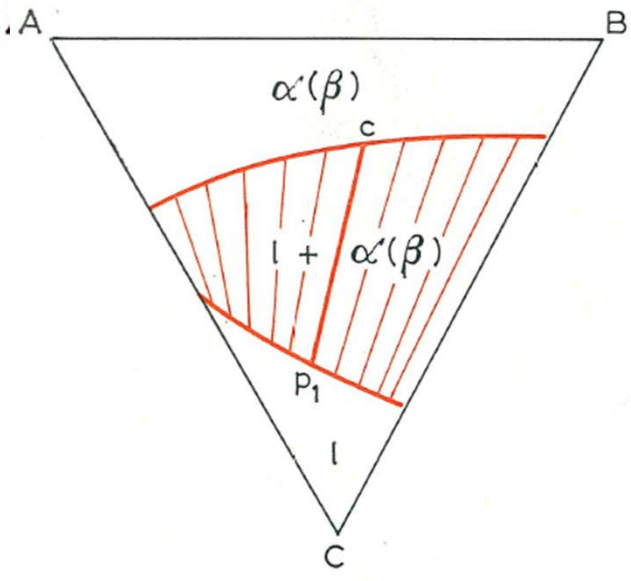
- **A peritectic solubility gap in one binary system**

  PP_1: monovariant curve for liquid

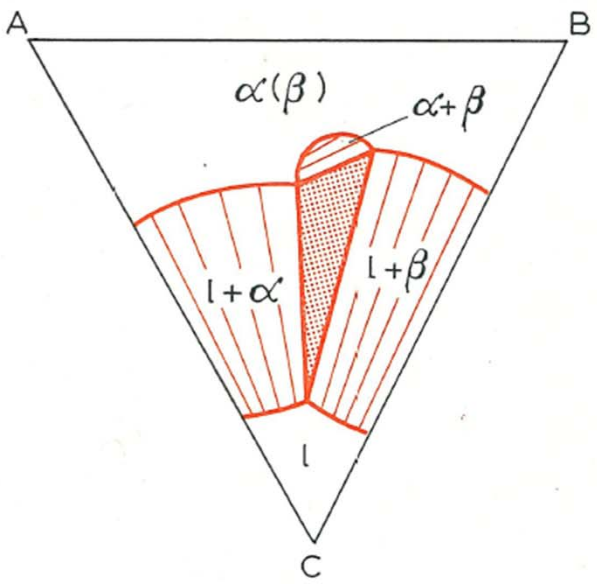
  Points P_1 and c lie at the same temperature and the line P_1c is a degenerate tie triangle.



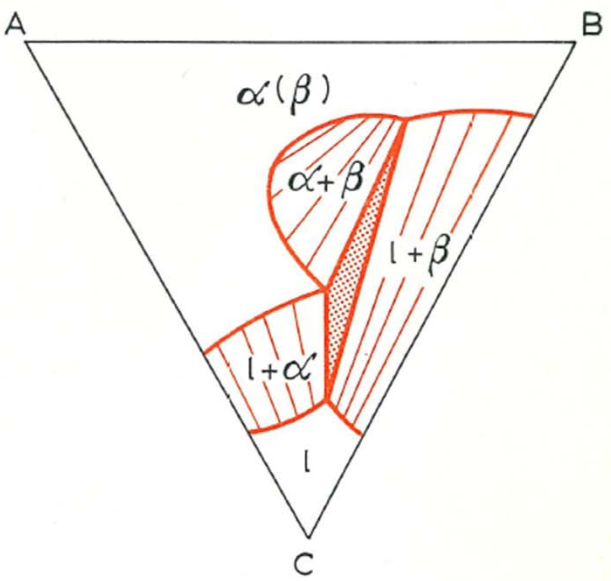
isothermal section



T = P_1



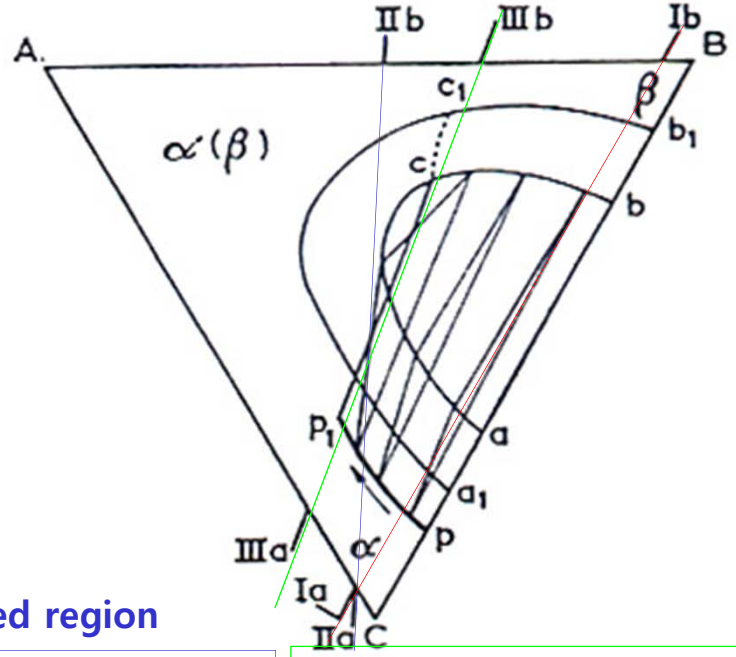
P_1 > T_1 > P



T_1 > T_2 > P

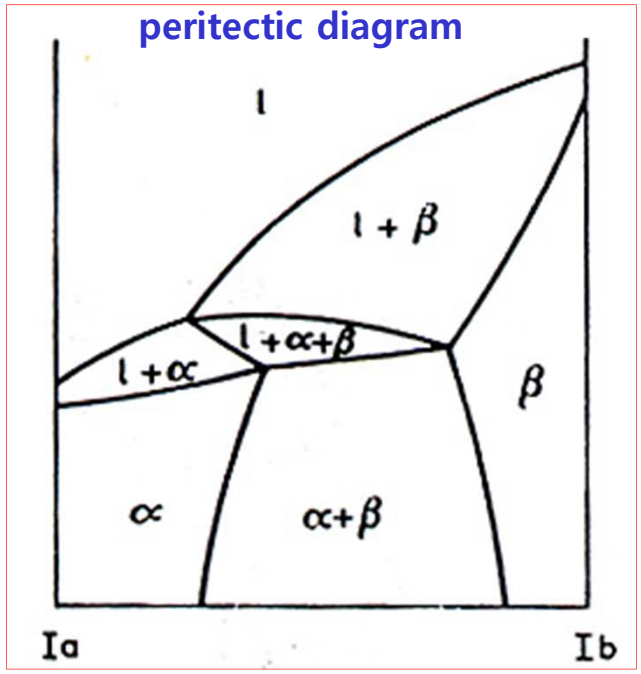
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- **A peritectic solubility gap in one binary system**

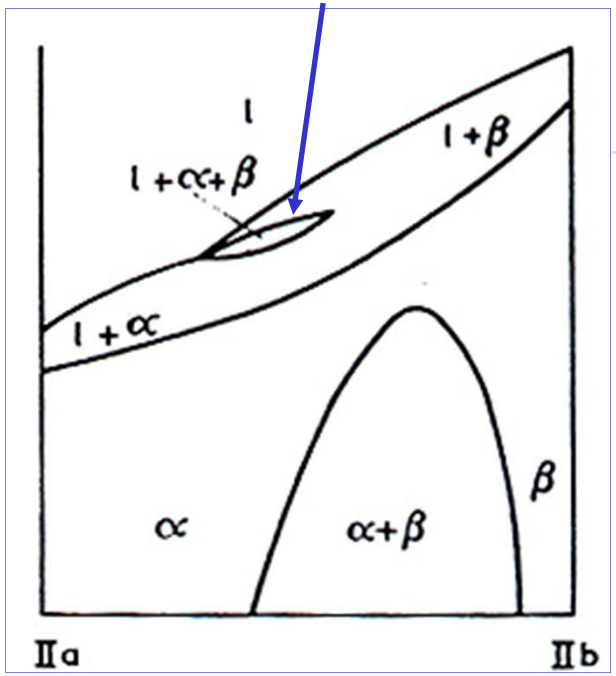


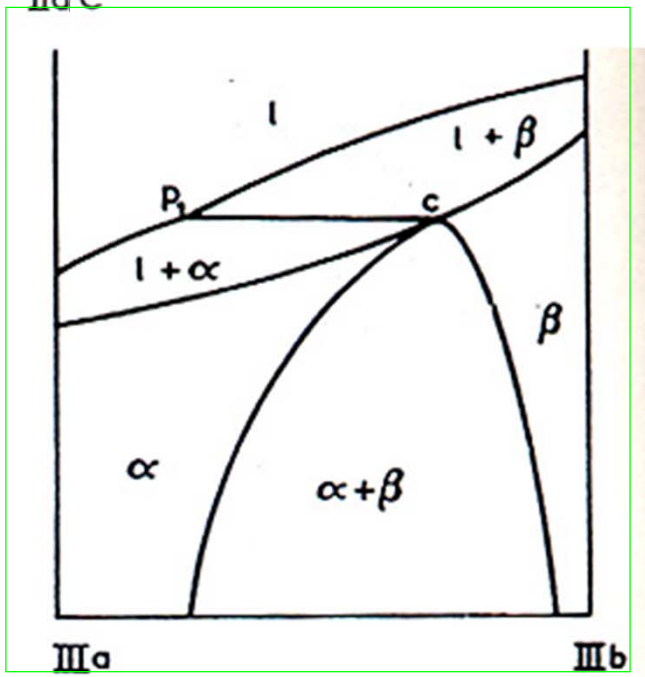
<vertical section>

Similar to the binary peritectic diagram



loop shaped region





9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

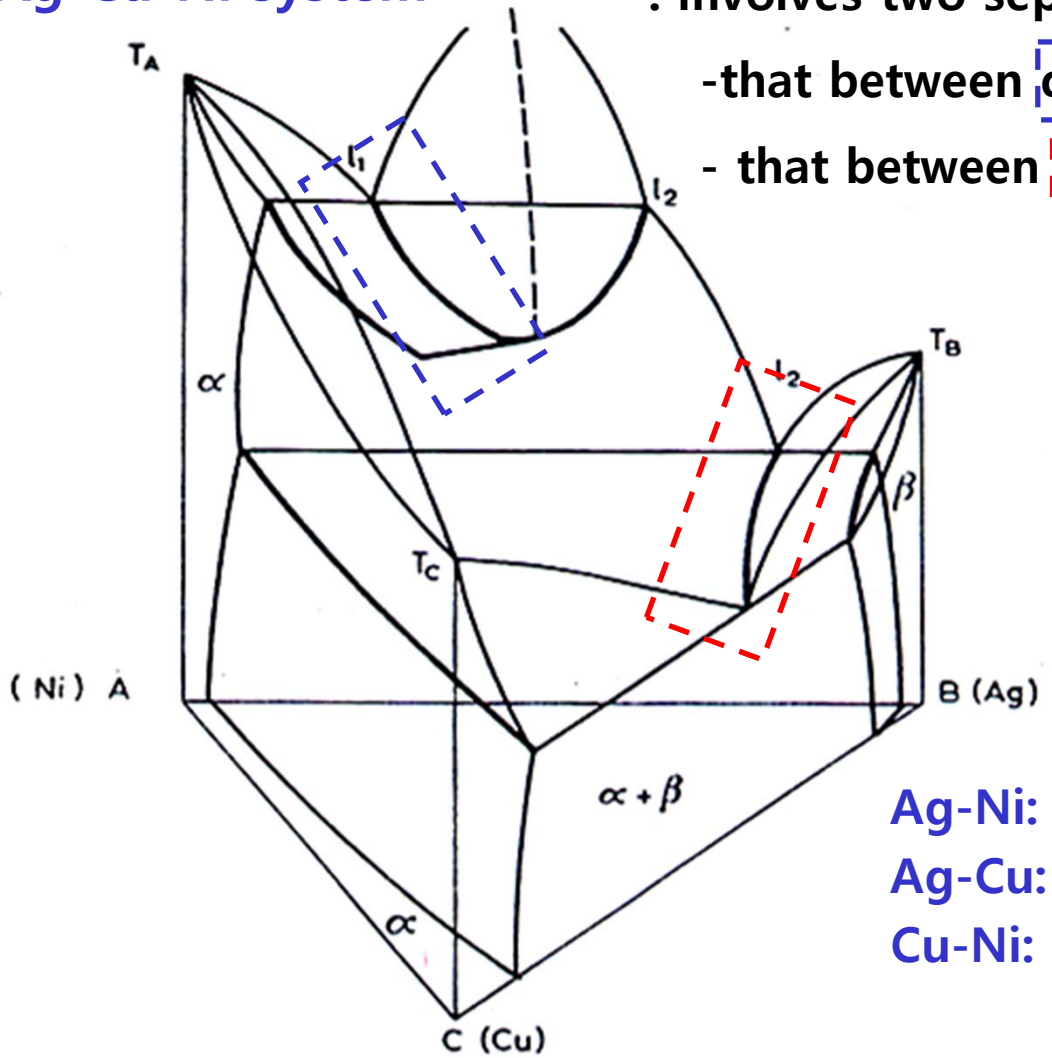
• **Binary Monotectic, syntectic and metatectic reactions in combination with each other as well as with binary eutectic and peritectic reactions.**

• **Ag-Cu-Ni system**

: involves two separate three phase equilibria

-that between α, l_1 and l_2, and

- that between α, β and l_2



Ag-Ni: monotectic

Ag-Cu: eutectic

Cu-Ni: continuous series of solid soln

Chapter 10. Ternary phase Diagrams

Four-Phase Equilibrium

a. THE TERNARY EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

b. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

c. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)

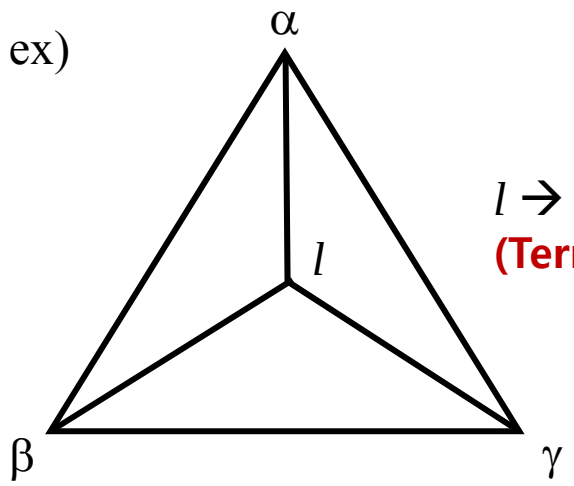
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Three phase equil. (*f* = 1) - eutectic, peritectic

Now we consider of four-phase equilibrium

- **max *N* of phase**
- ***f* = 0** : composition of four phases at temp.→ fixed
- **isothermal four phase regions**

ex)

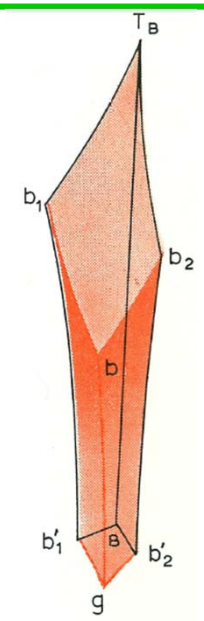


$l \rightarrow \alpha + \beta + \gamma$
(Ternary eutectic)

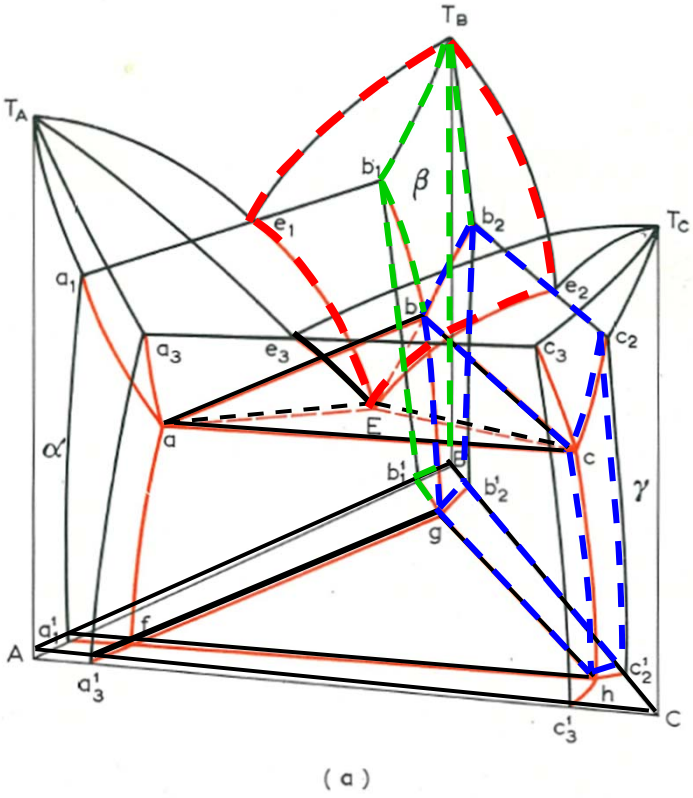
cf) $l + \alpha \rightarrow \beta + \gamma$: **ternary quasi-peritectic**
$l + \alpha + \beta \rightarrow \gamma$: **ternary peritectic**

10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

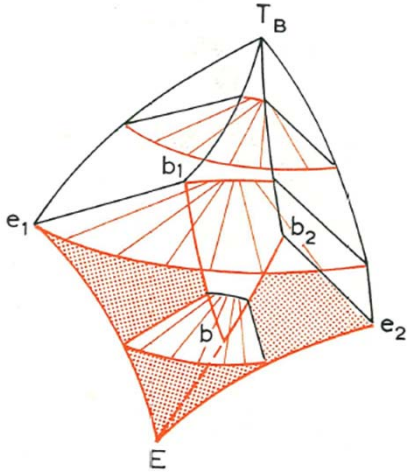
Ternary eutectic



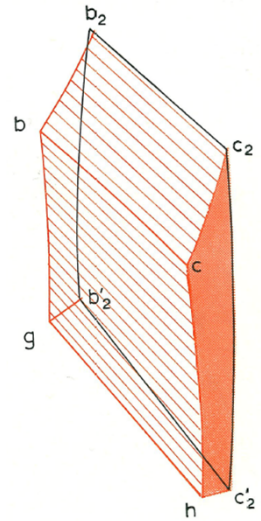
β phase region



(a)



($l + \beta$) phase region

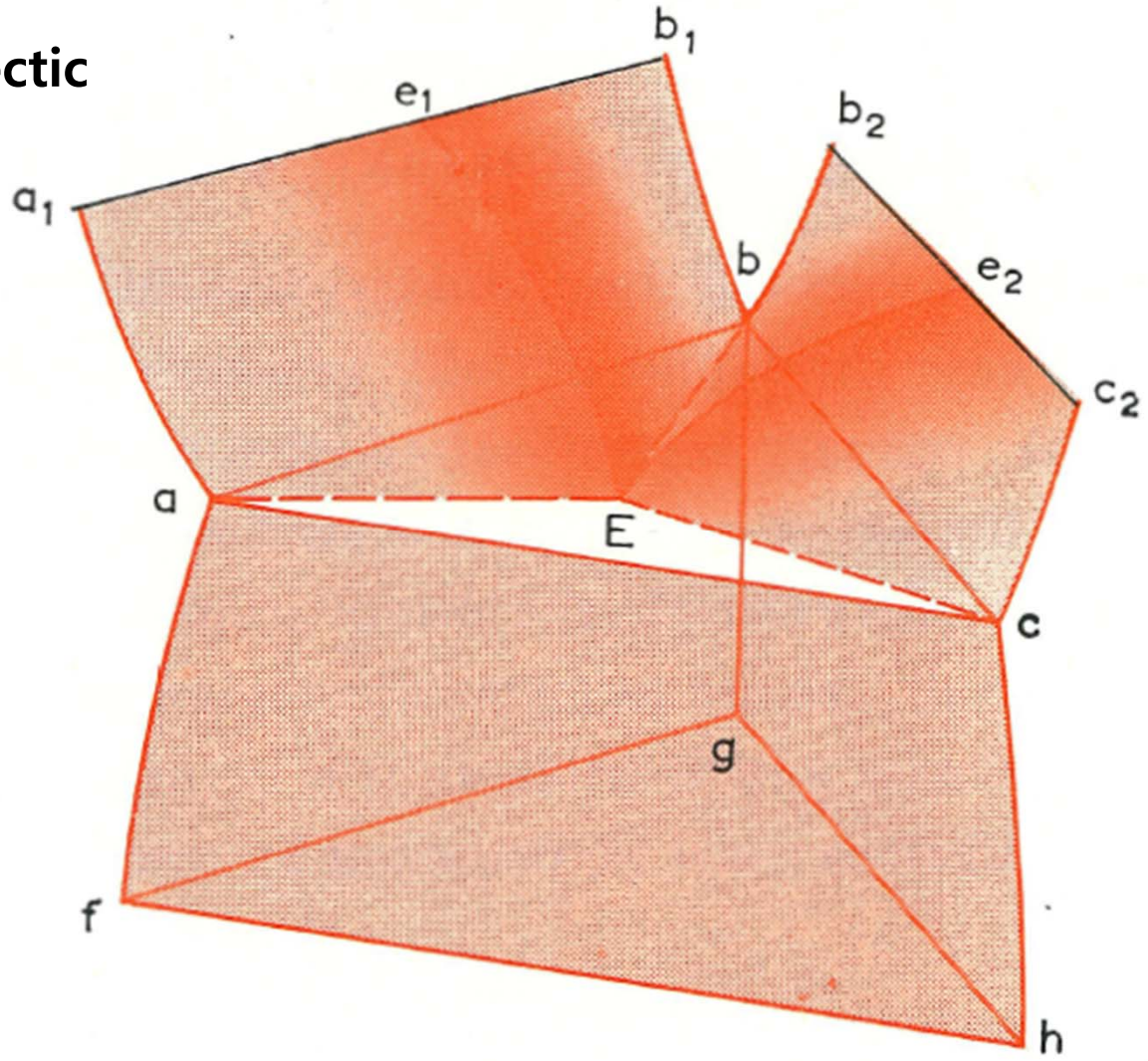


($\beta + \gamma$) phase region

$$T_A > T_B > T_C > e_1 > e_3 > e_2 > E$$

10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

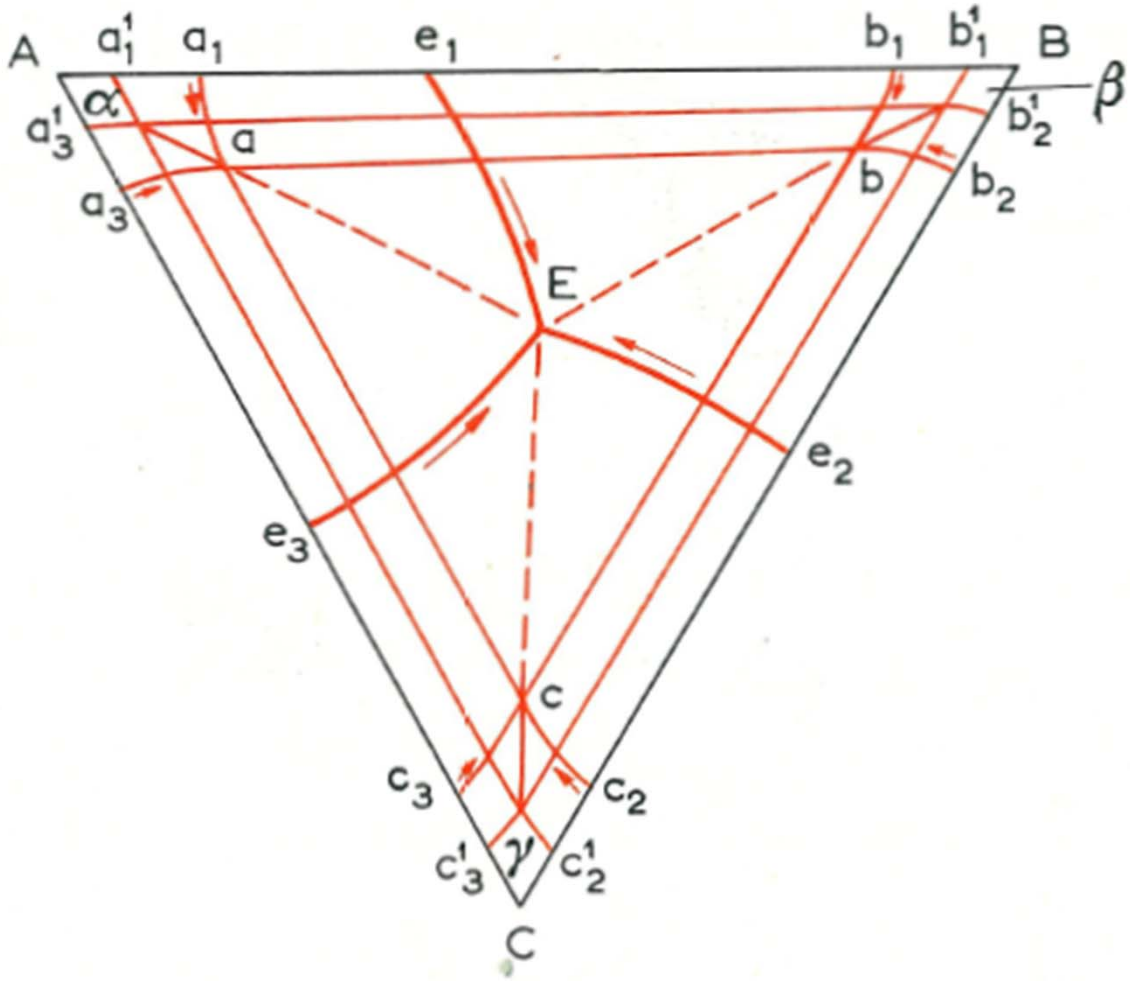
Ternary eutectic



The eutectic four-phase plane as the junction of four tie triangles

10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

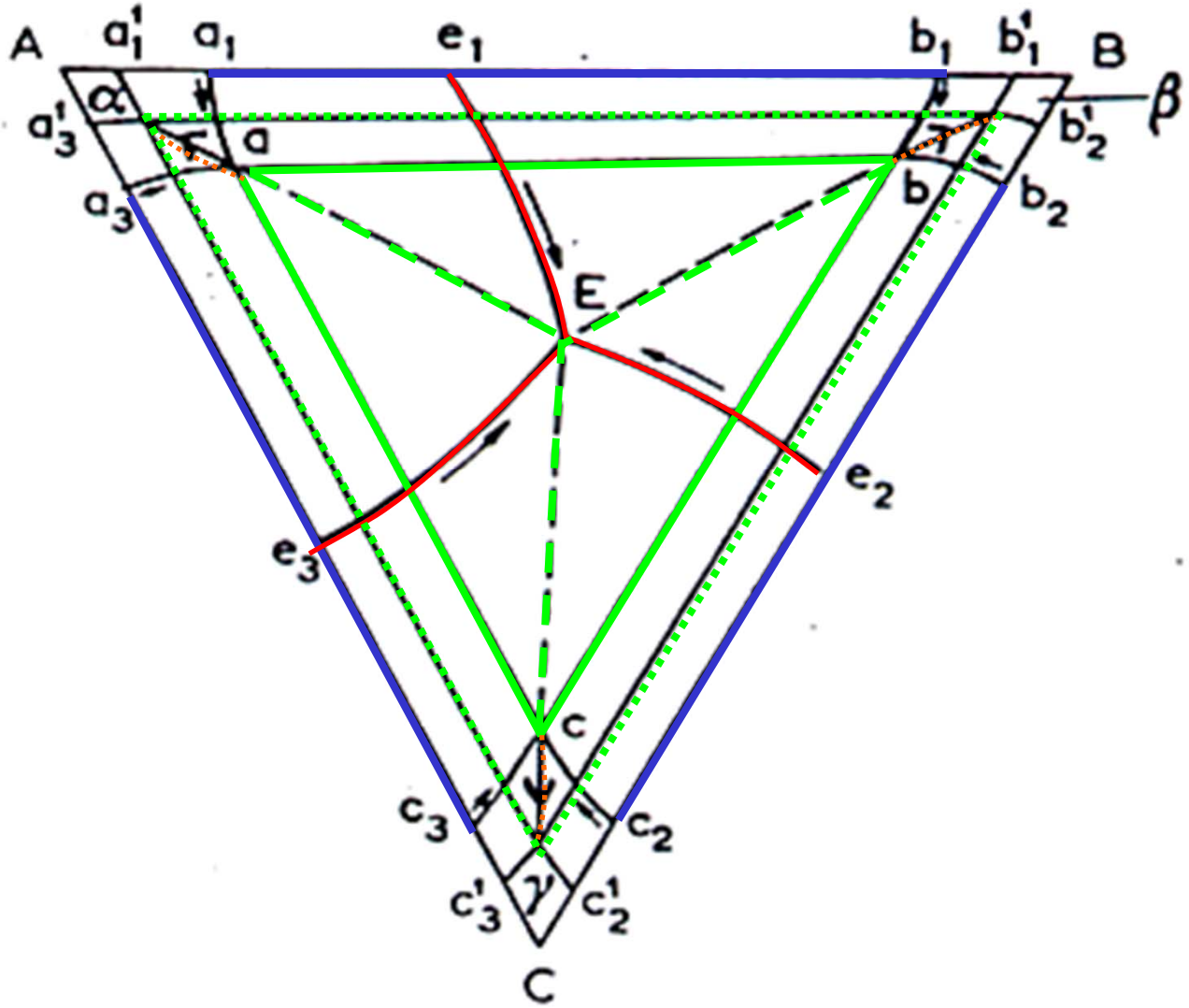
Ternary eutectic • **Projection : solid solubility limit surface**
: monovariant liquidus curve

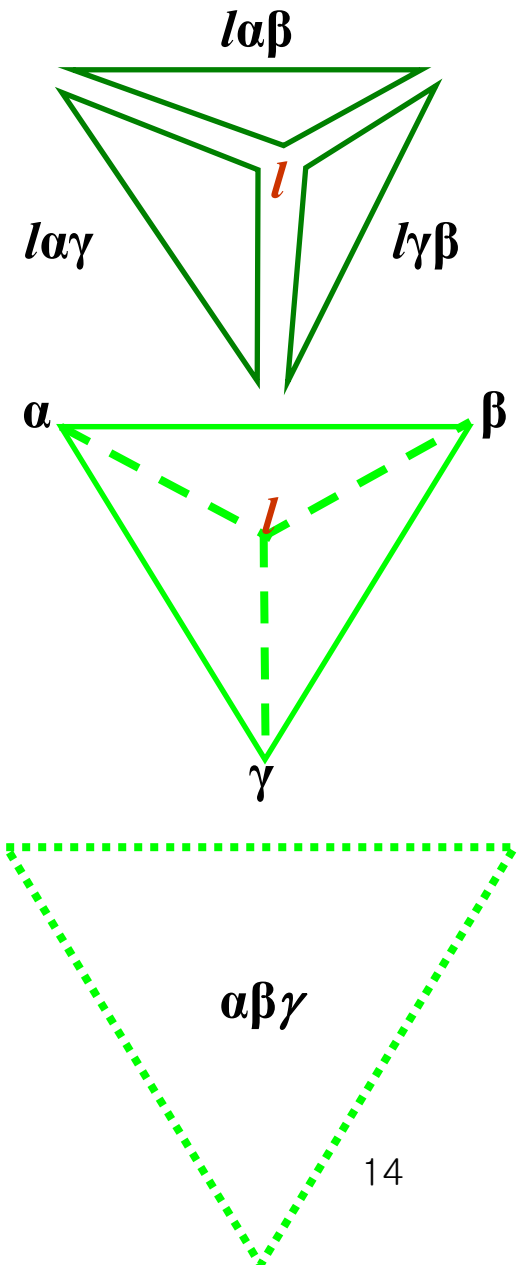


$T_A > T_B > T_C > e_1 > e_3 > e_2 > E$

THE TERNARY EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

- **Projection** : solid solubility limit surface
  : monovariant liquidus curve

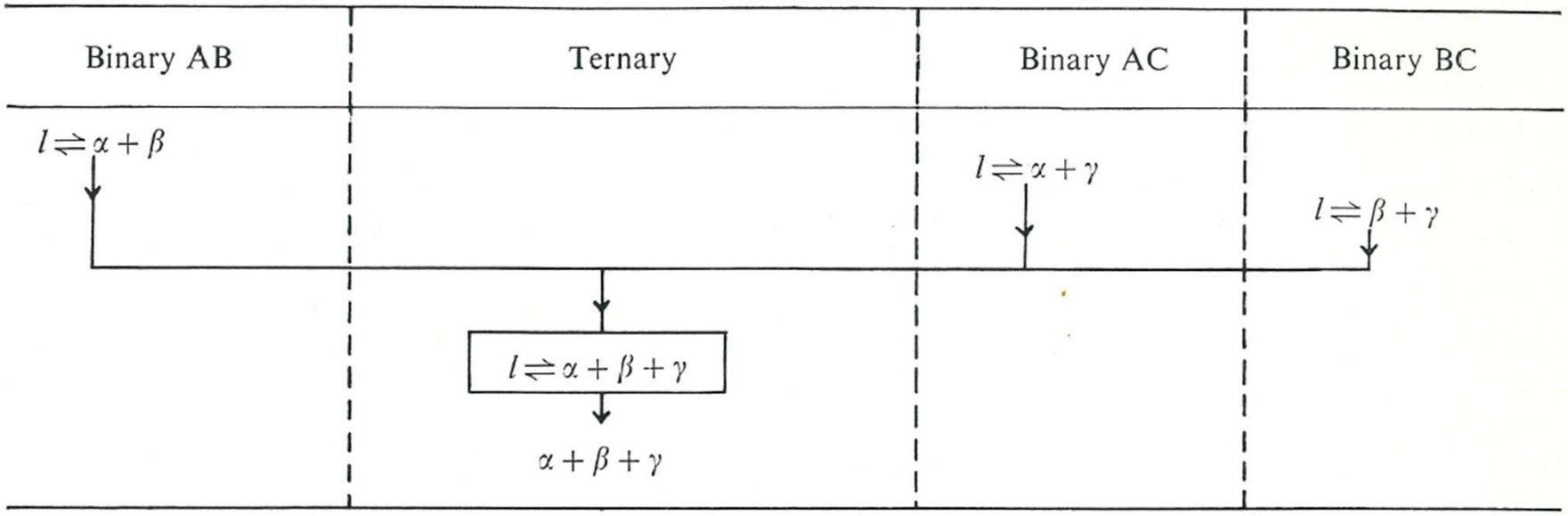




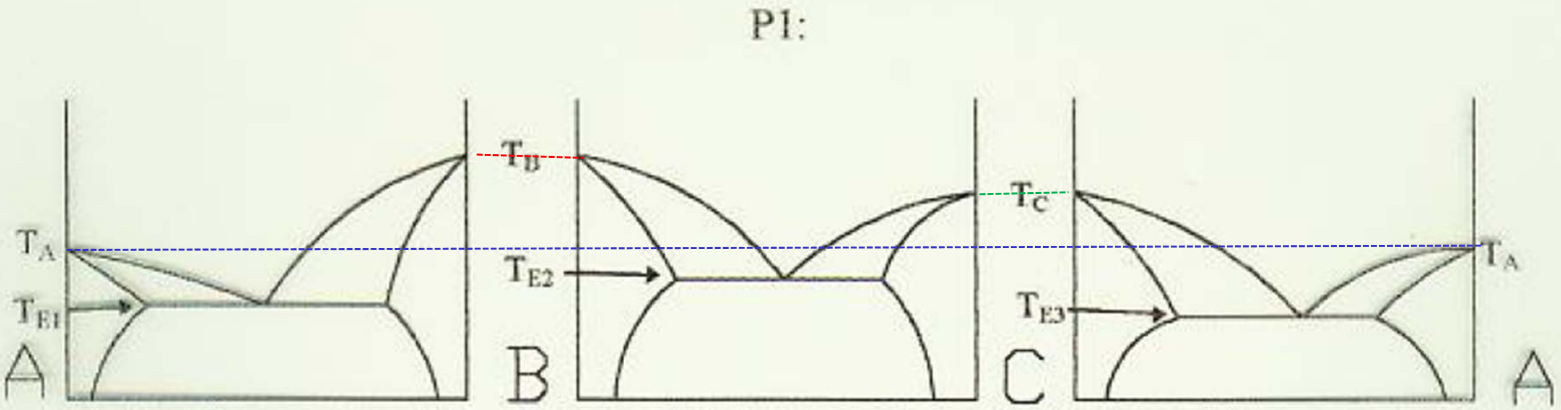
Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

EUTECTIC EQUILIBRIUM $l \rightleftharpoons \alpha + \beta + \gamma$



Ternary Eutectic System
(with Solid Solubility)



T_A: Melting Point Of Material A

T_B: Melting Point Of Material B

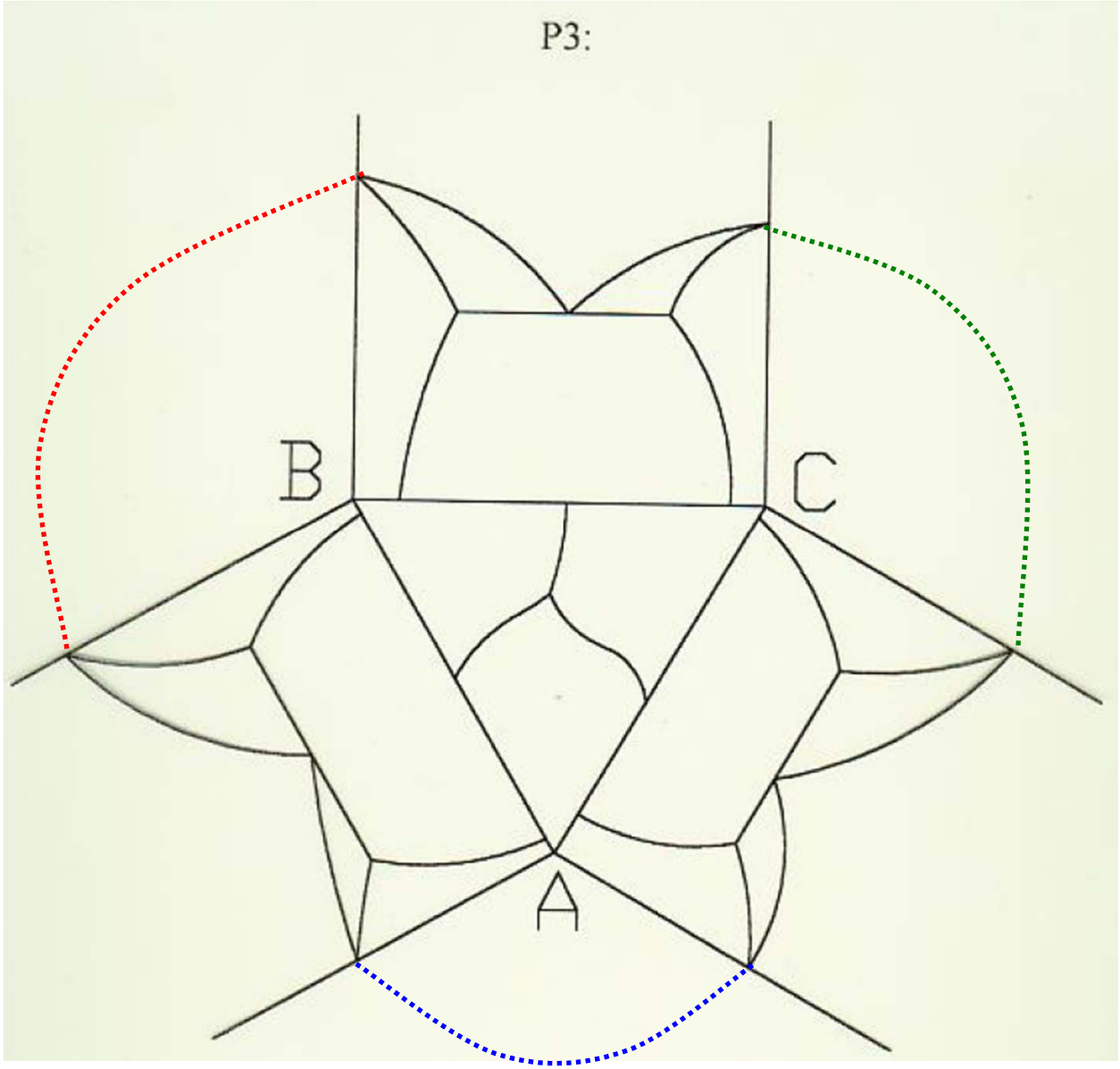
T_C: Melting Point Of Material C

T_{E1}: Eutectic Temperature Of A-B

T_{E2}: Eutectic Temperature Of B-C

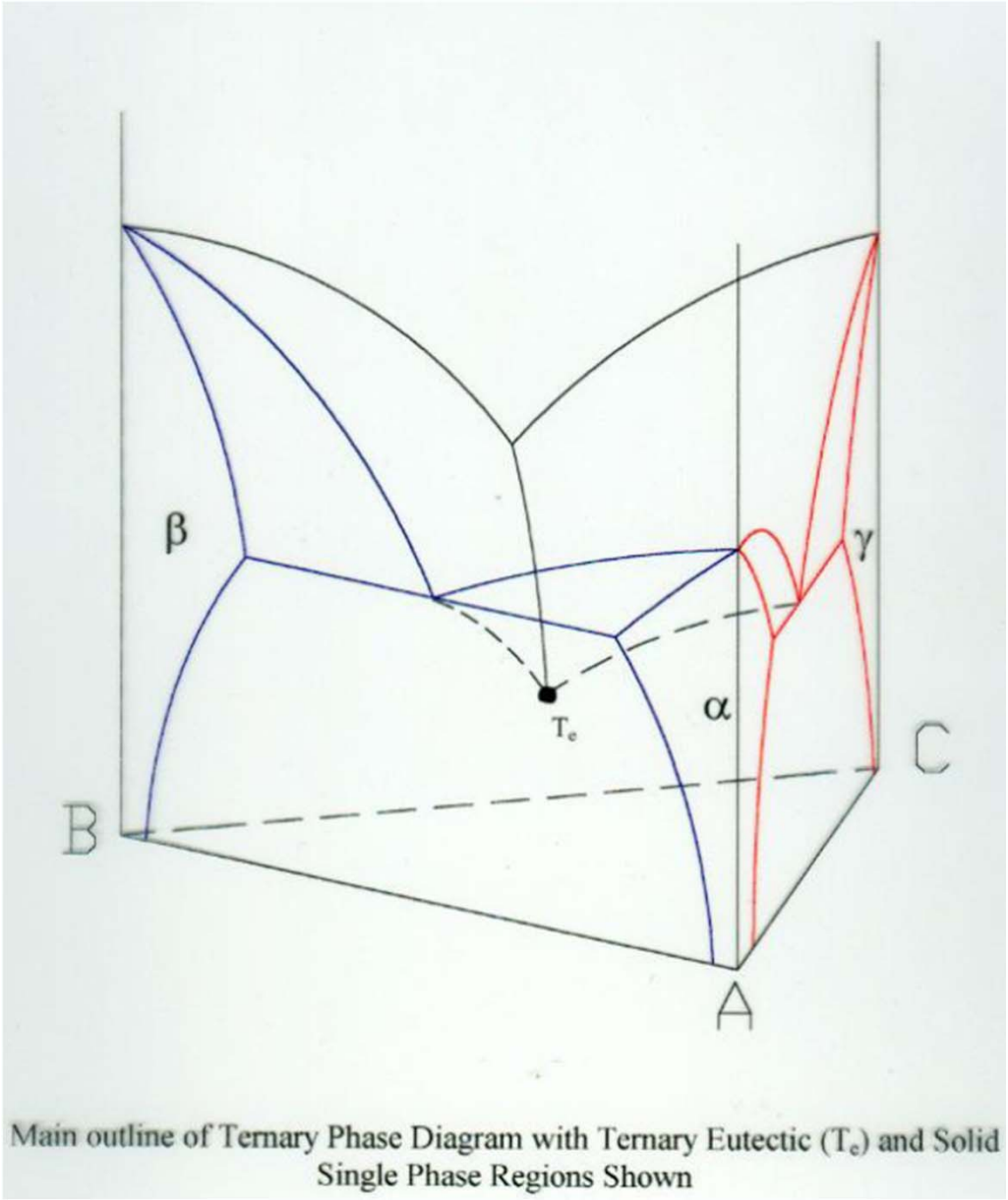
T_{E3}: Eutectic Temperature Of C-A

Ternary Eutectic System
(with Solid Solubility)

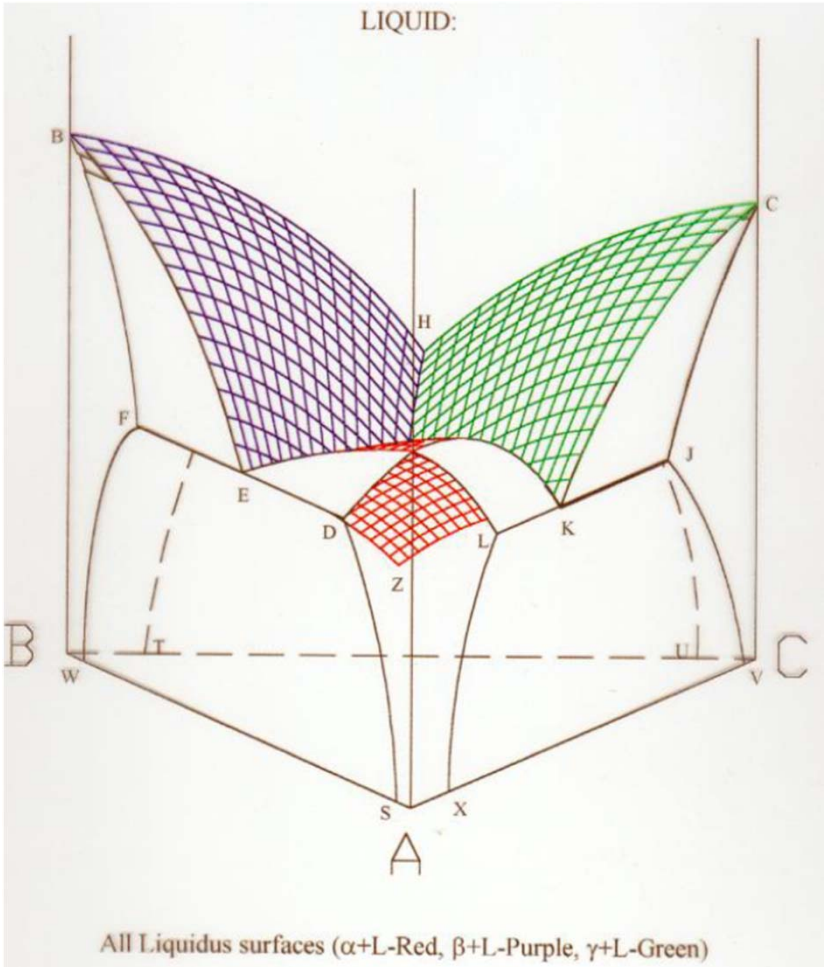


Ternary Eutectic System

(with Solid Solubility)

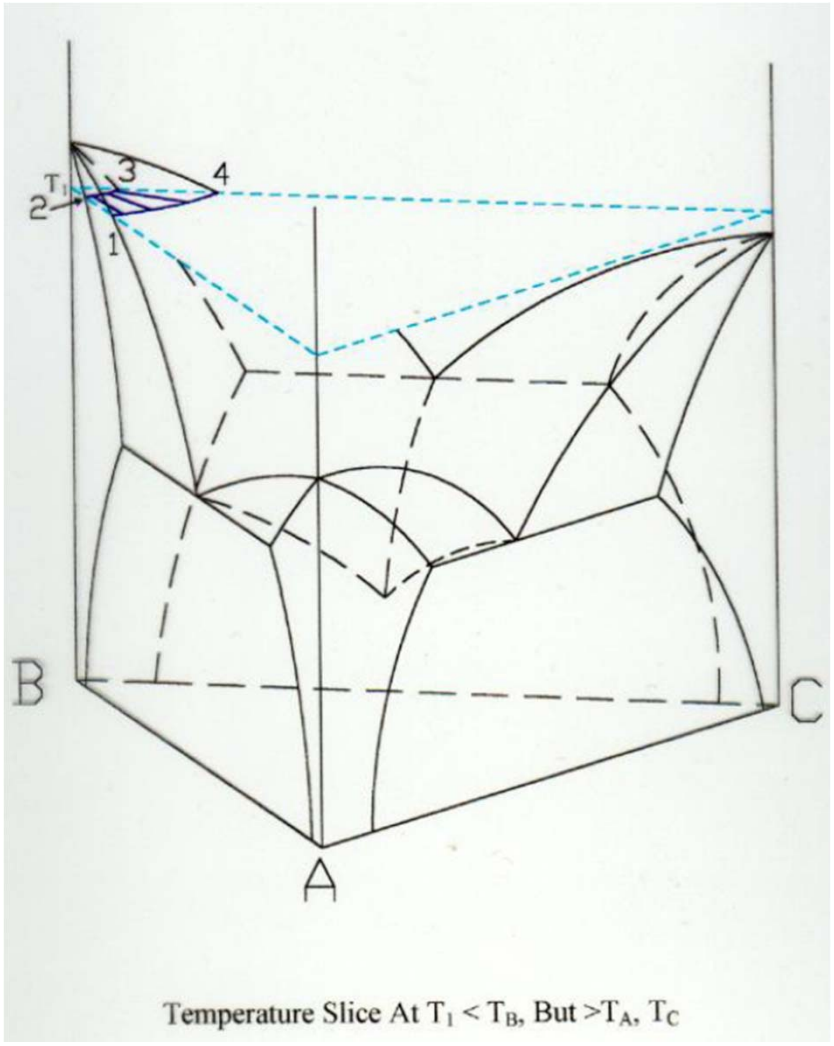


Main outline of Ternary Phase Diagram with Ternary Eutectic (T_e) and Solid Single Phase Regions Shown

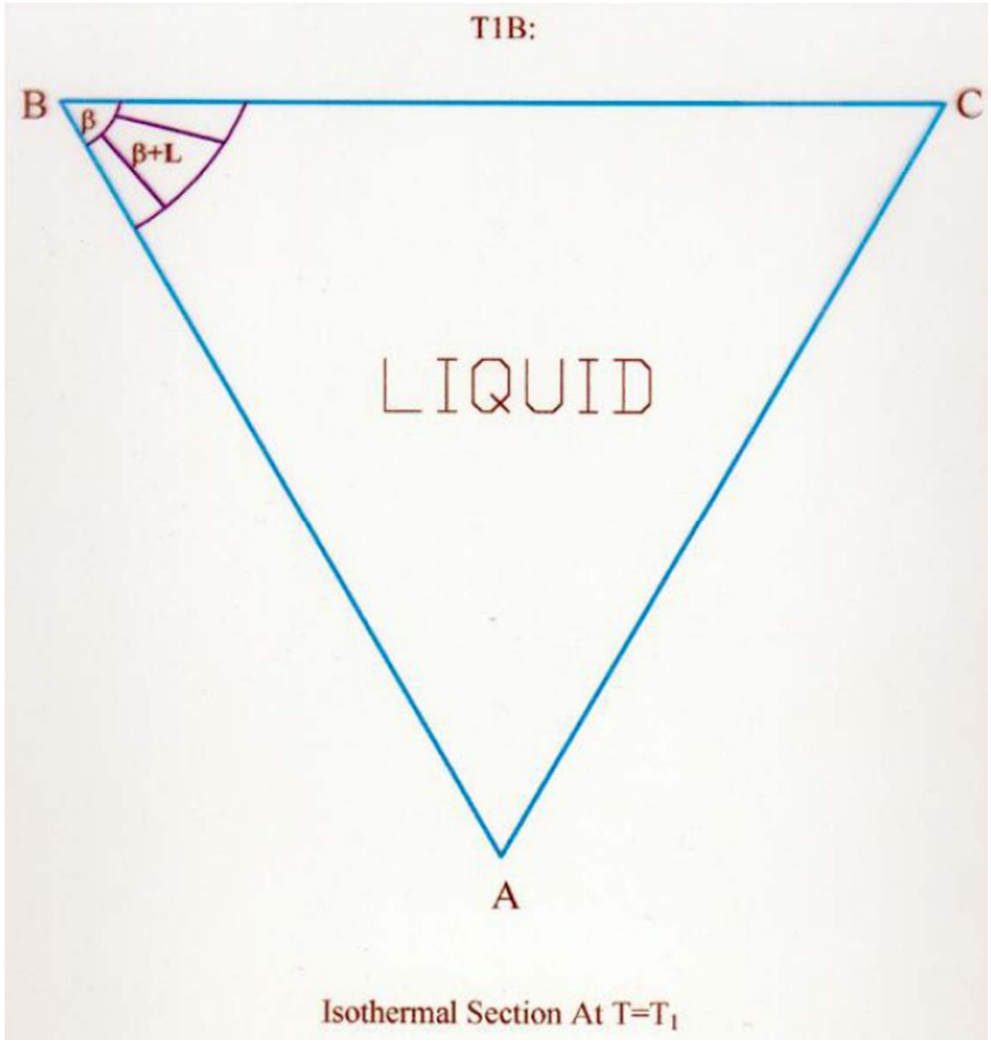


All Liquidus surfaces (α+L-Red, β+L-Purple, γ+L-Green)

Ternary Eutectic System
(with Solid Solubility)



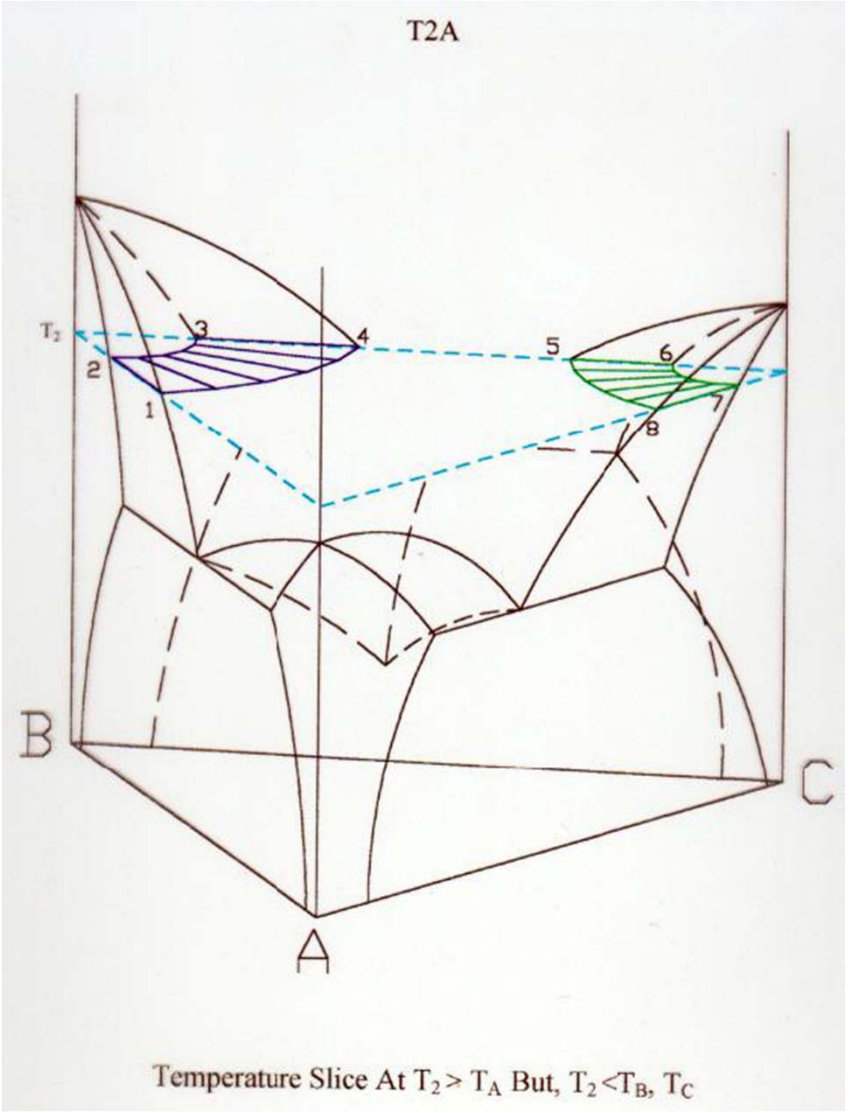
Temperature Slice At $T_1 < T_B$, But $> T_A, T_C$



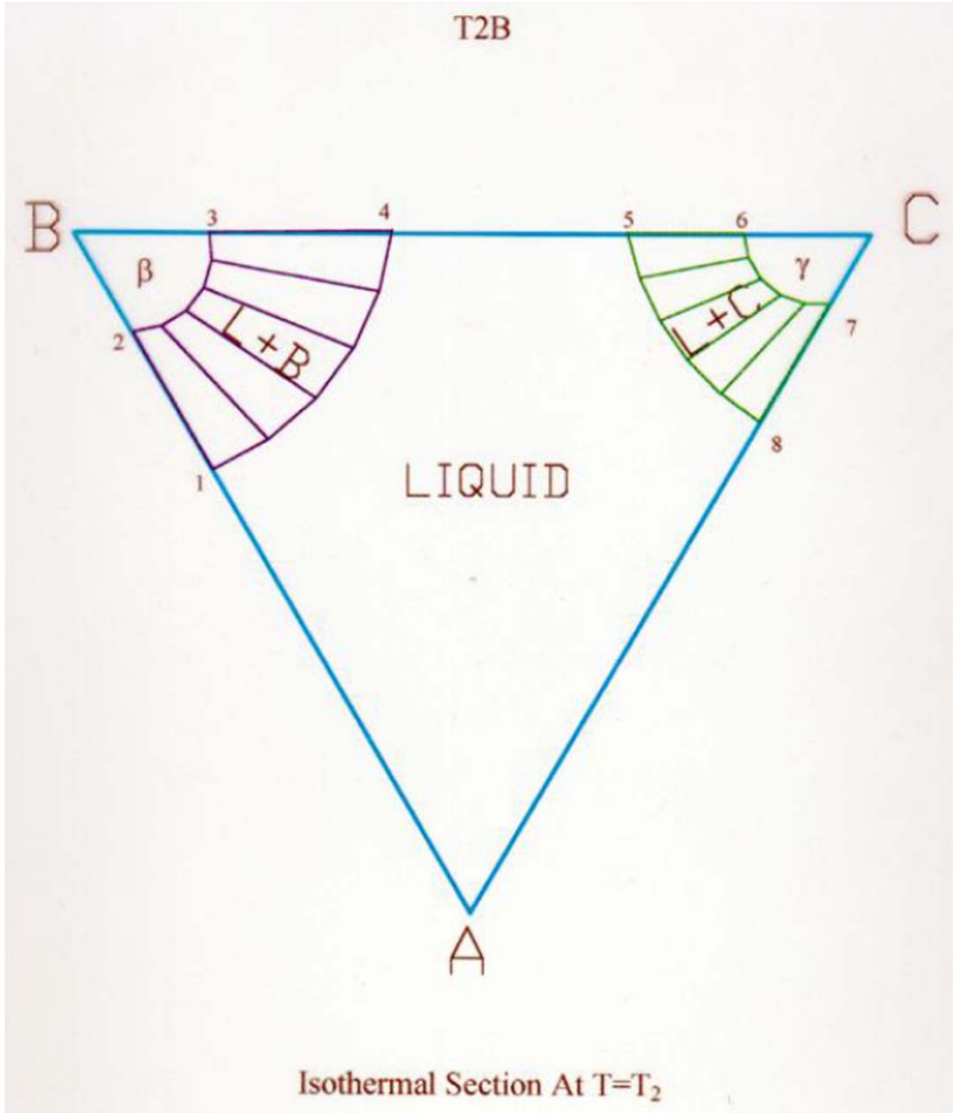
Isothermal Section At $T=T_1$

Ternary Eutectic System

(with Solid Solubility)



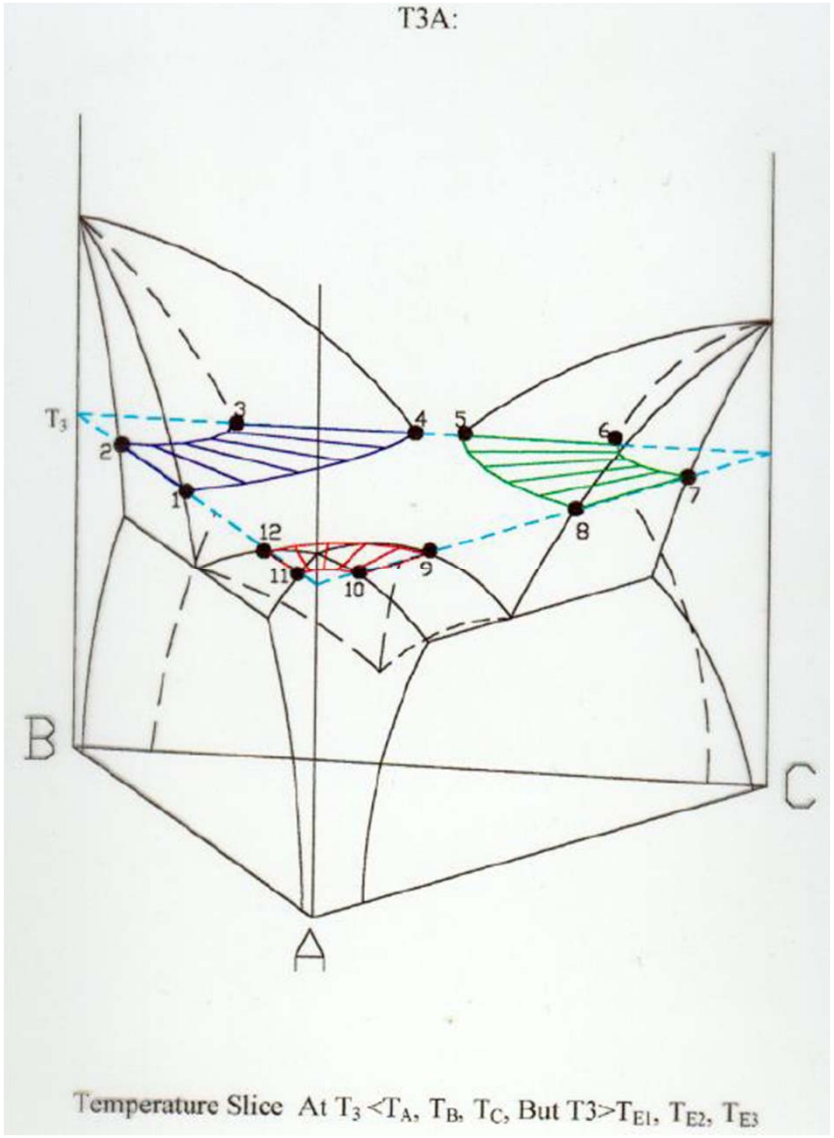
Temperature Slice At $T_2 > T_A$ But, $T_2 < T_B, T_C$



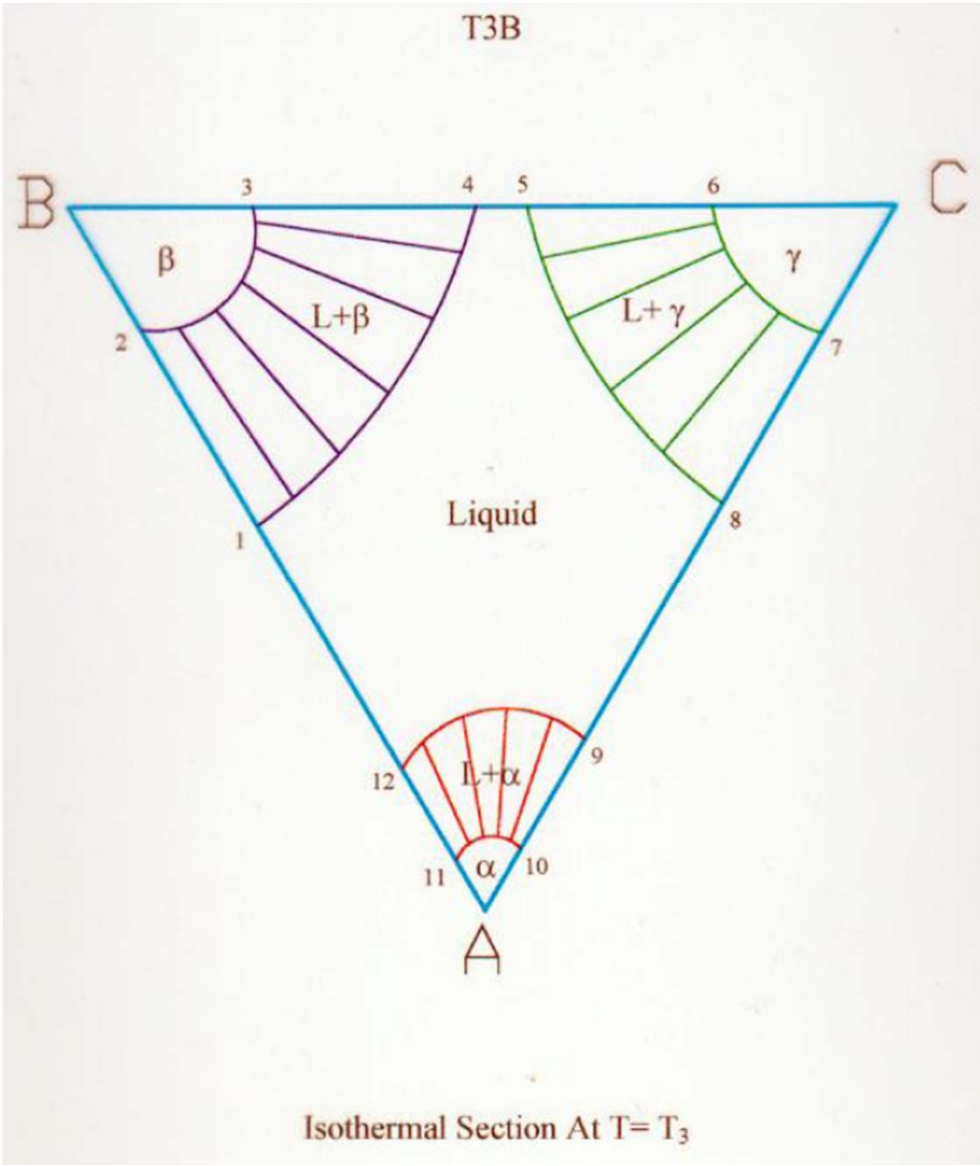
Isothermal Section At $T=T_2$

Ternary Eutectic System

(with Solid Solubility)



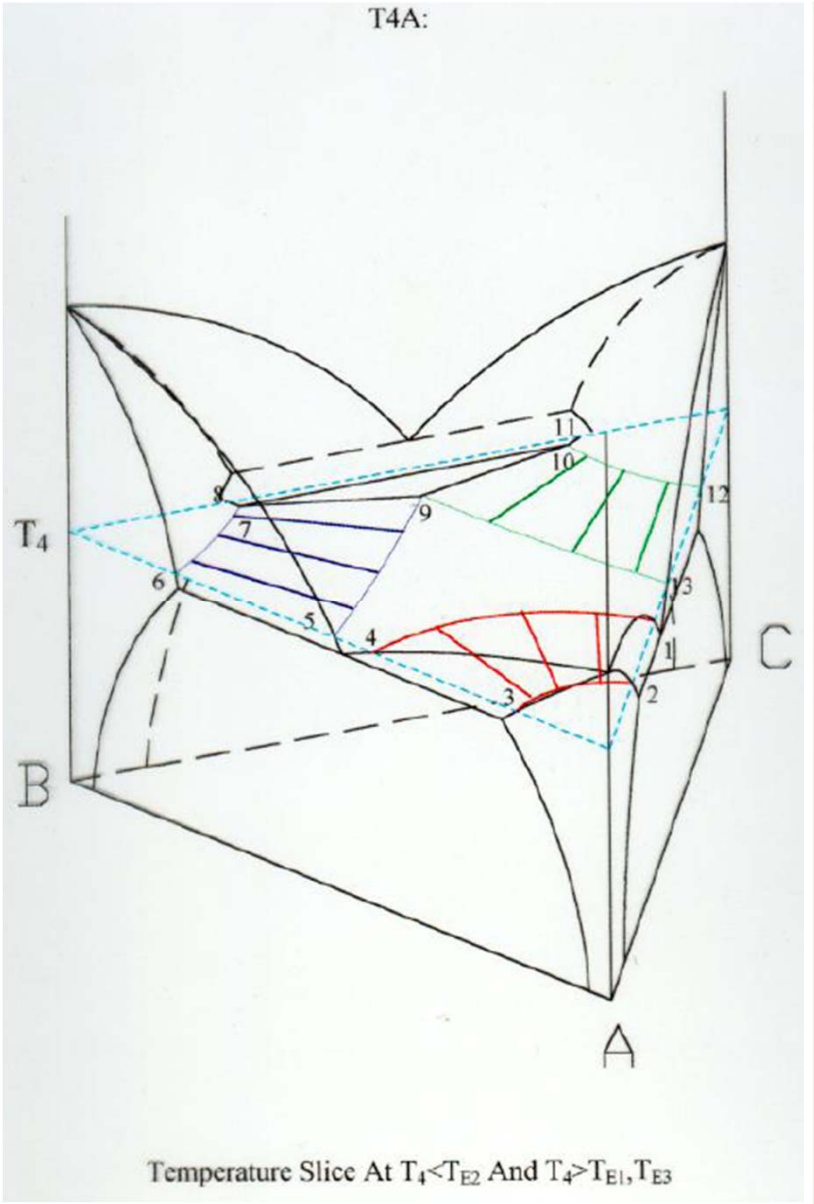
Temperature Slice At $T_3 < T_A, T_B, T_C$, But $T3 > T_{E1}, T_{E2}, T_{E3}$



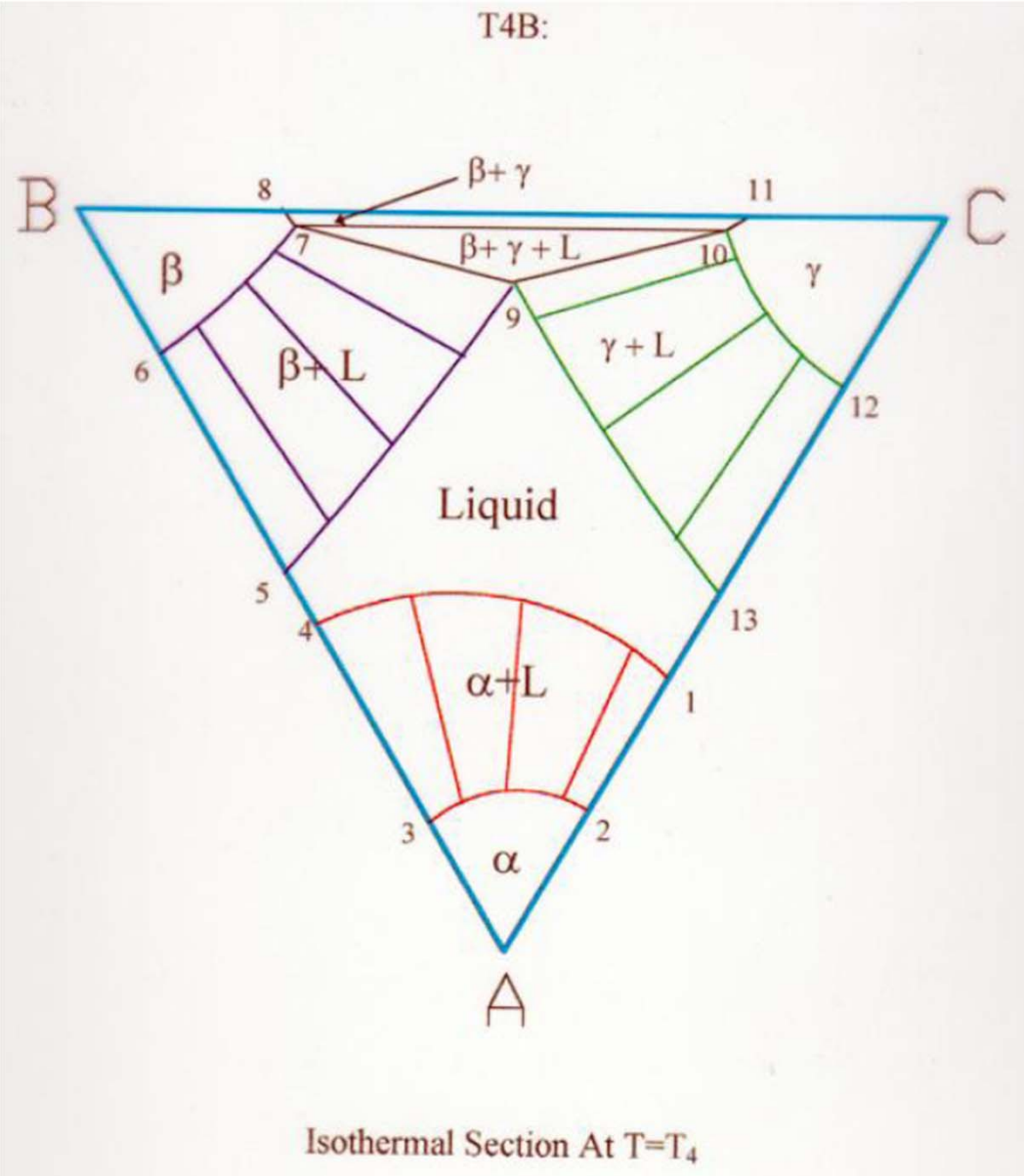
Isothermal Section At $T = T_3$

Ternary Eutectic System

(with Solid Solubility)

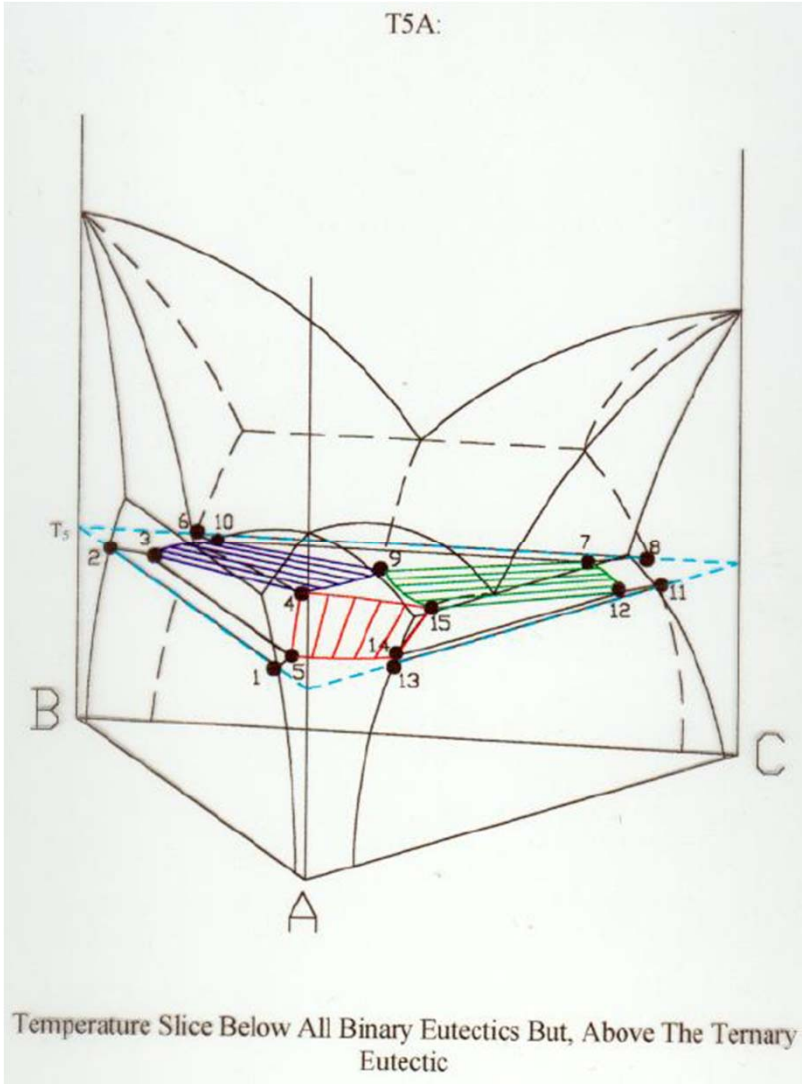


Temperature Slice At $T_4 < T_{E2}$ And $T_4 > T_{E1}, T_{E3}$

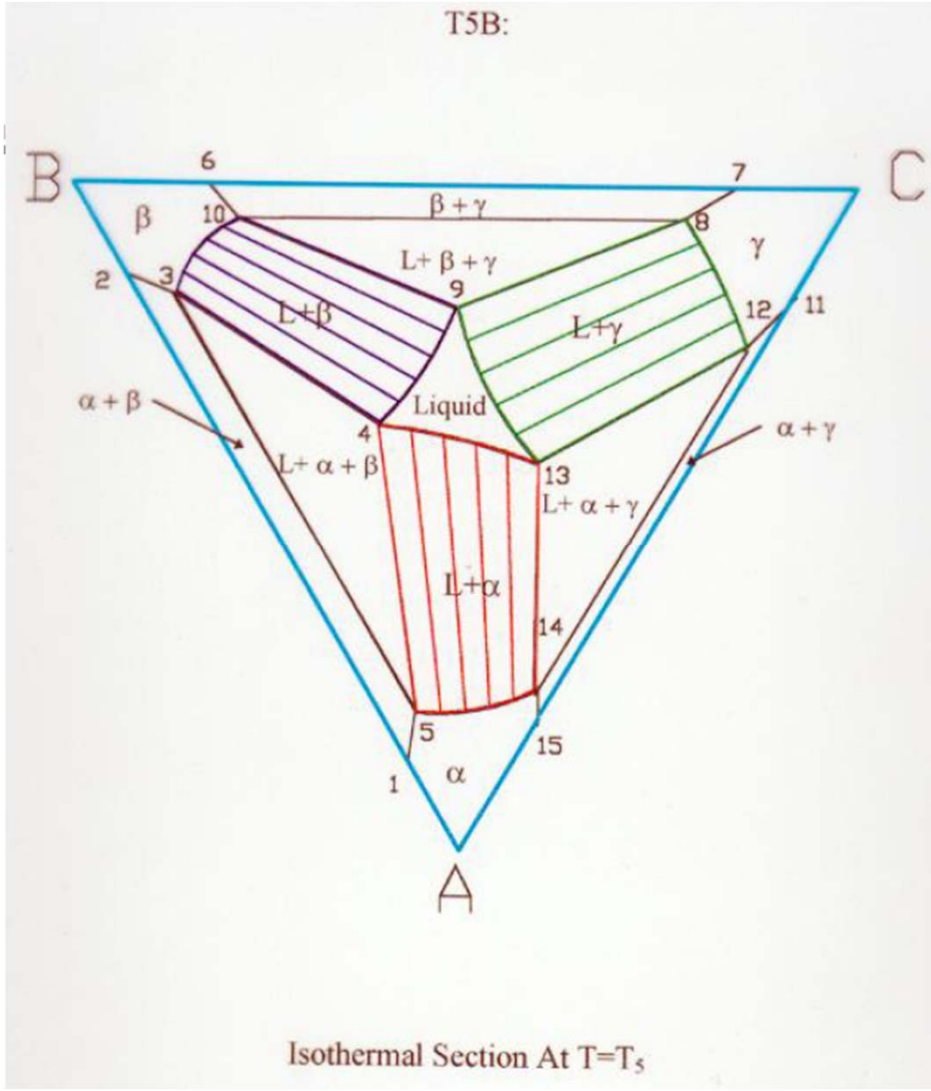


Isothermal Section At $T = T_4$

Ternary Eutectic System
(with Solid Solubility)



Temperature Slice Below All Binary Eutectics But, Above The Ternary Eutectic

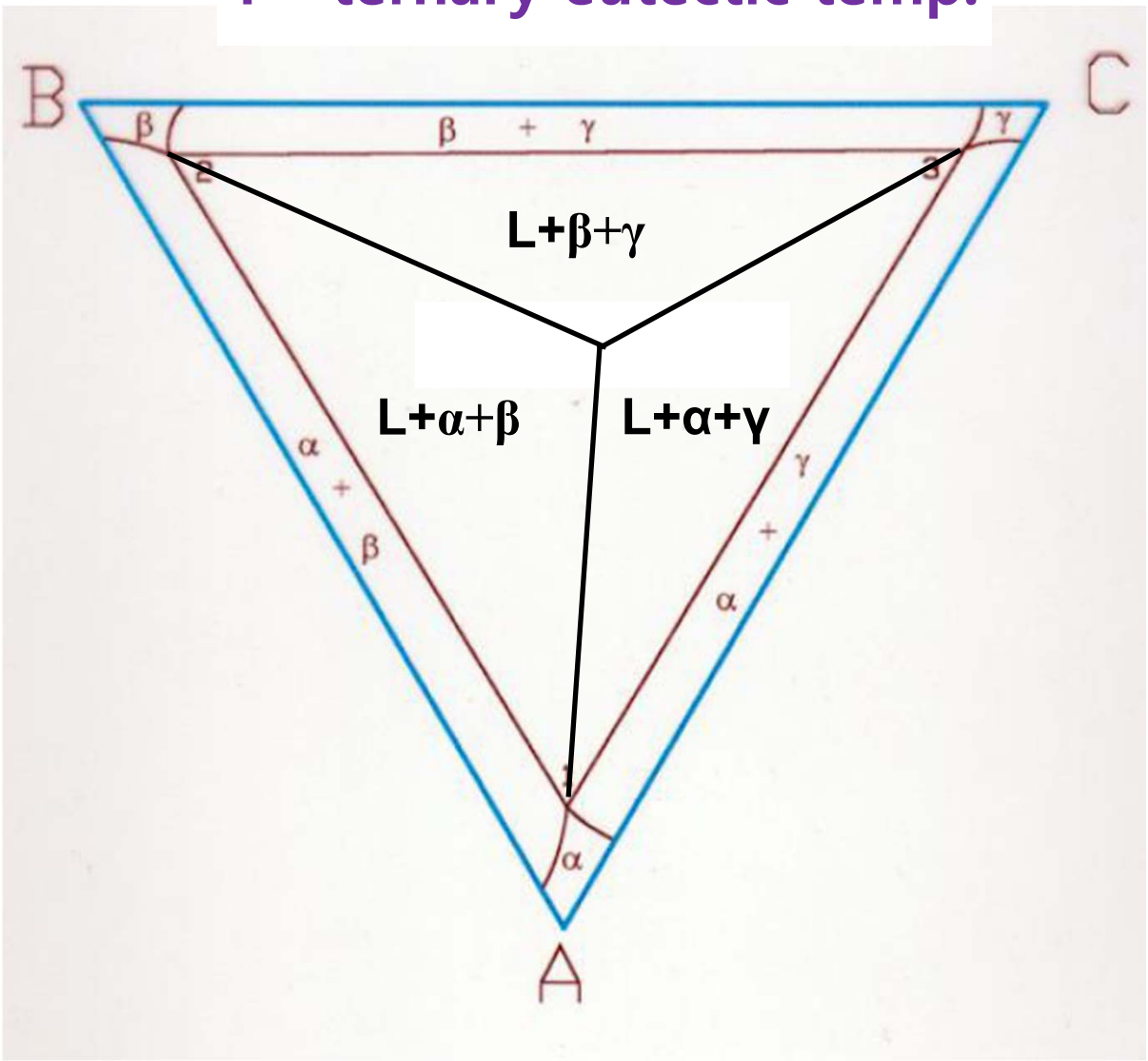


Isothermal Section At $T=T_5$

Ternary Eutectic System

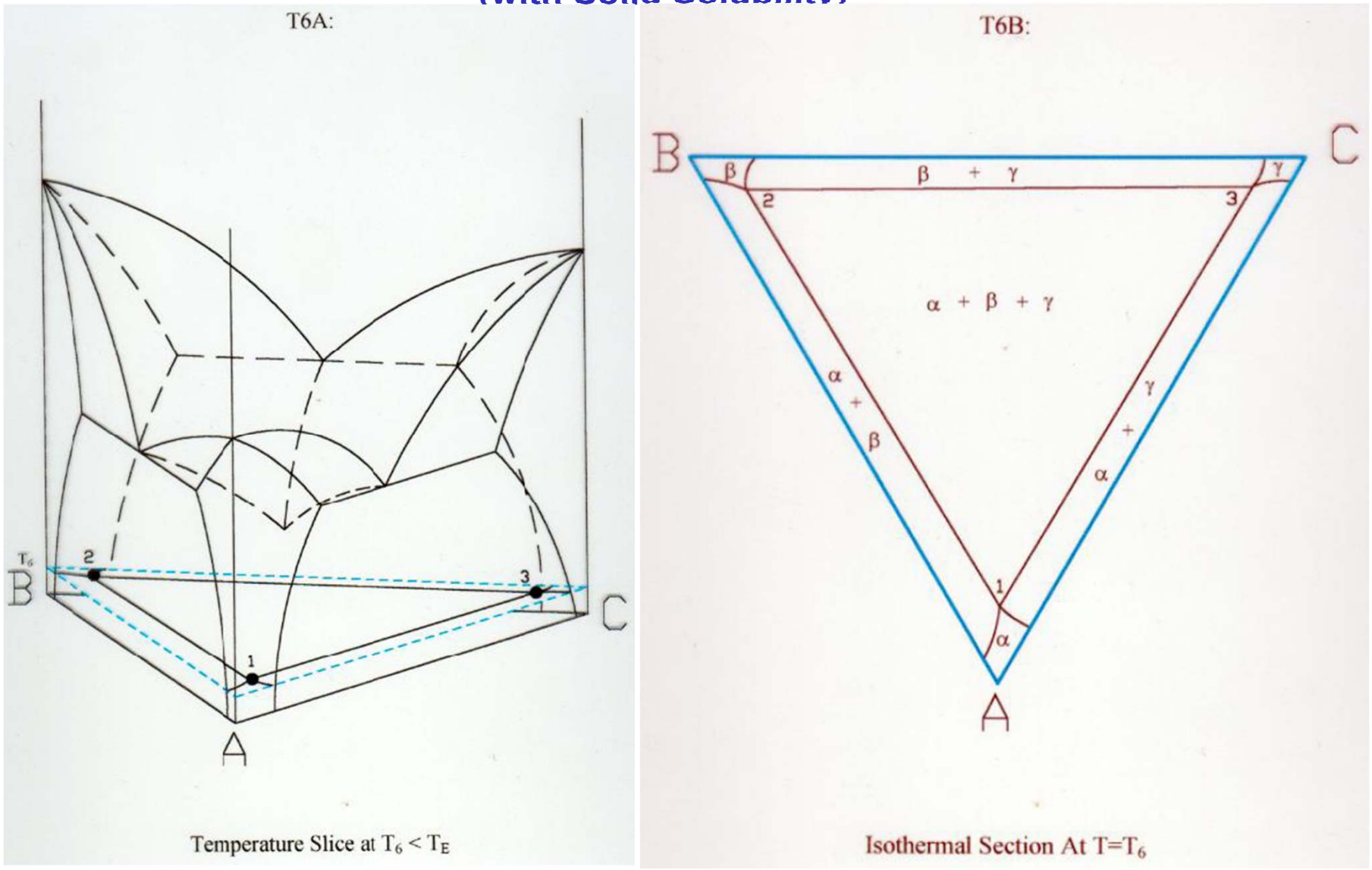
(with Solid Solubility)

T= ternary eutectic temp.



Ternary Eutectic System

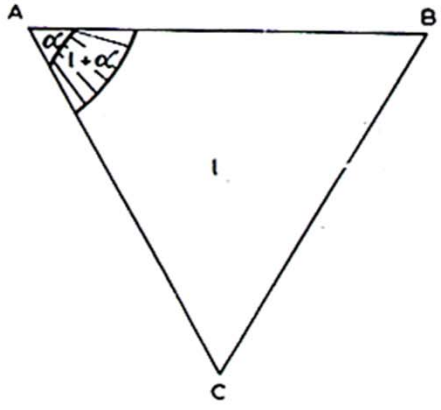
(with Solid Solubility)



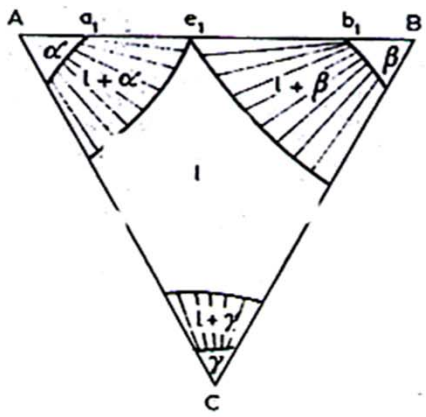
http://www.youtube.com/watch?v=yzhVomAdetM

10.1. THE EUTECTIC EQUILIBRIUM (l = α + β + γ)

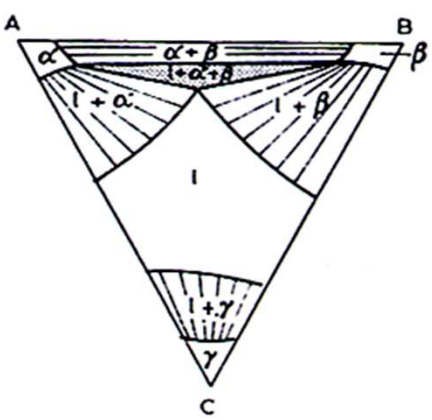
- **Isothermal section** ($T_A > T > T_B$)



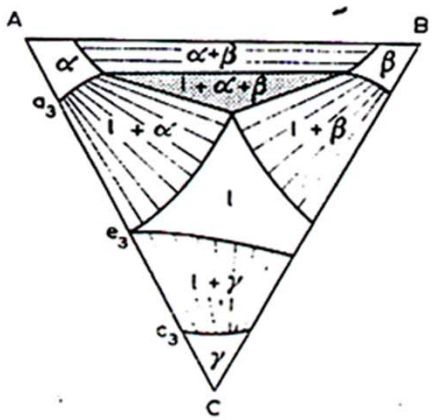
(a) $T_A > T > T_B$



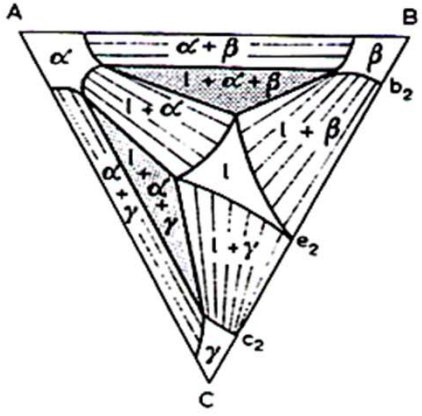
(b) $T = e_1$



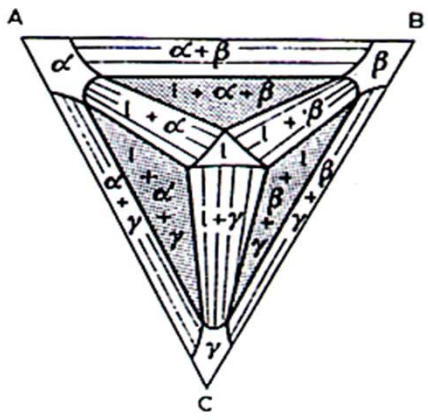
(c) $e_1 > T > e_3$



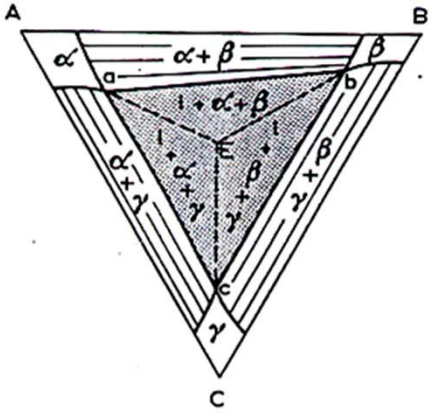
(d) $T = e_3$



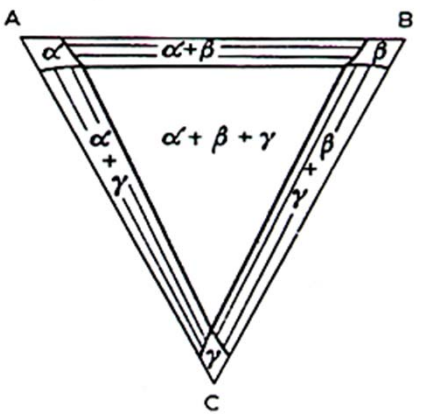
(e) $T = e_2$



(f) $e_2 > T > E$



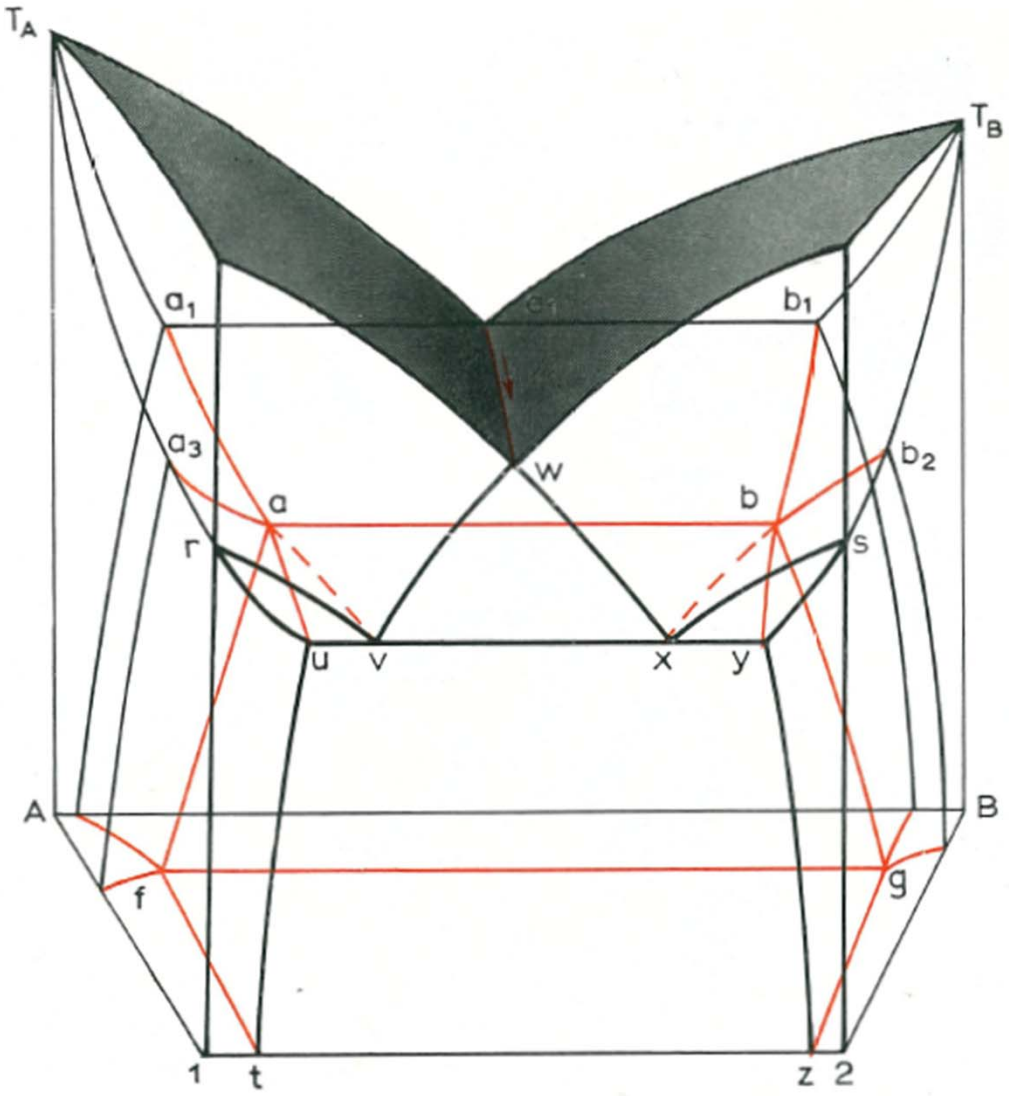
(g) $T_A = E$



(h) E = T

10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**



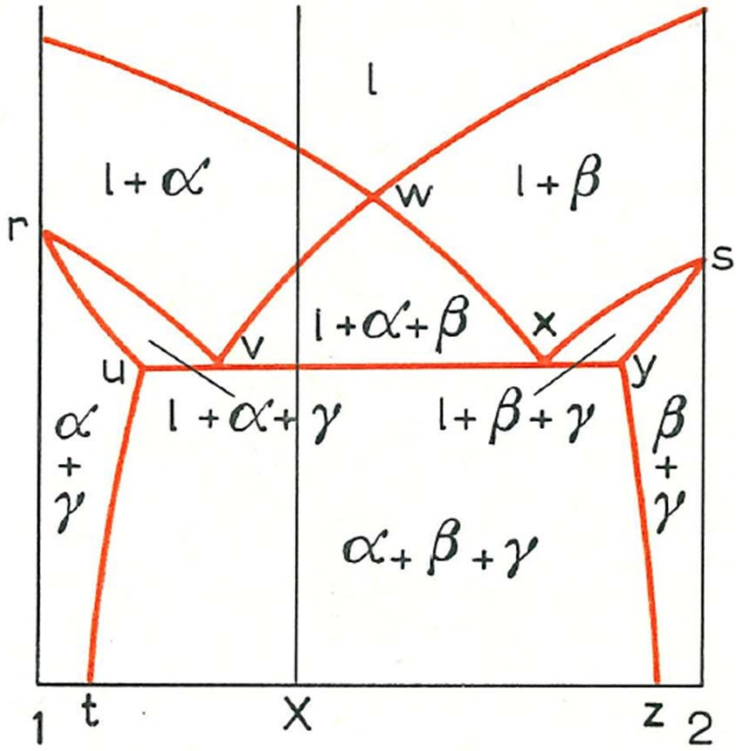
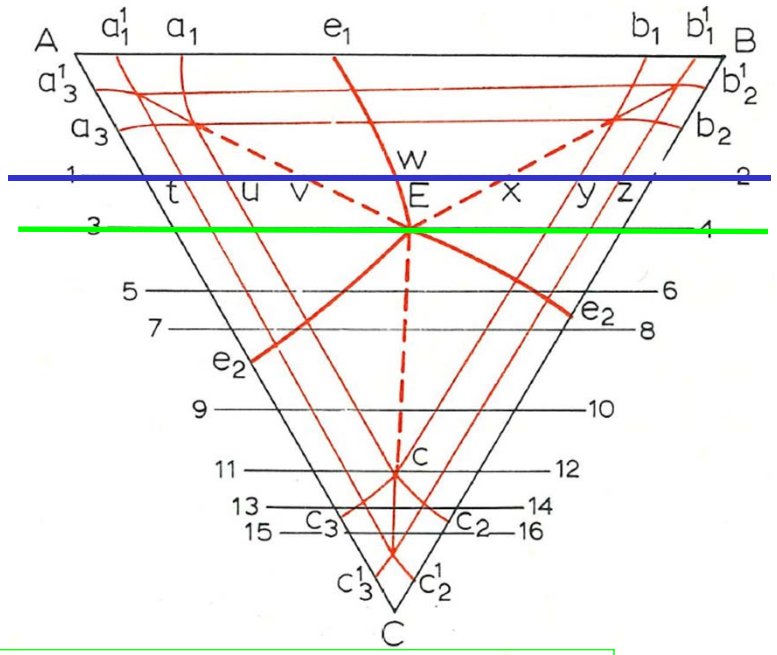


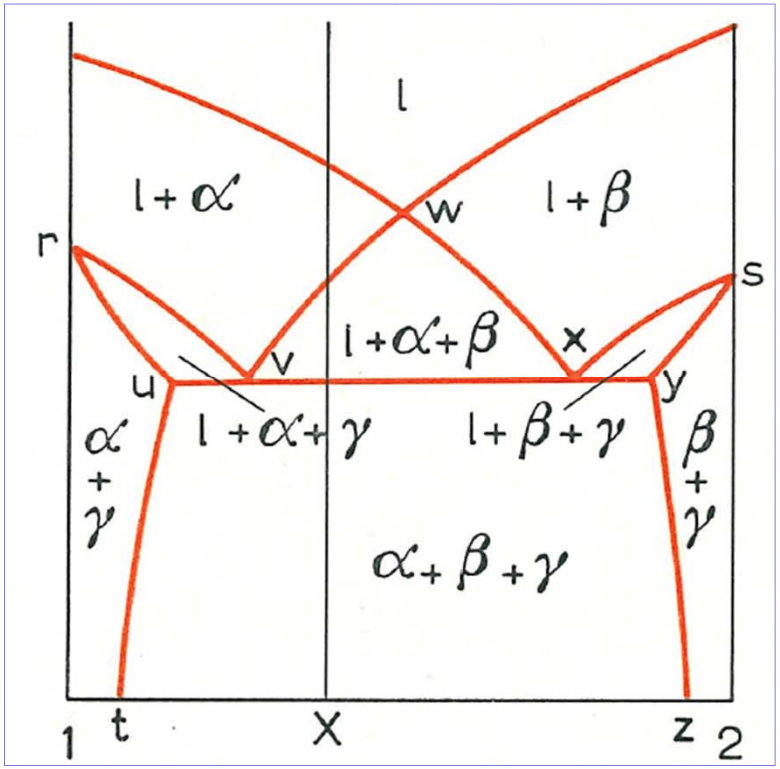
Fig. 179. Construction of vertical section 1–2.

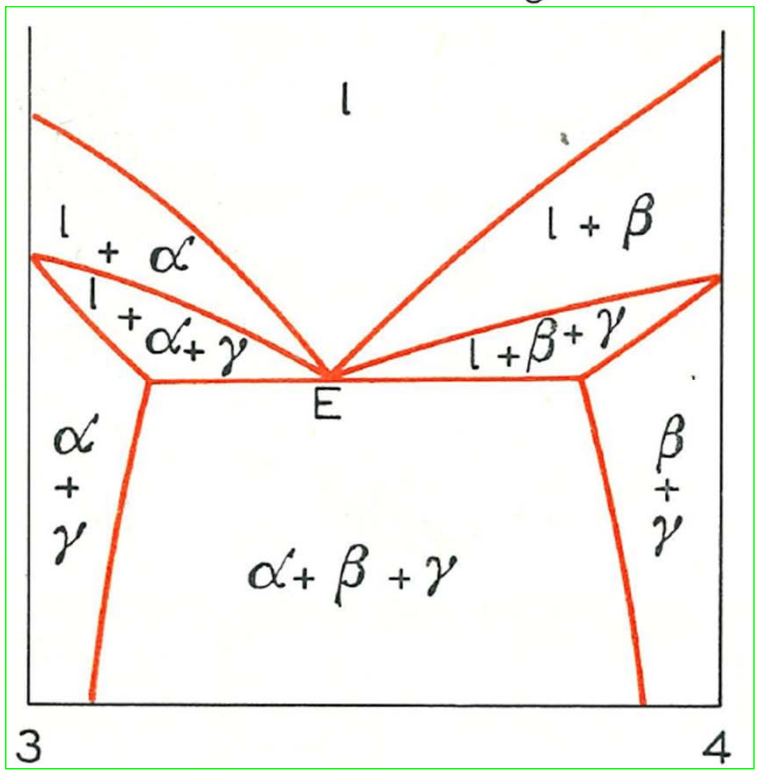
10.1. THE EUTECTIC EQUILIBRIUM

$(l = \alpha + \beta + \gamma)$

Vertical section **Location of vertical section**

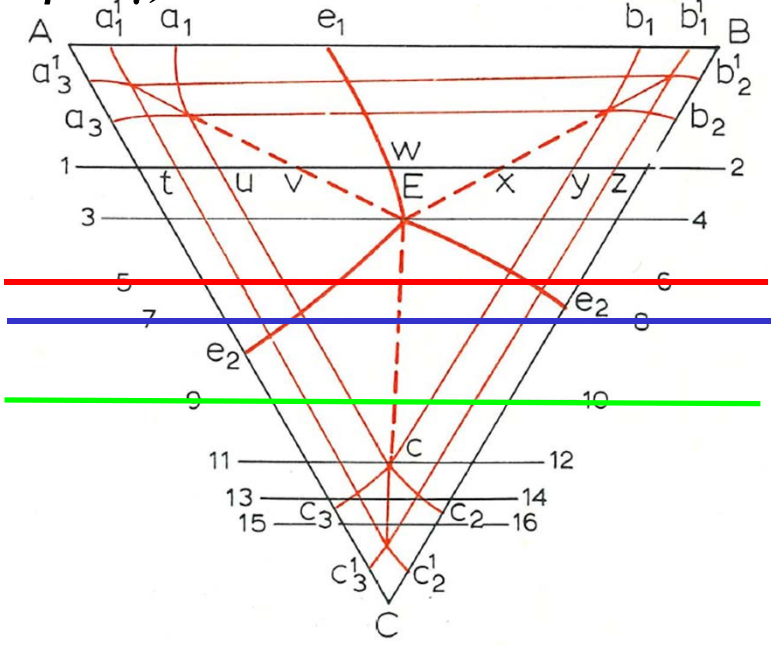


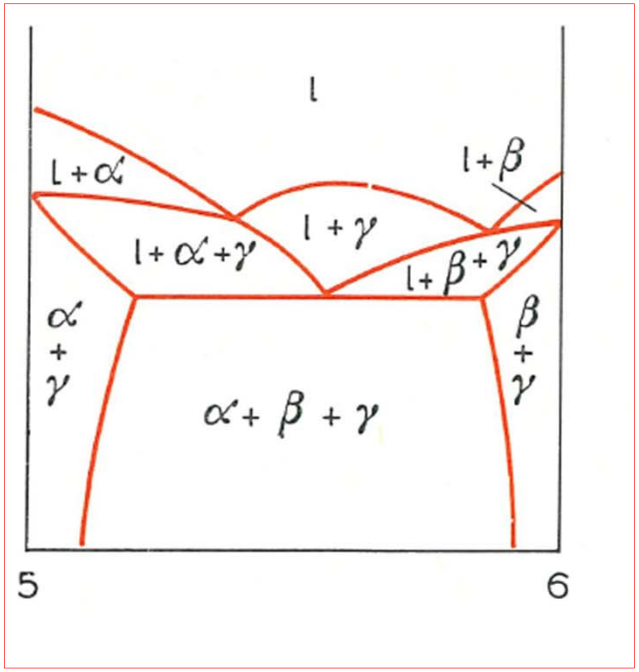


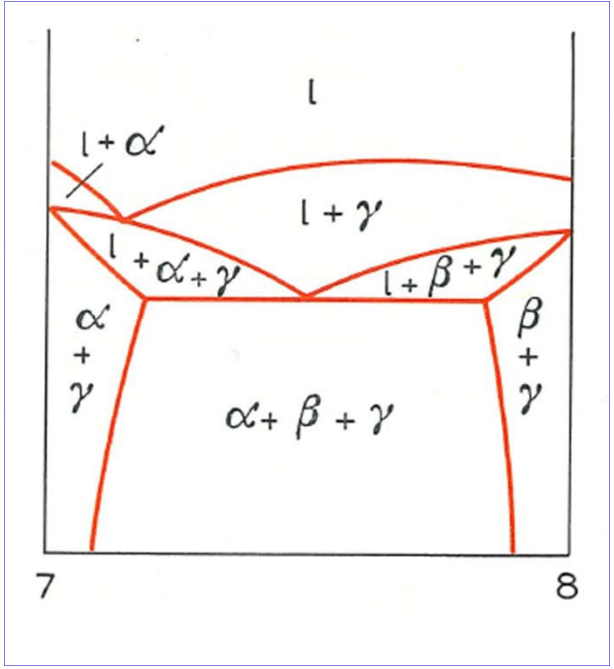


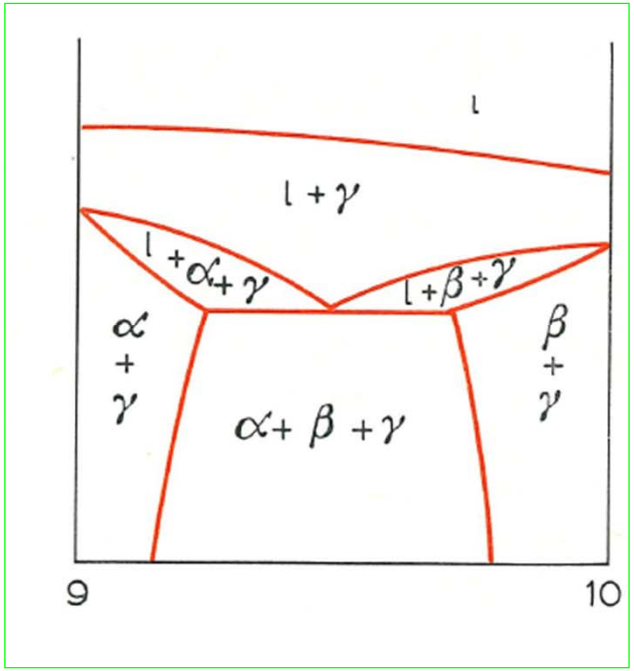
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**



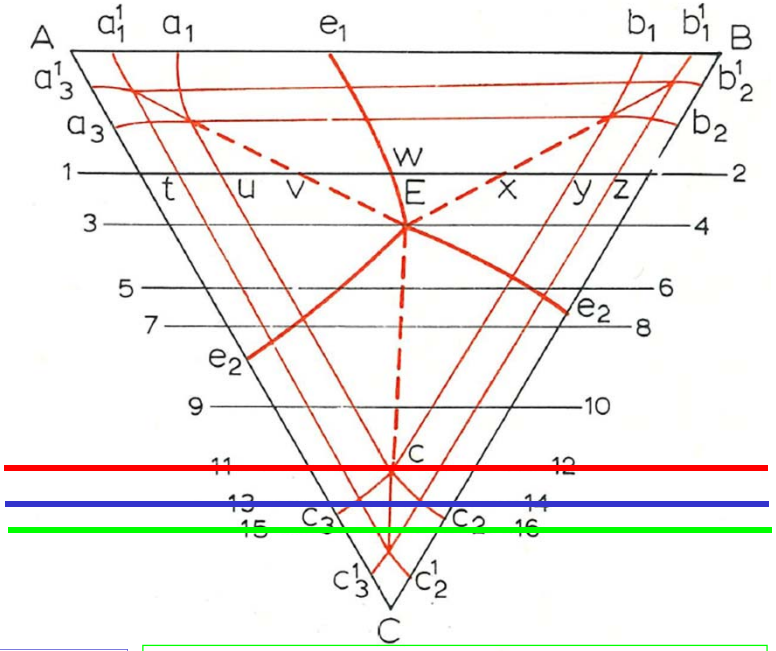


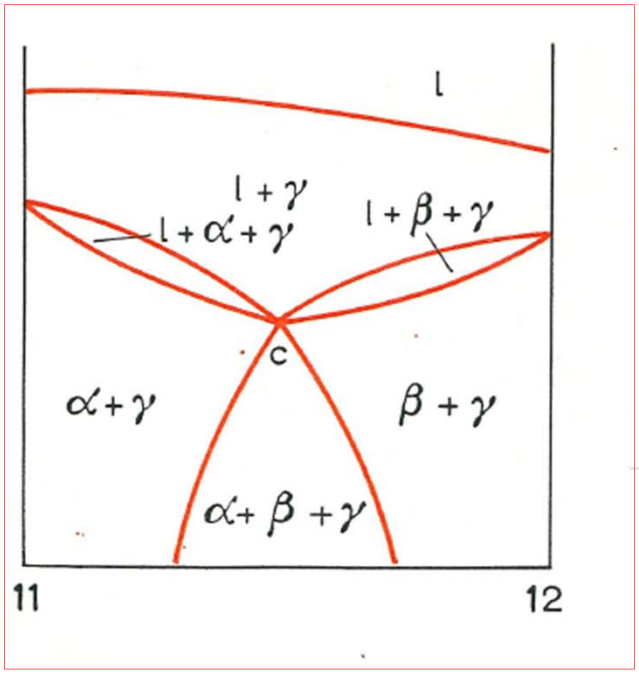


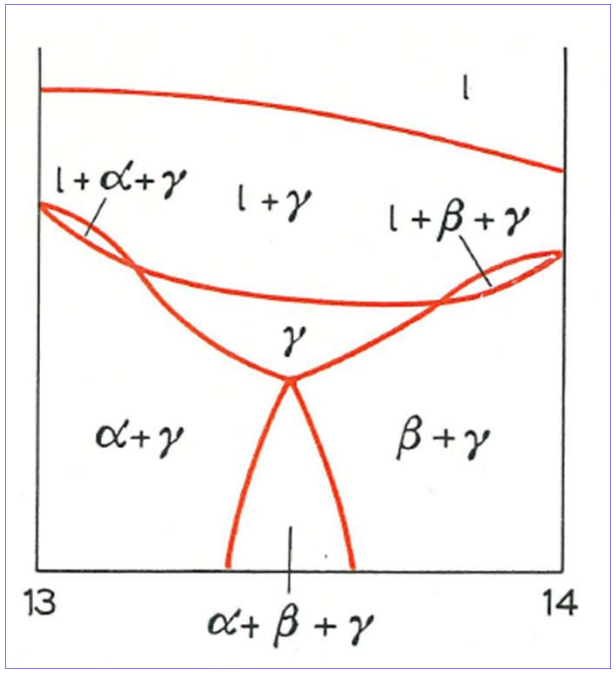


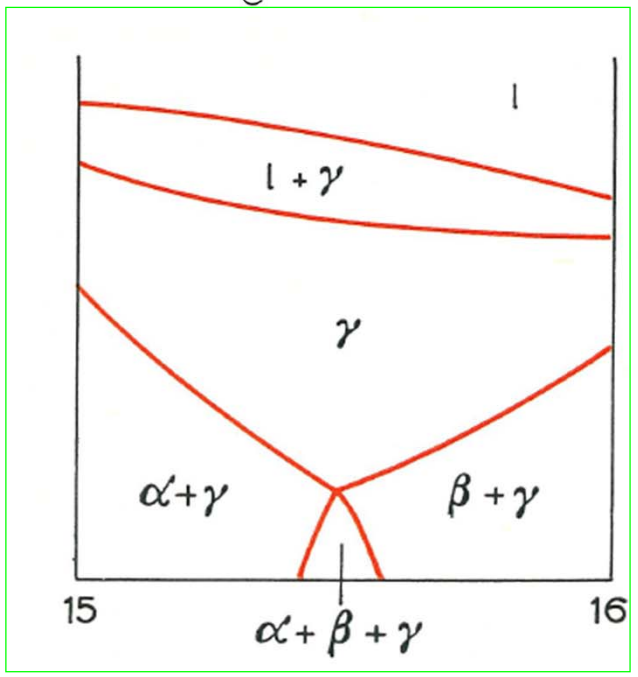
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

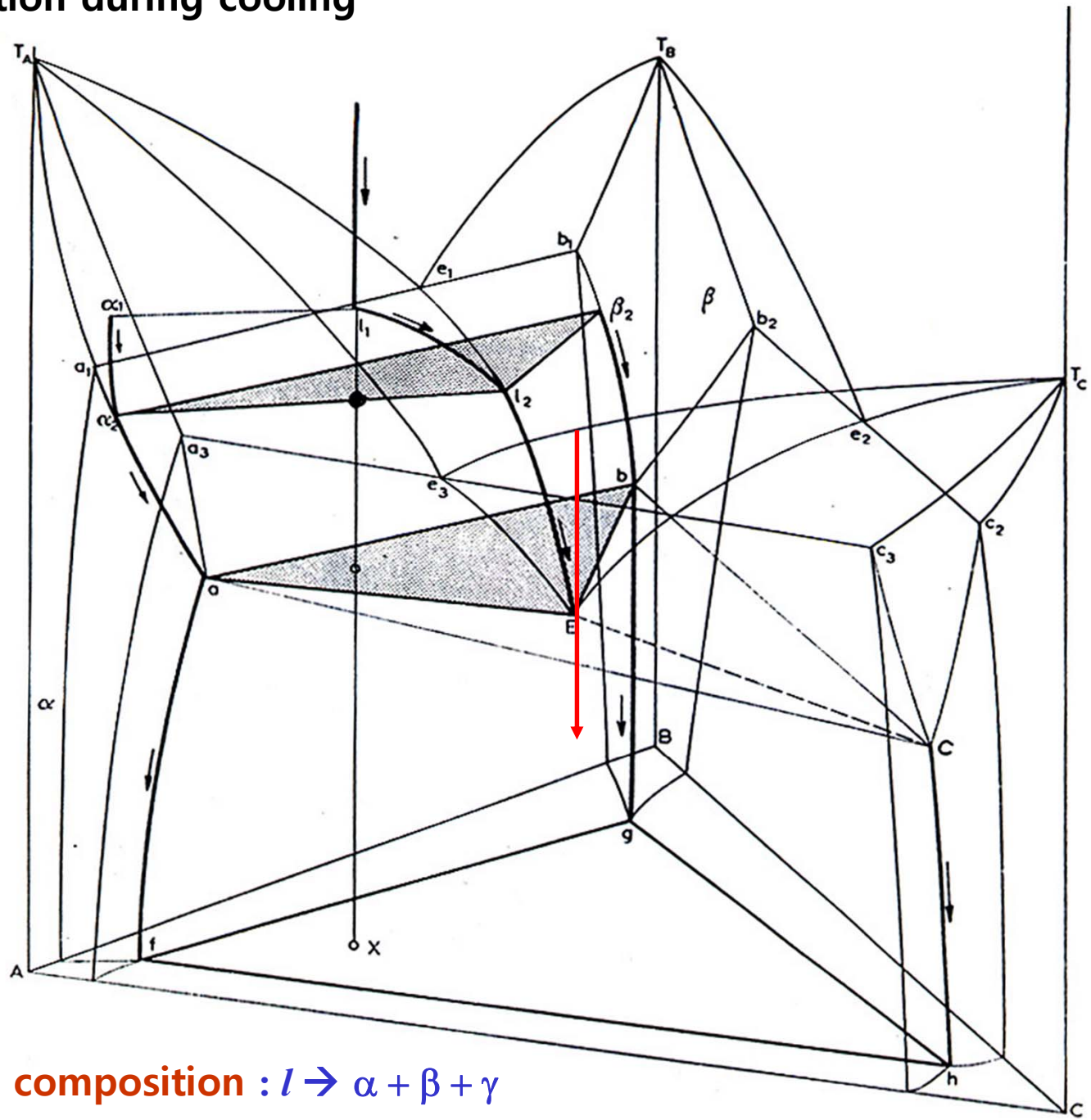






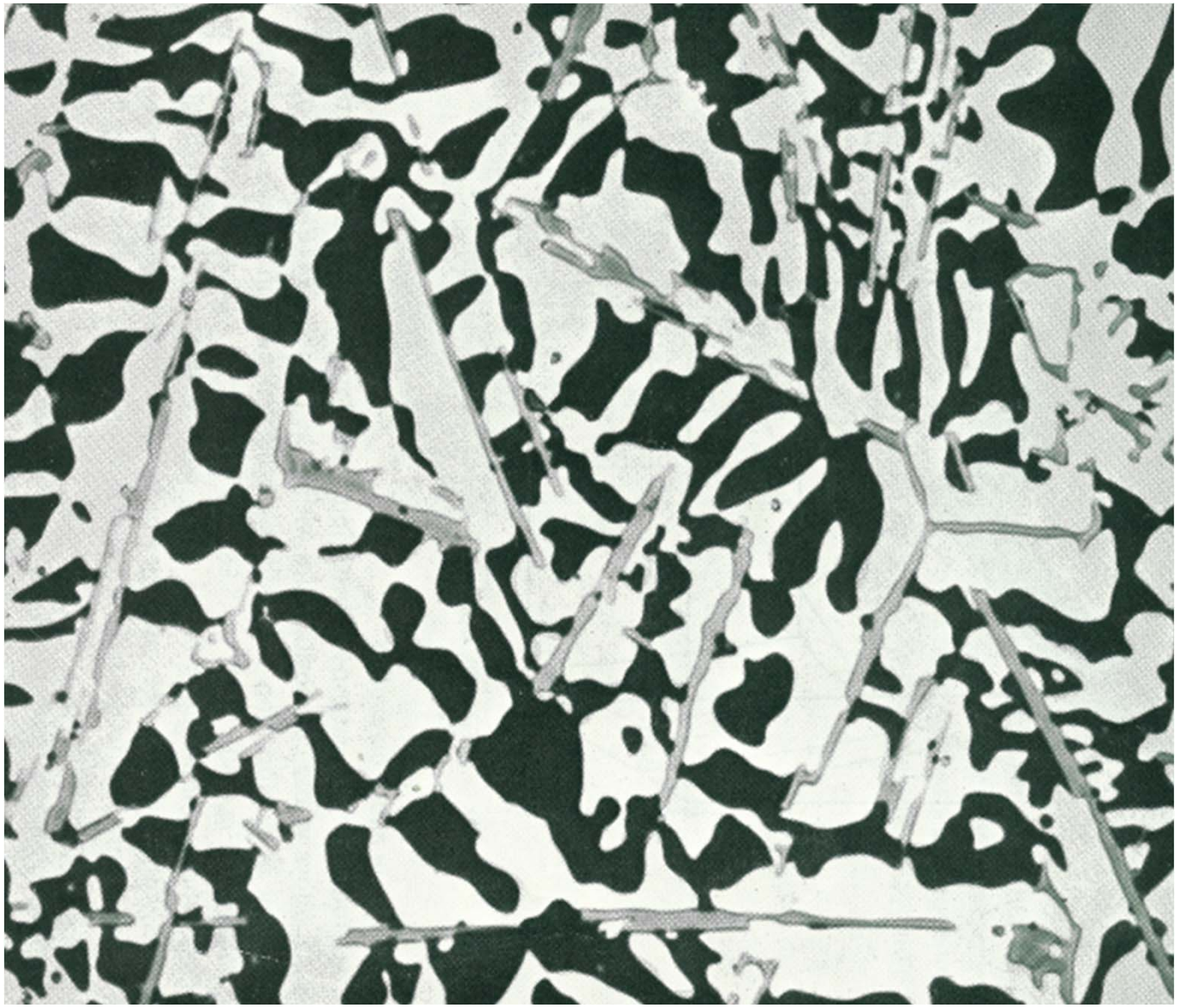


Transformation during cooling



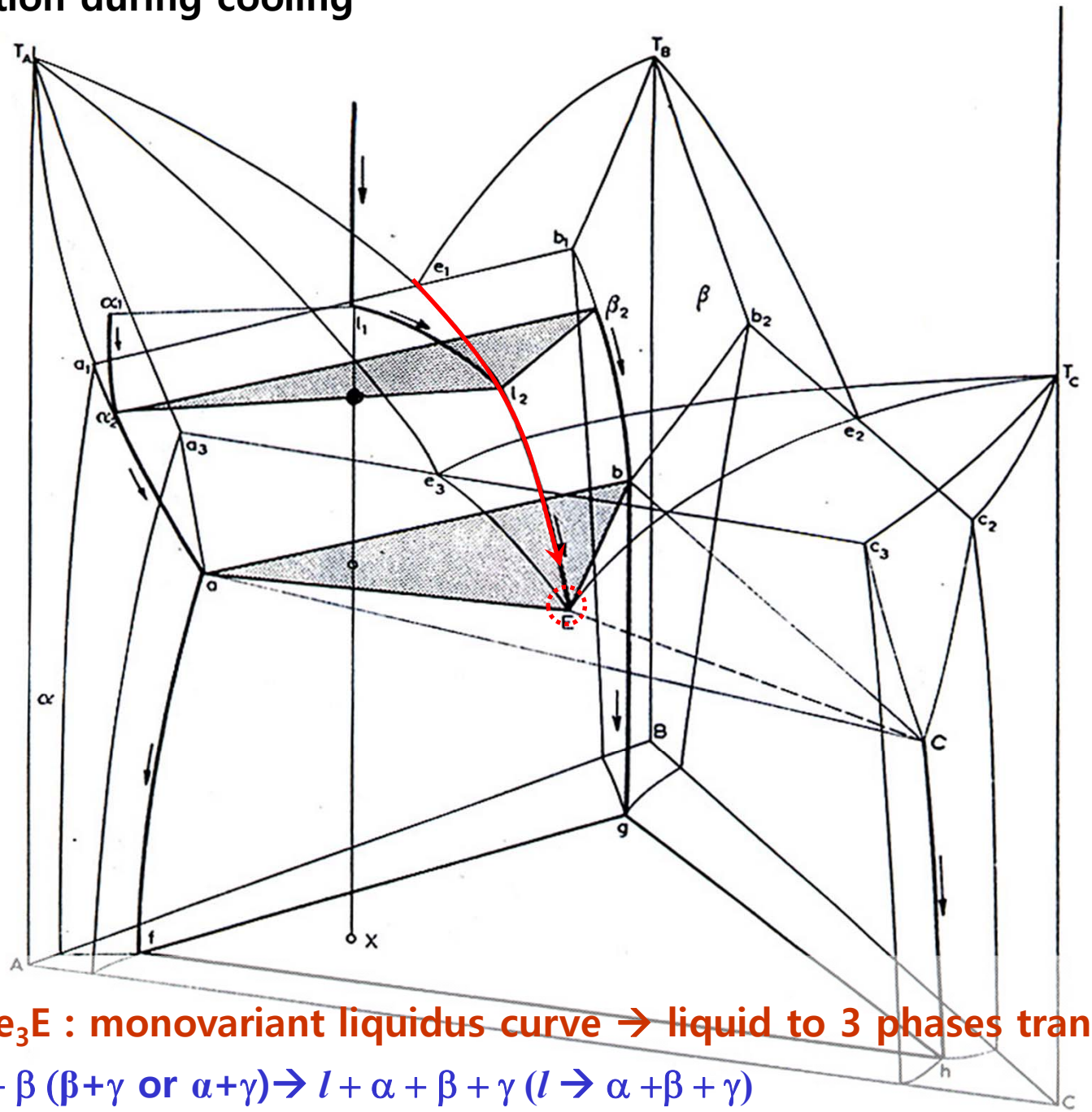
① **Eutectic composition : $l \rightarrow \alpha + \beta + \gamma$**

Ternary Eutectic microstructure



Microstructure of the ternary eutectic in the Al-Cu-Si system. α light, Θ dark, Si grey, (x 900)

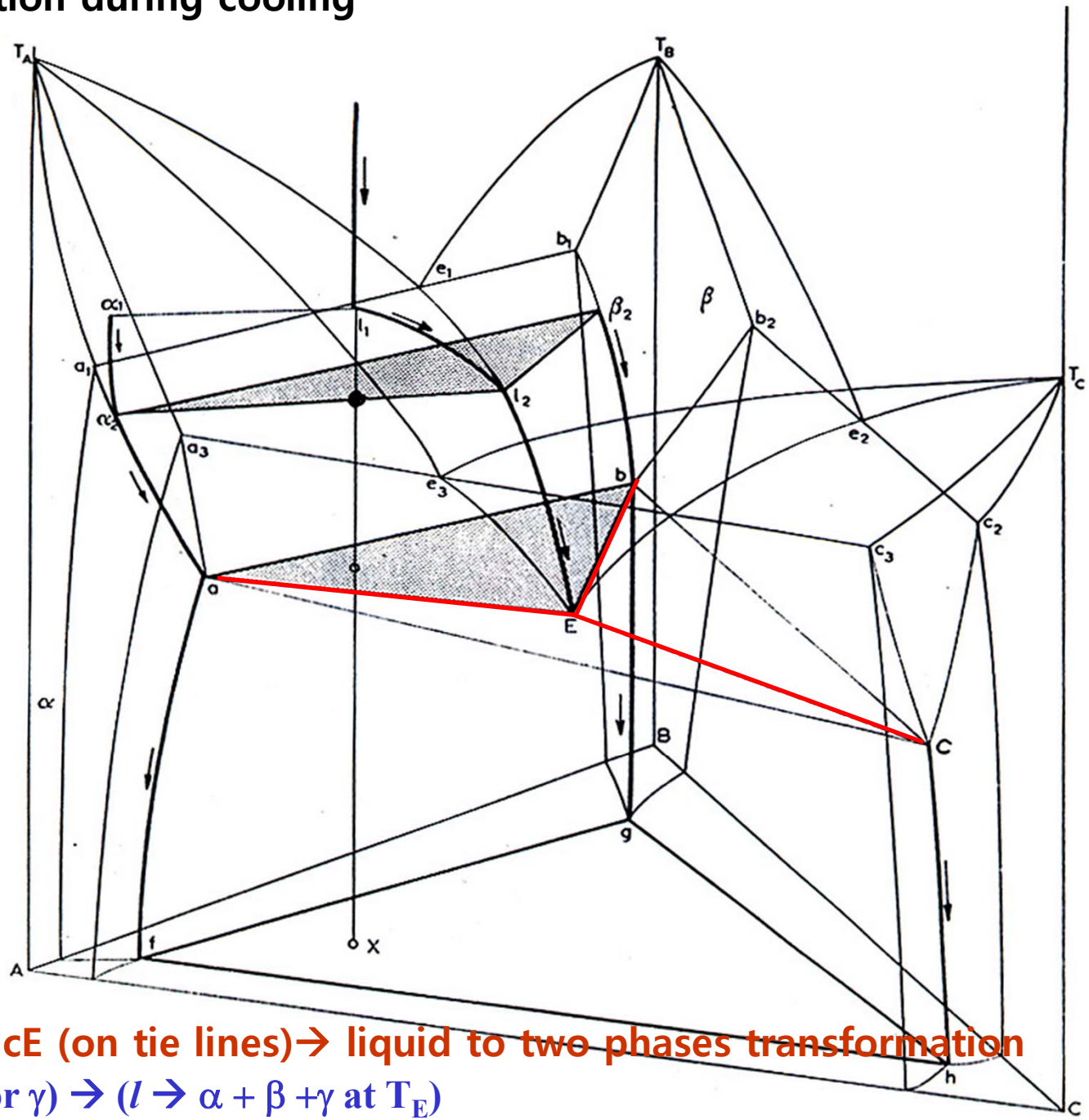
Transformation during cooling



② e_1E, e_2E, e_3E : monovariant liquidus curve → liquid to 3 phases transformation

: $l \rightarrow l + \alpha + \beta$ (β+γ or α+γ) $\rightarrow l + \alpha + \beta + \gamma$ ($l \rightarrow \alpha + \beta + \gamma$)

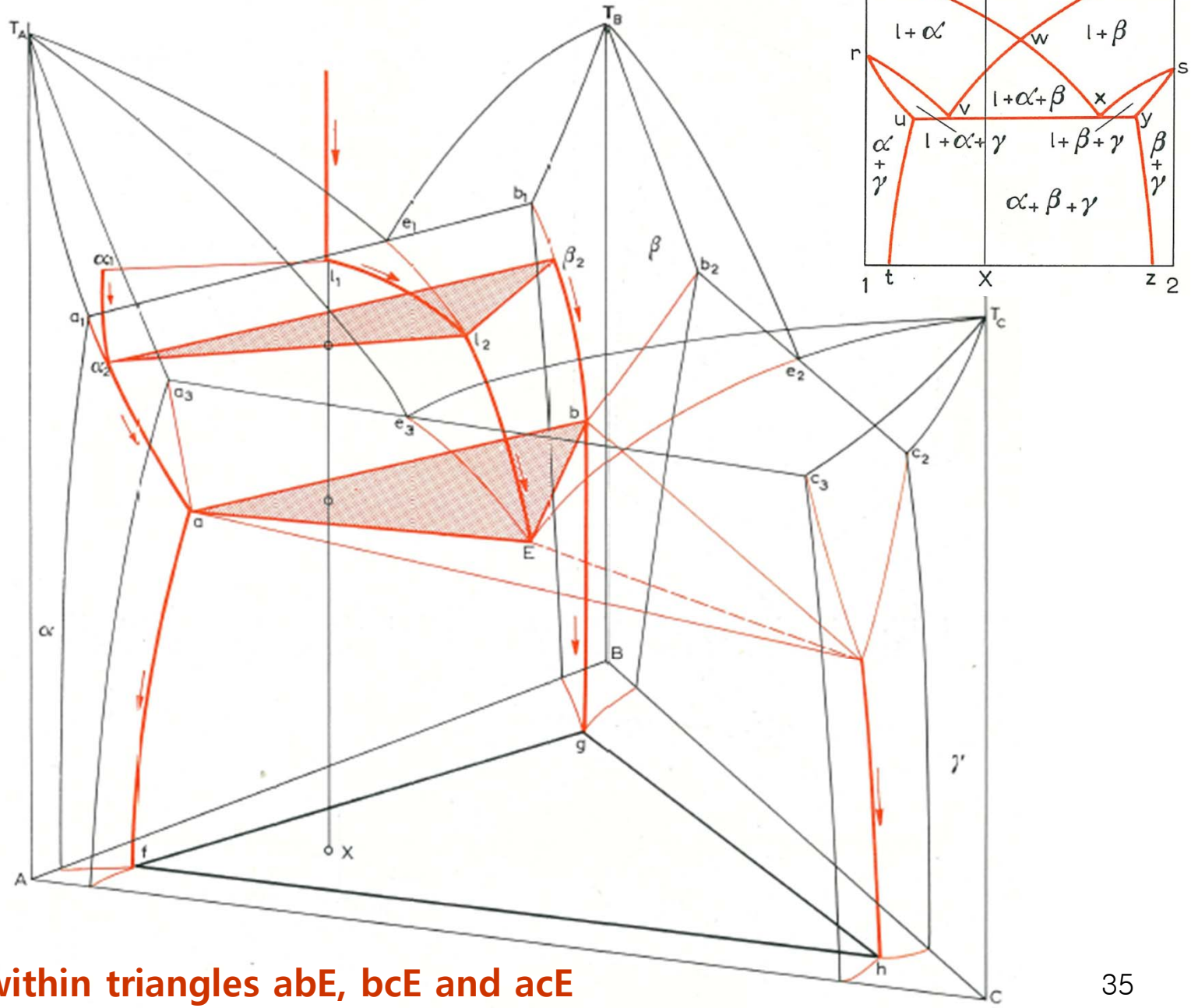
Transformation during cooling



③ aE, bE, cE (on tie lines)→ liquid to two phases transformation

: $l + \alpha$ (β or γ) → (l → $\alpha + \beta + \gamma$ at T_E)

Transformation during cooling

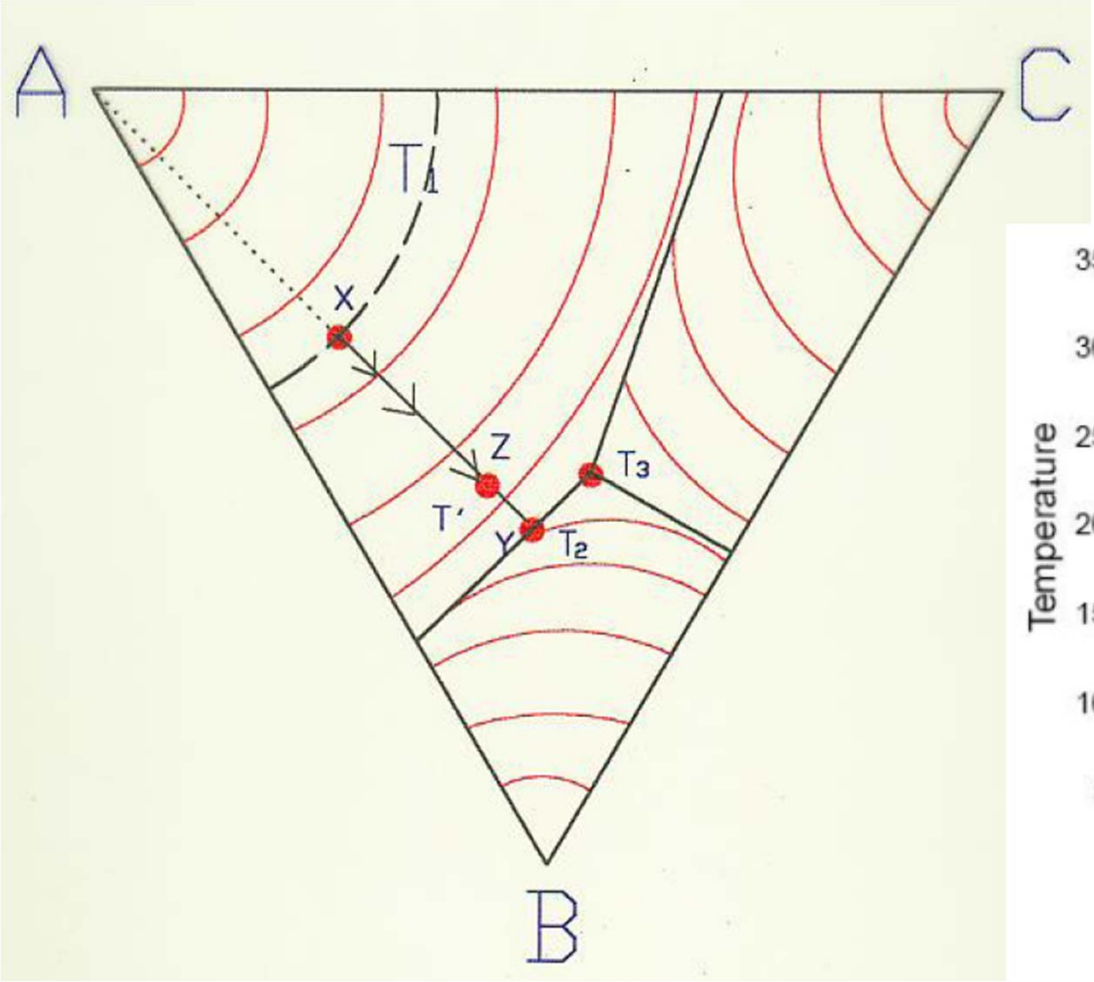


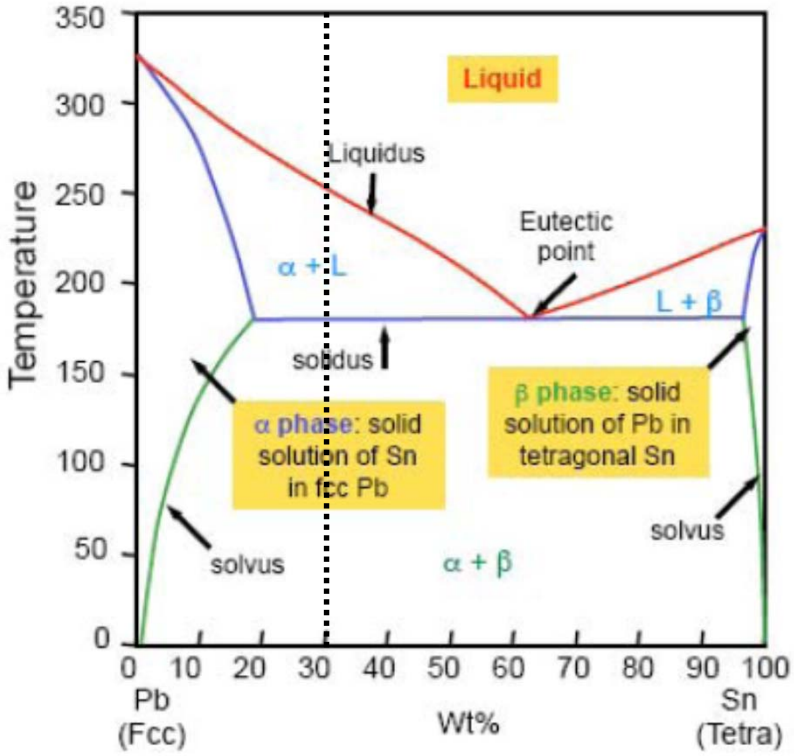
④ **Alloys within triangles abE, bcE and acE**

ex) abE: $l + \alpha$ (or β) → $l + \alpha + \beta$ → (l → $\alpha + \beta + \gamma$ at T_E)

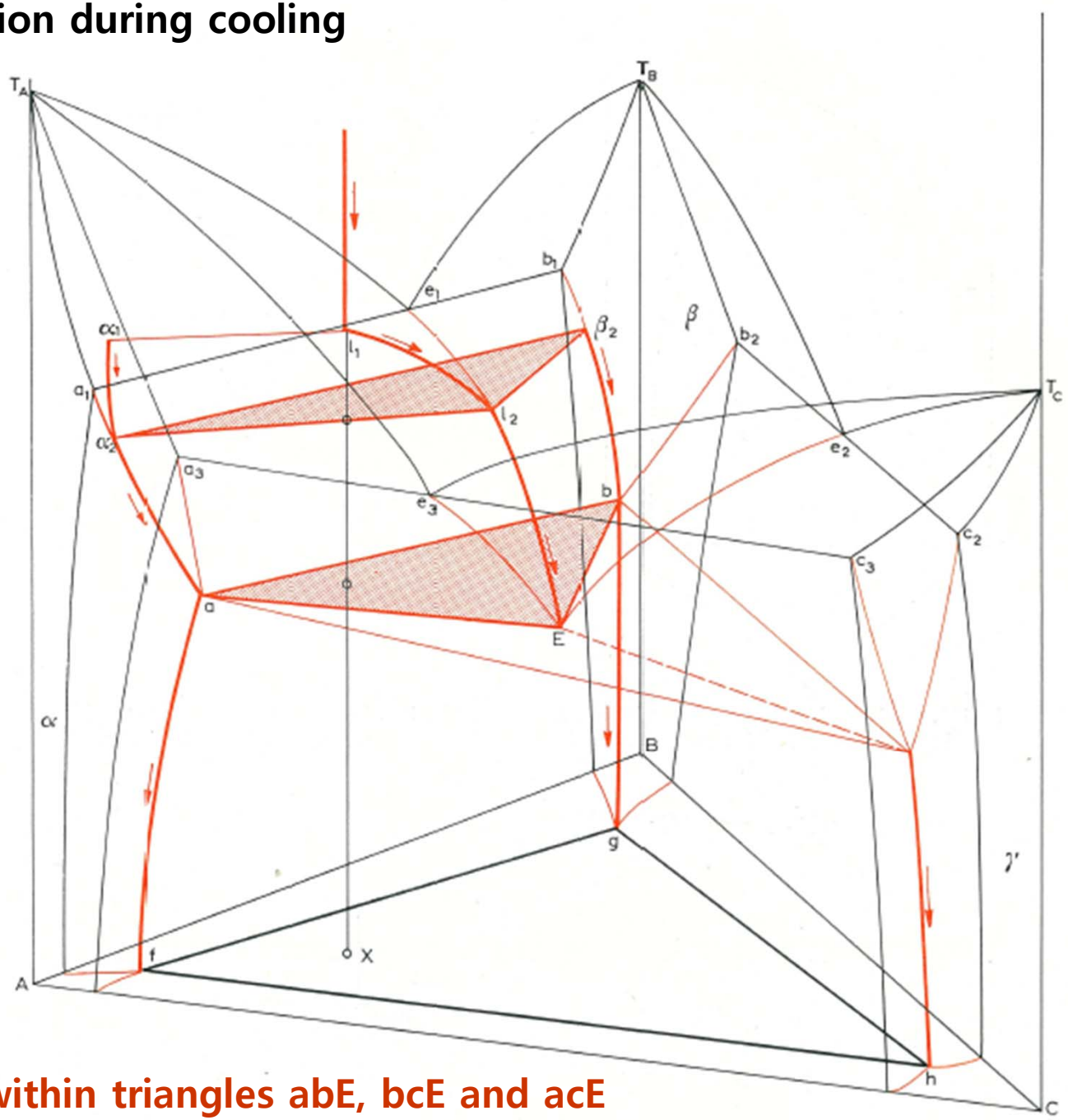
Ternary Eutectic System

Solidification Sequence





Transformation during cooling

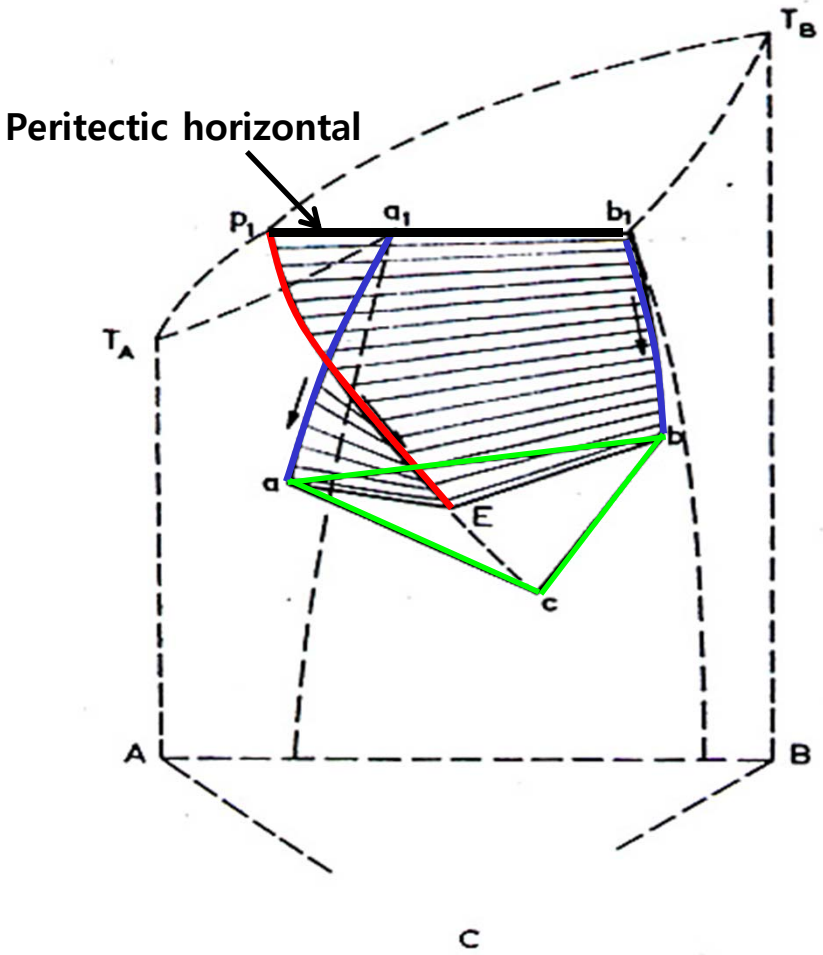


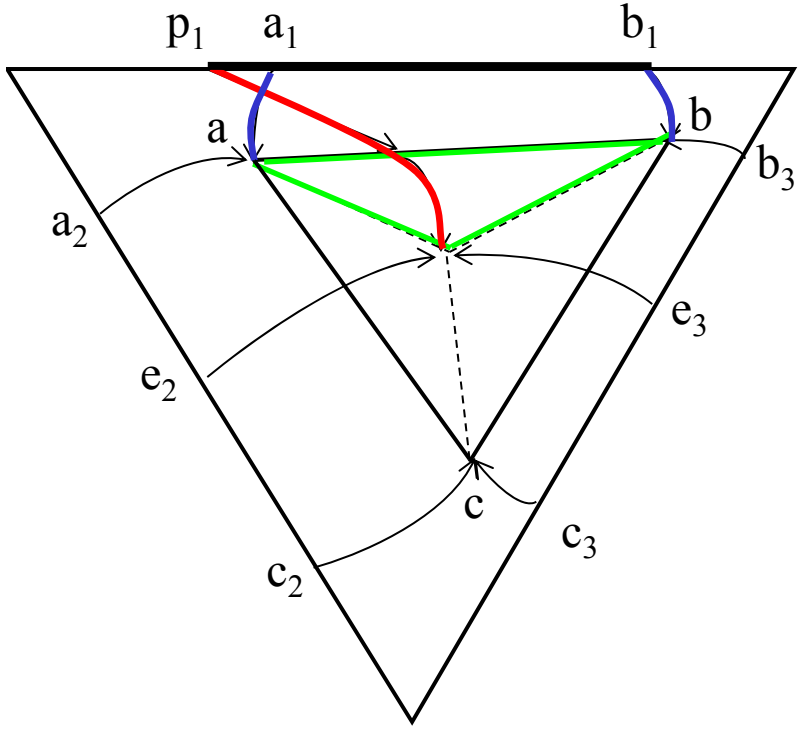
④ Alloys within triangles abE, bcE and acE

ex) abE: $l + \alpha$ (or β) → $l + \alpha + \beta$ → (l → $\alpha + \beta + \gamma$ at T_E)

10.2. VARIANTS OF THE TERNARY EUTECTIC DIAGRAM

(a) Variant of the ternary eutectic system in which one binary is a peritectic



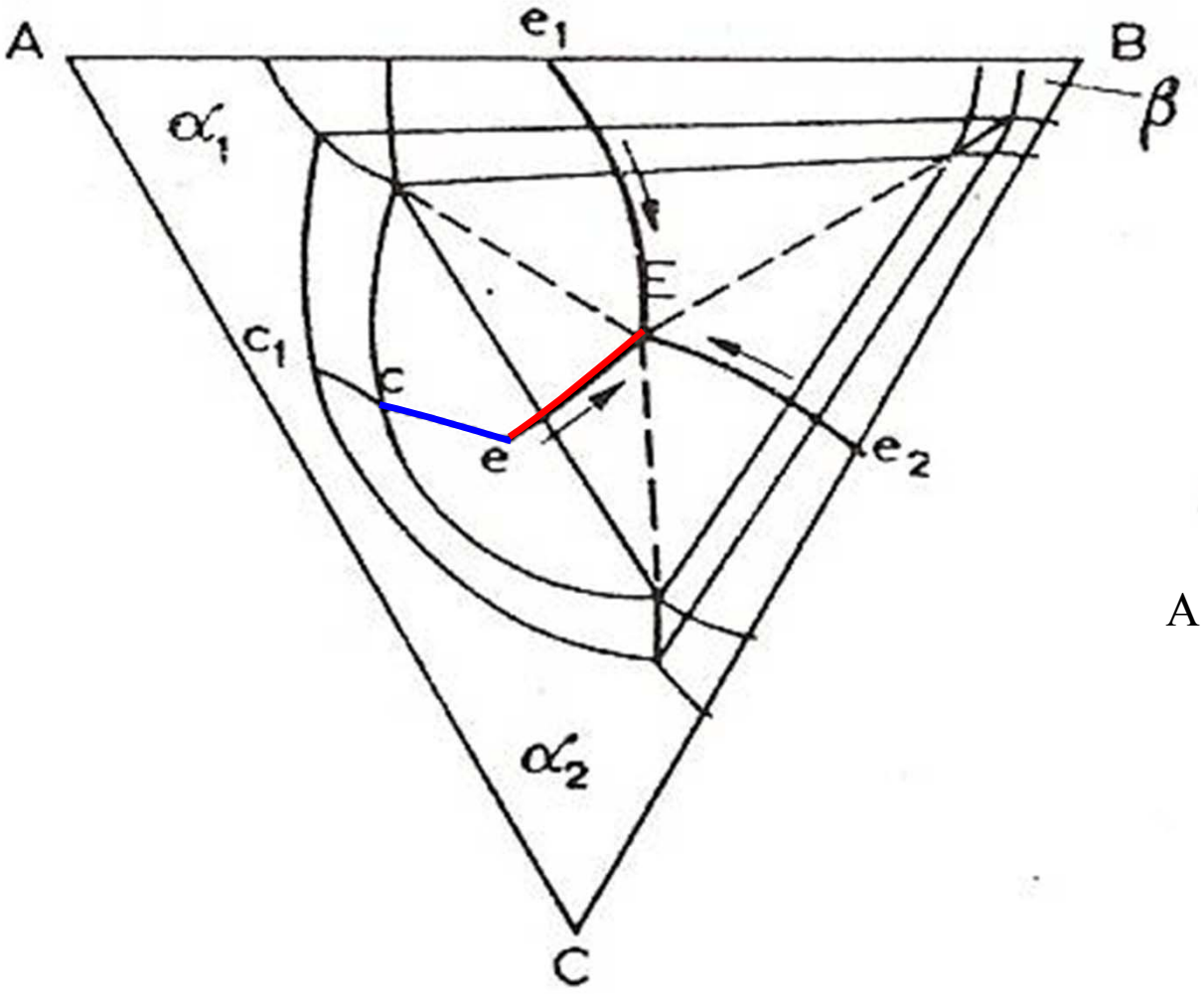


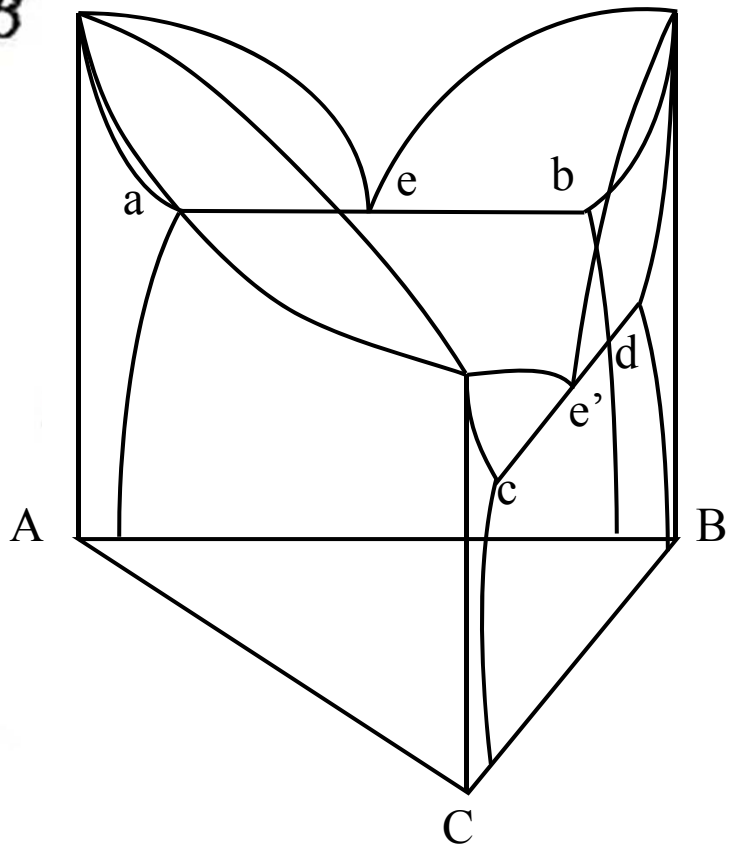
Monovariant liquidus line (P_1E) lies above monovariant solidus line (a_1a).

→ **A ternary eutectic can be produced with one, two or three binary peritectic systems.**

10.2. VARIANTS OF THE TERNARY EUTECTIC DIAGRAM

(b) Ternary eutectic system
in which two of the binary eutectics and one of ternary miscibility gap exist.



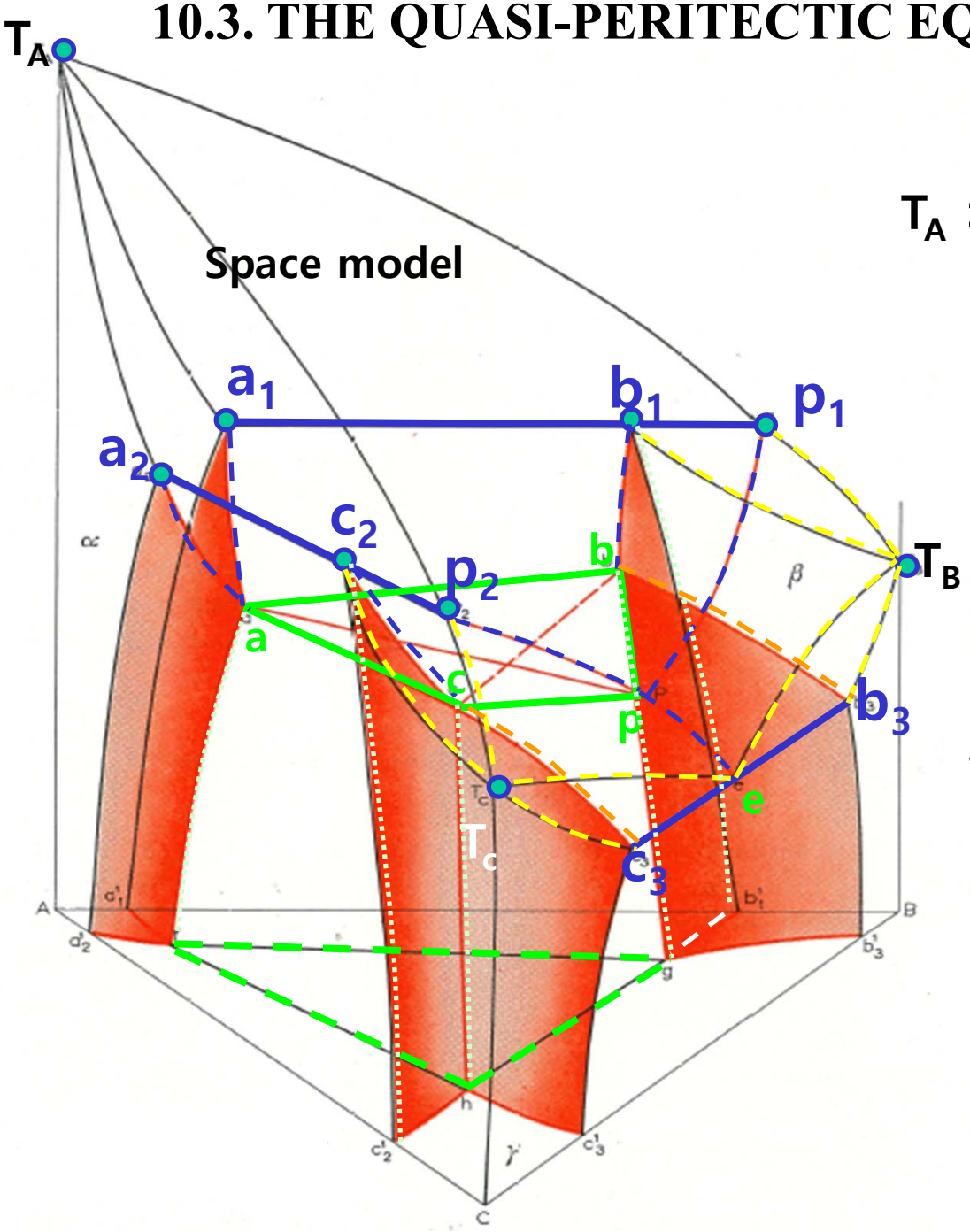


<one complete solid solution + two binary eutectic>

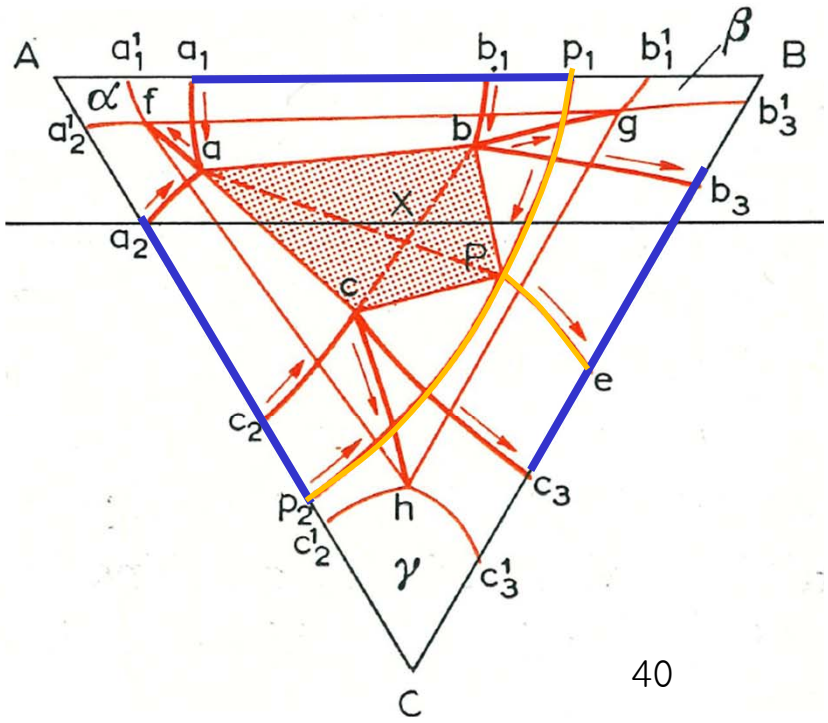
10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

$T_A > P_1 > P_2 > T_B > P > T_C > e$

Space model

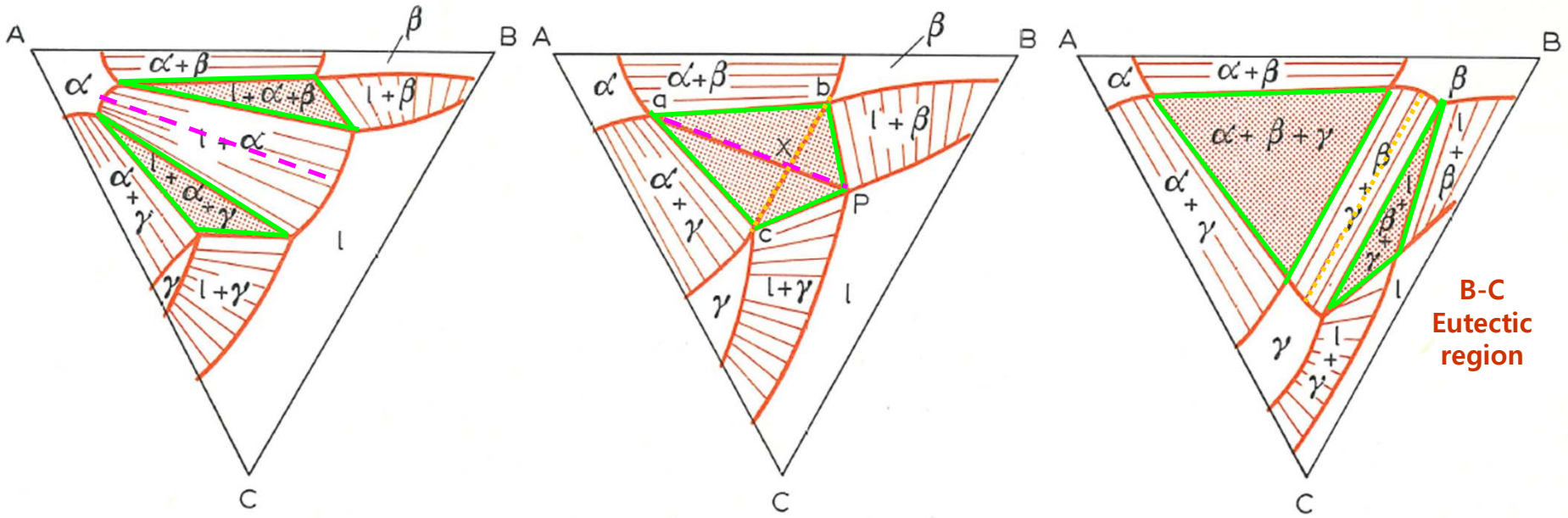


Projection



10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

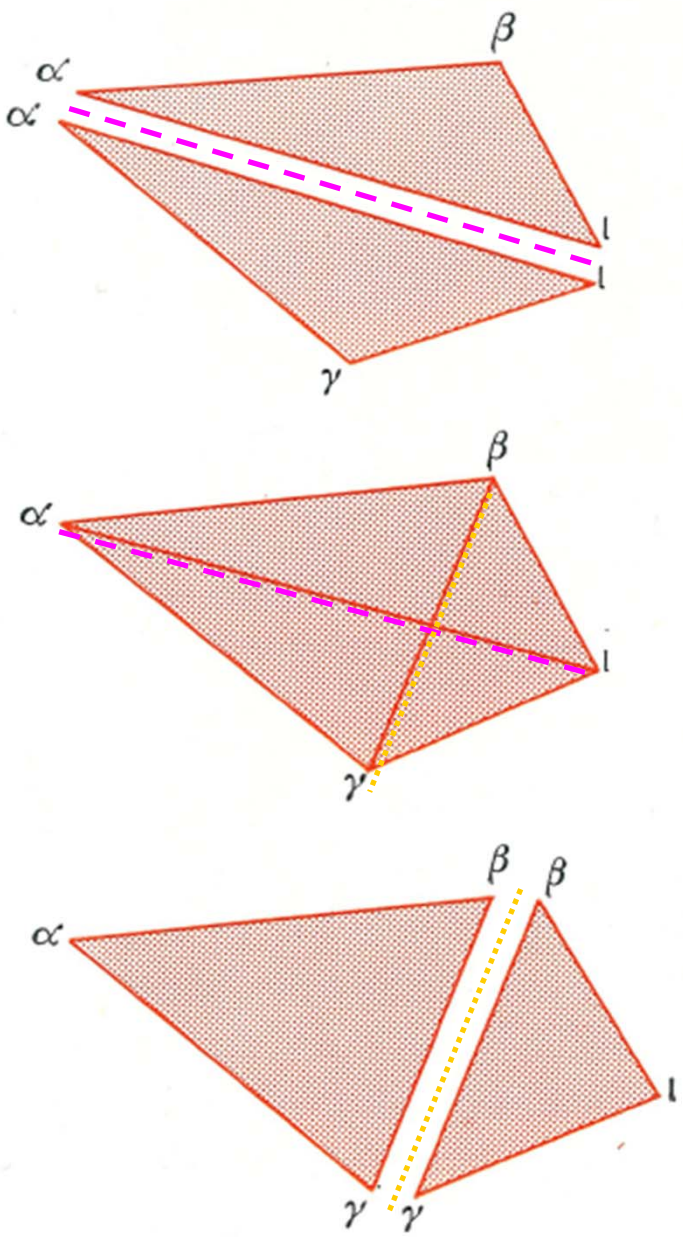
Isothermal section



$T_B > T > P$ $\qquad$ $T = P$ $\qquad$ $P > T > T_C$

abP	peritectic	$l\alpha\beta$ equilibrium	descending to the four-phase plane;
acP	peritectic	$l\alpha\gamma$ equilibrium	
bcP	eutectic	$l\beta\gamma$ equilibrium	descending from the four-phase plane.
abc		$\alpha\beta\gamma$ equilibrium	

10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)



Both three phase monovariant equilibria preceding the quasi-peritectic reaction are peritectic

abP peritectic lαβ equilibrium

acP peritectic lαγ equilibrium

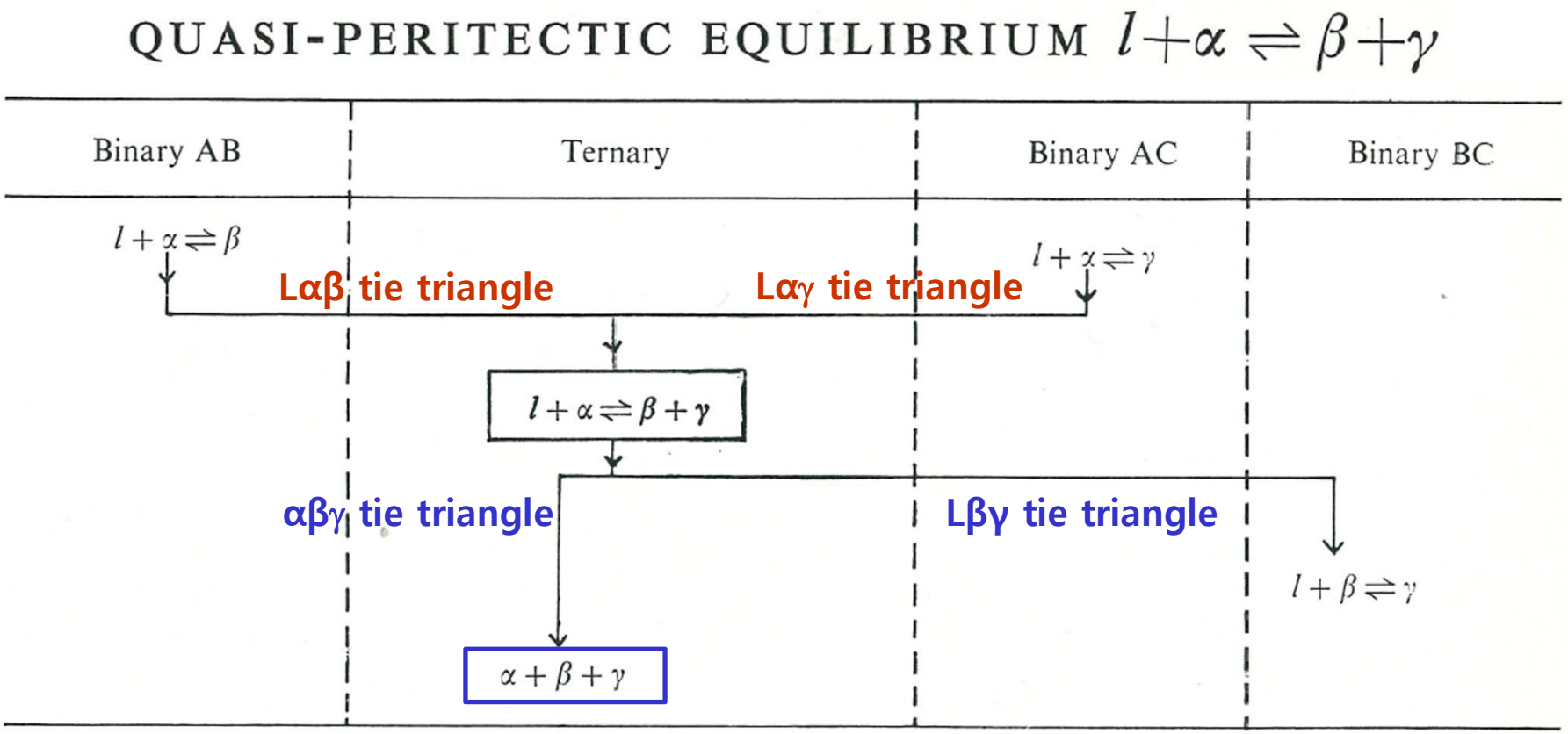
decreasing temperature

bcP eutectic lβγ equilibrium

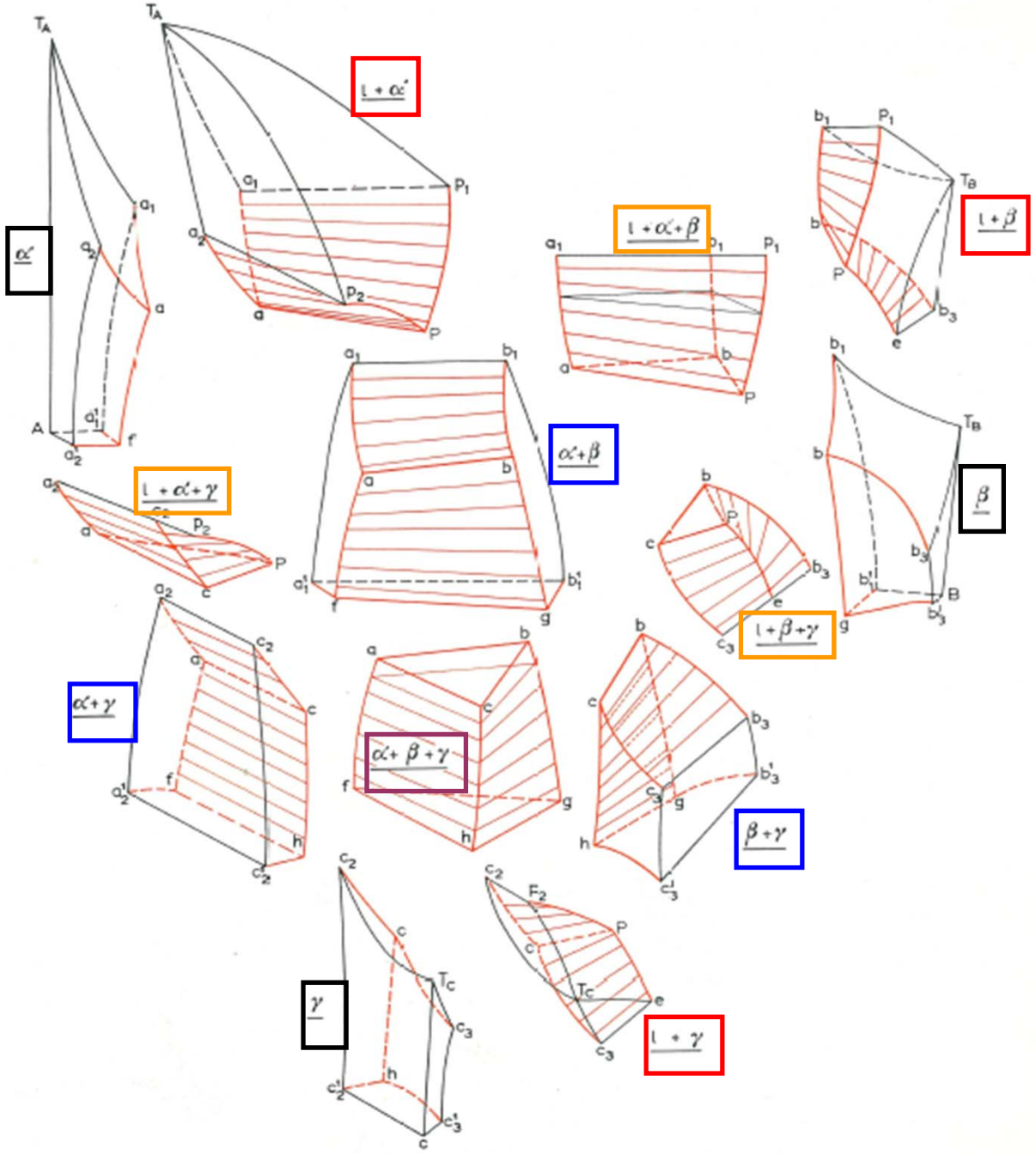
abc peritectic αβγ equilibrium

Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

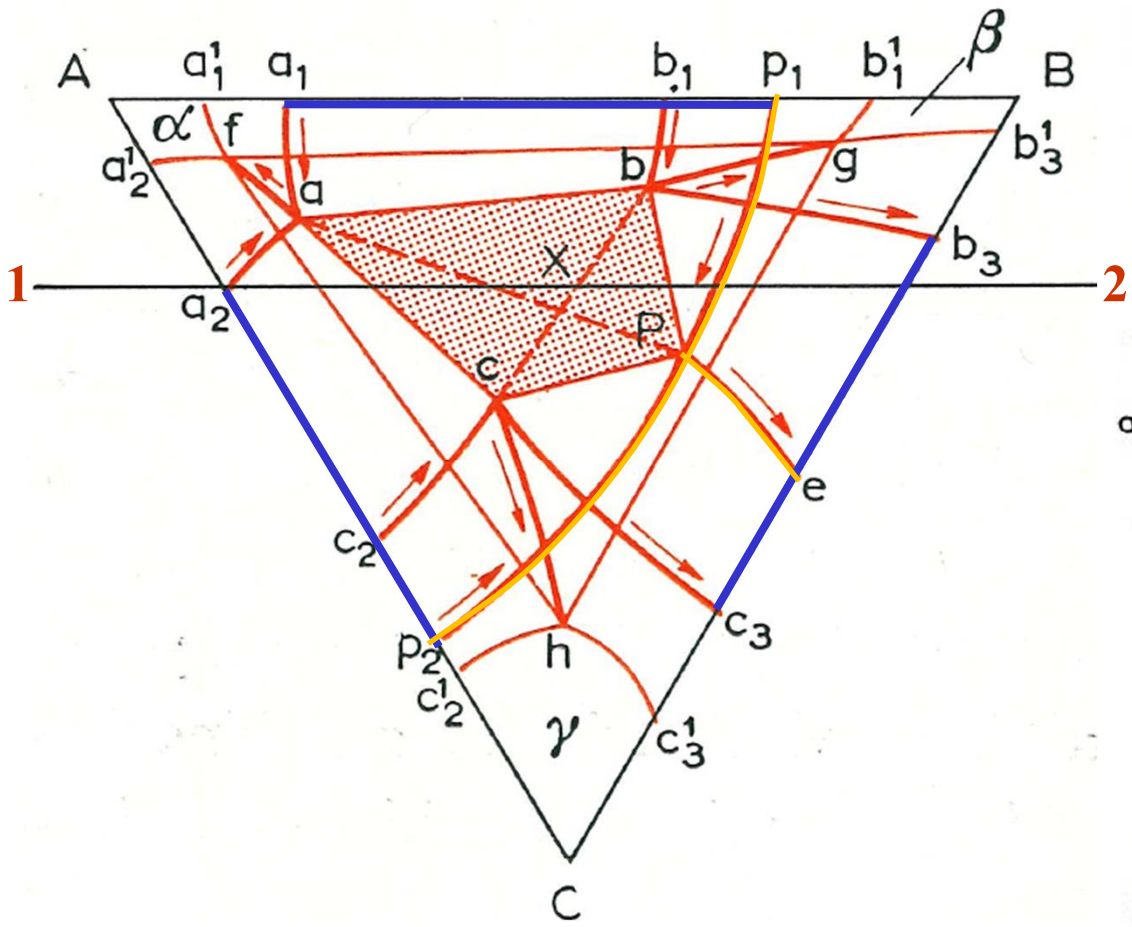


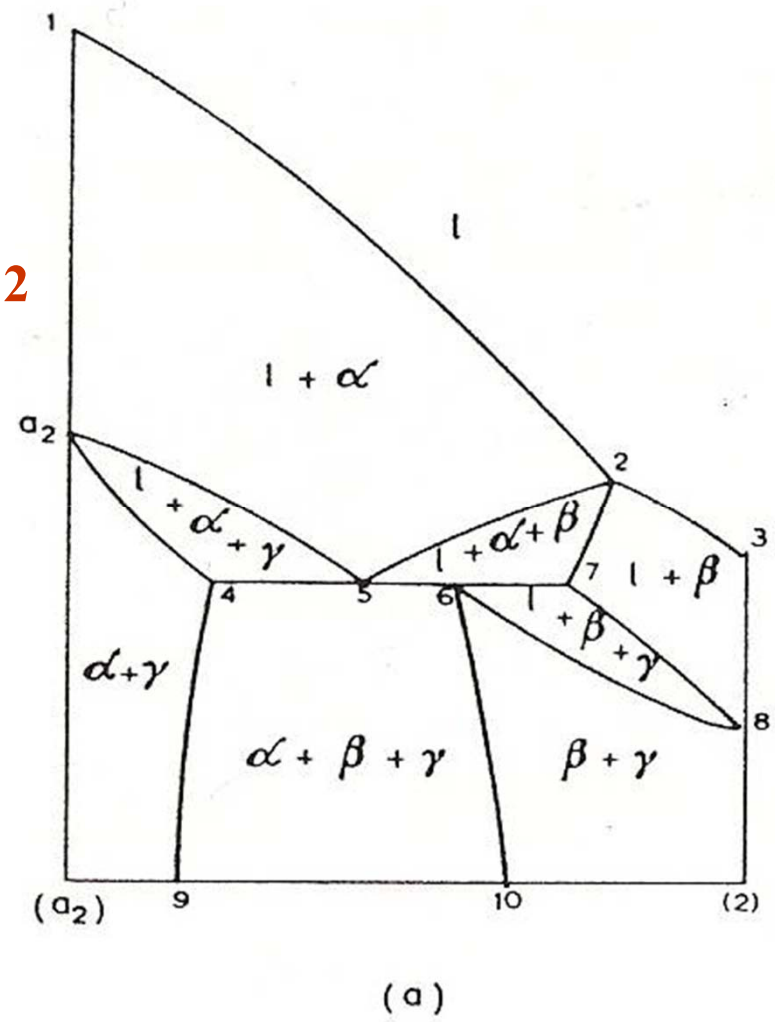
10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)



10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

Vertical section





(a)

10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

Vertical section

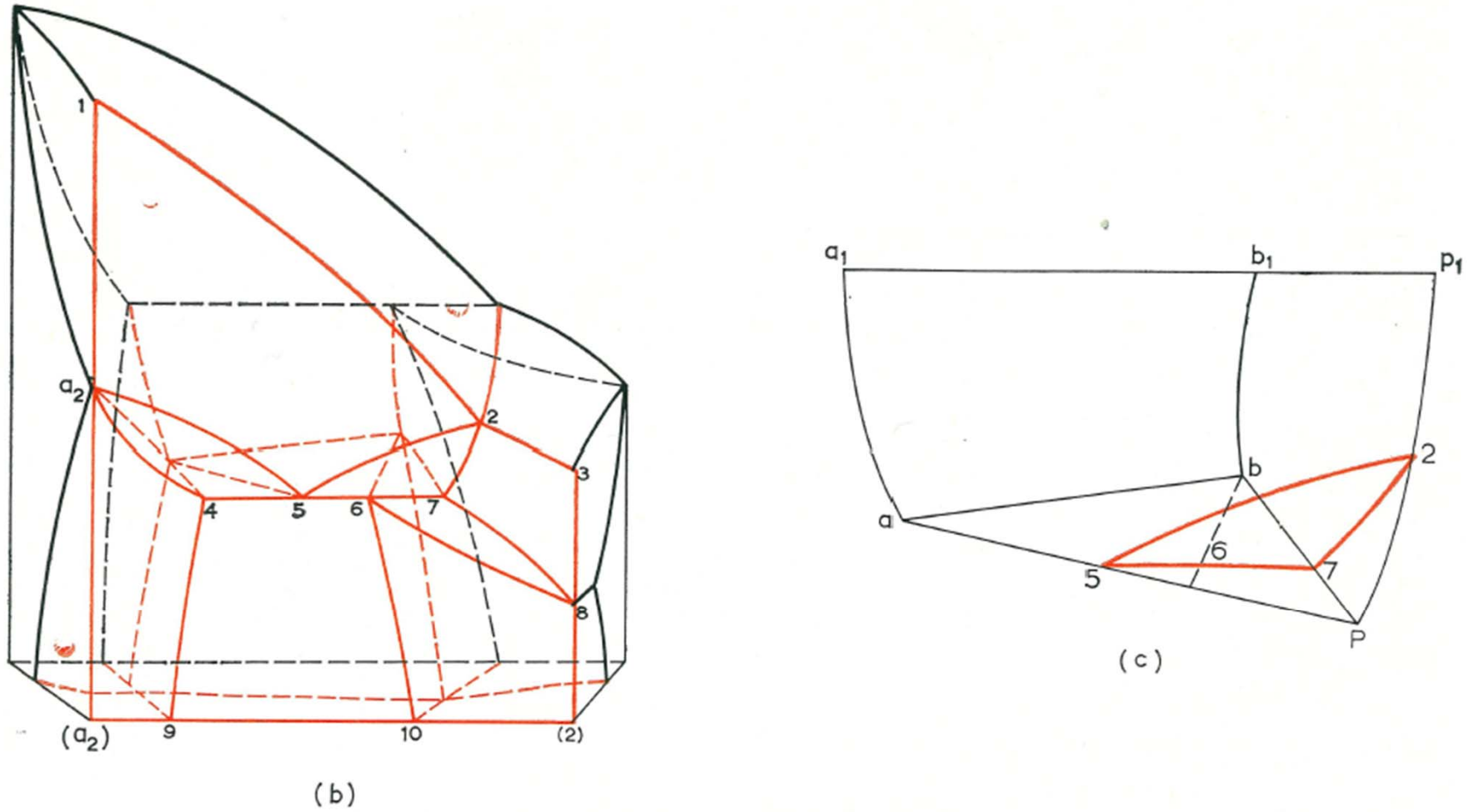


Fig. 188. A vertical section through the space model of Fig. 185a. (a) The vertical section a_2–2; (b) construction of the vertical section; (c) intersection of the vertical section with the $l+\alpha+\beta$ phase region.

10.3.2. one of the three phase monovariant equilibria preceding the quasi-peritectic reaction is eutectic and one peritectic.

*** Ternary system involving an incogruently-melting binary intermediate phase:**

Quasi-peritectic diagram and ternary eutectic diagram

e.g. **Au-Ge-Sb ternary *in which the δ phase is intermediate phase $AuSb_2$.***

$P_1d_1b_1 \rightarrow dbp\ (\delta\beta L)$ / $b_3e_3C_3 \rightarrow bpc\ (\beta L\gamma)$

⇩

$d^1\varepsilon c(\delta + \gamma + L)$ / $gfn(\beta + \delta + \gamma)$

$d^1\varepsilon c^1(\delta\gamma L)$ / $a_1e_1d_2 \rightarrow a^1\varepsilon d^1(\alpha\delta L)$ / $a_2e_2c_2 \rightarrow a^1\varepsilon c^1(\alpha L\gamma)$

⇩

$Jkm\ (\alpha + \gamma + \delta)$

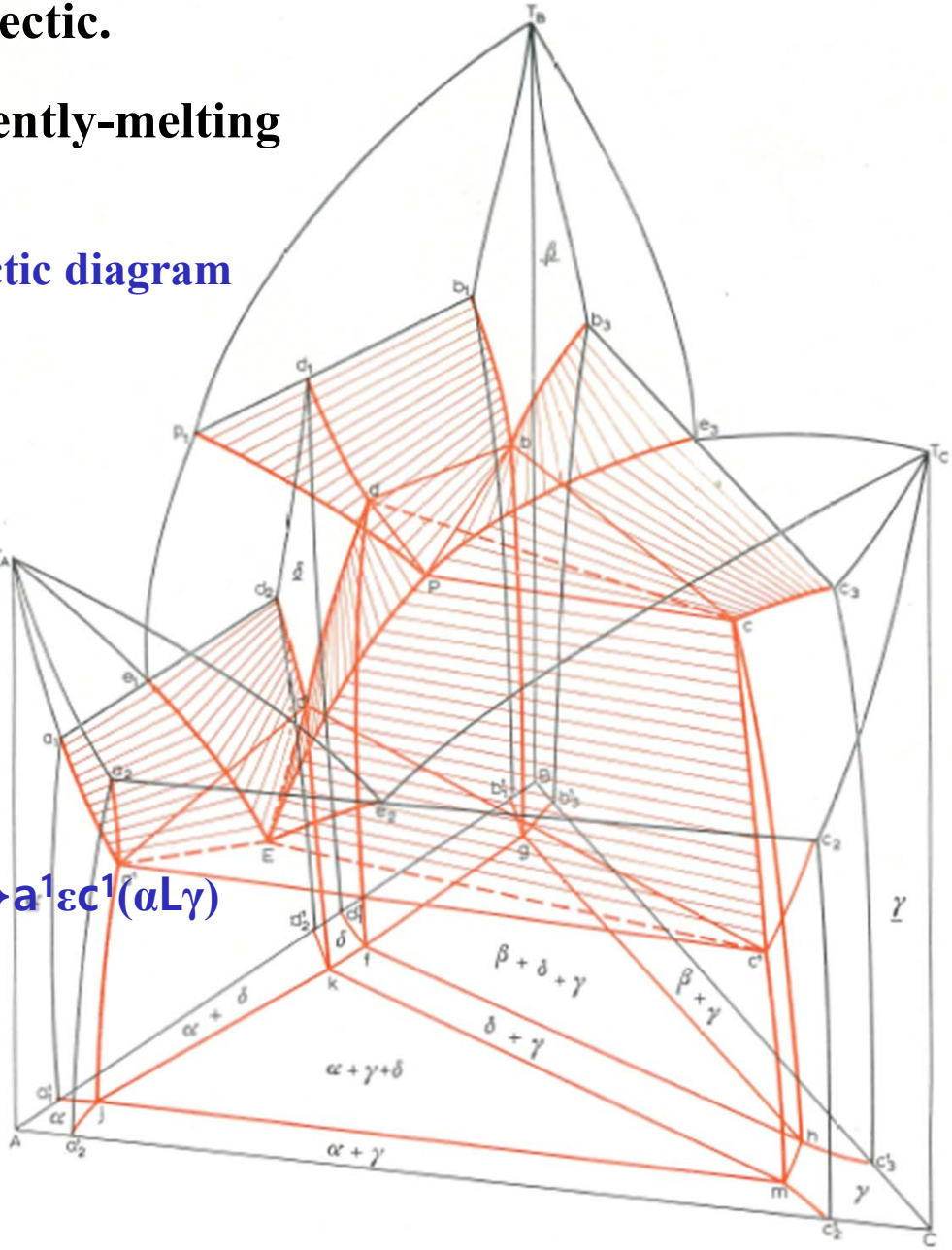
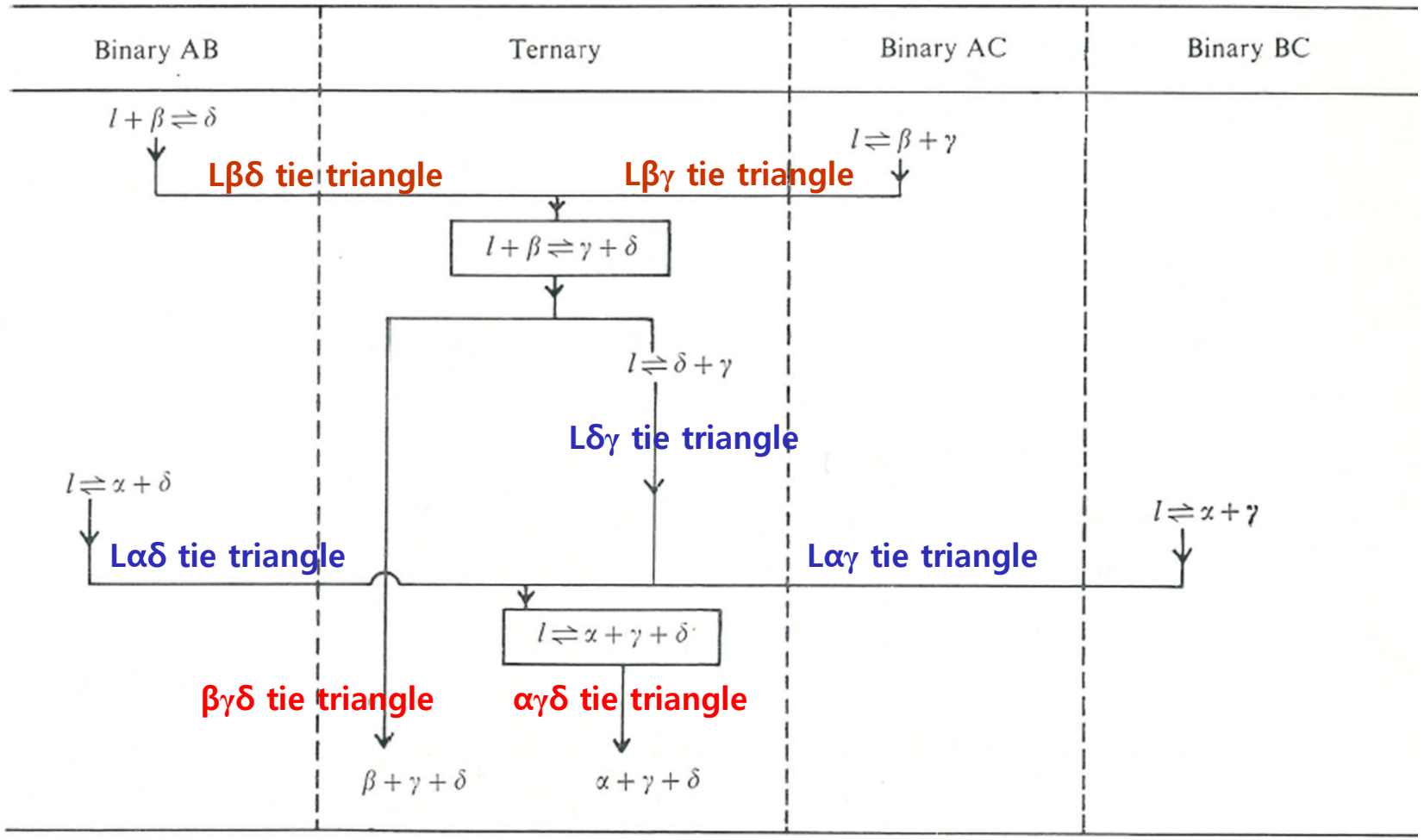


Fig. 189. Ternary system involving an incongruently-melting binary intermediate phase.

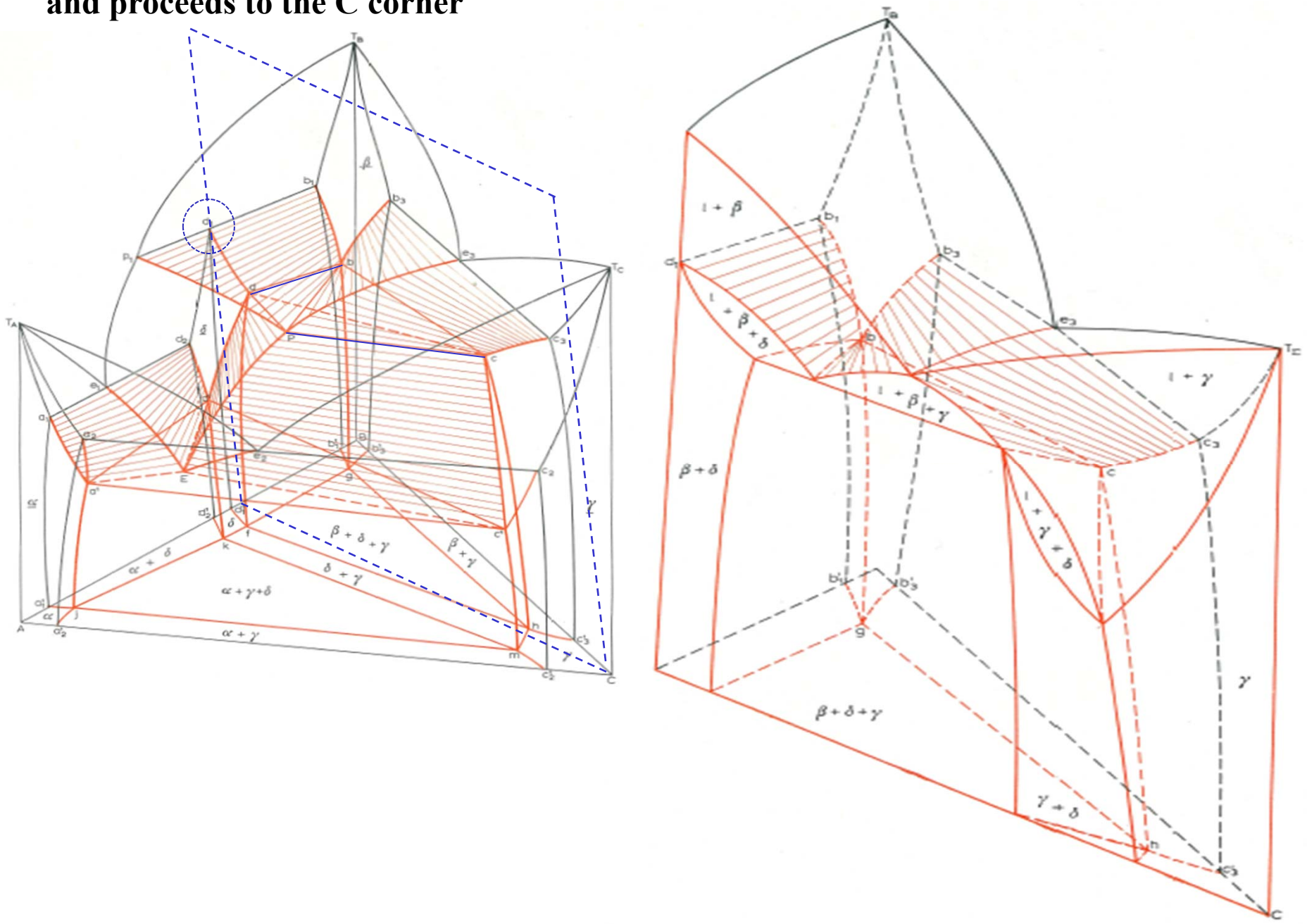
Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

Quasi-peritectic diagram and ternary eutectic diagram

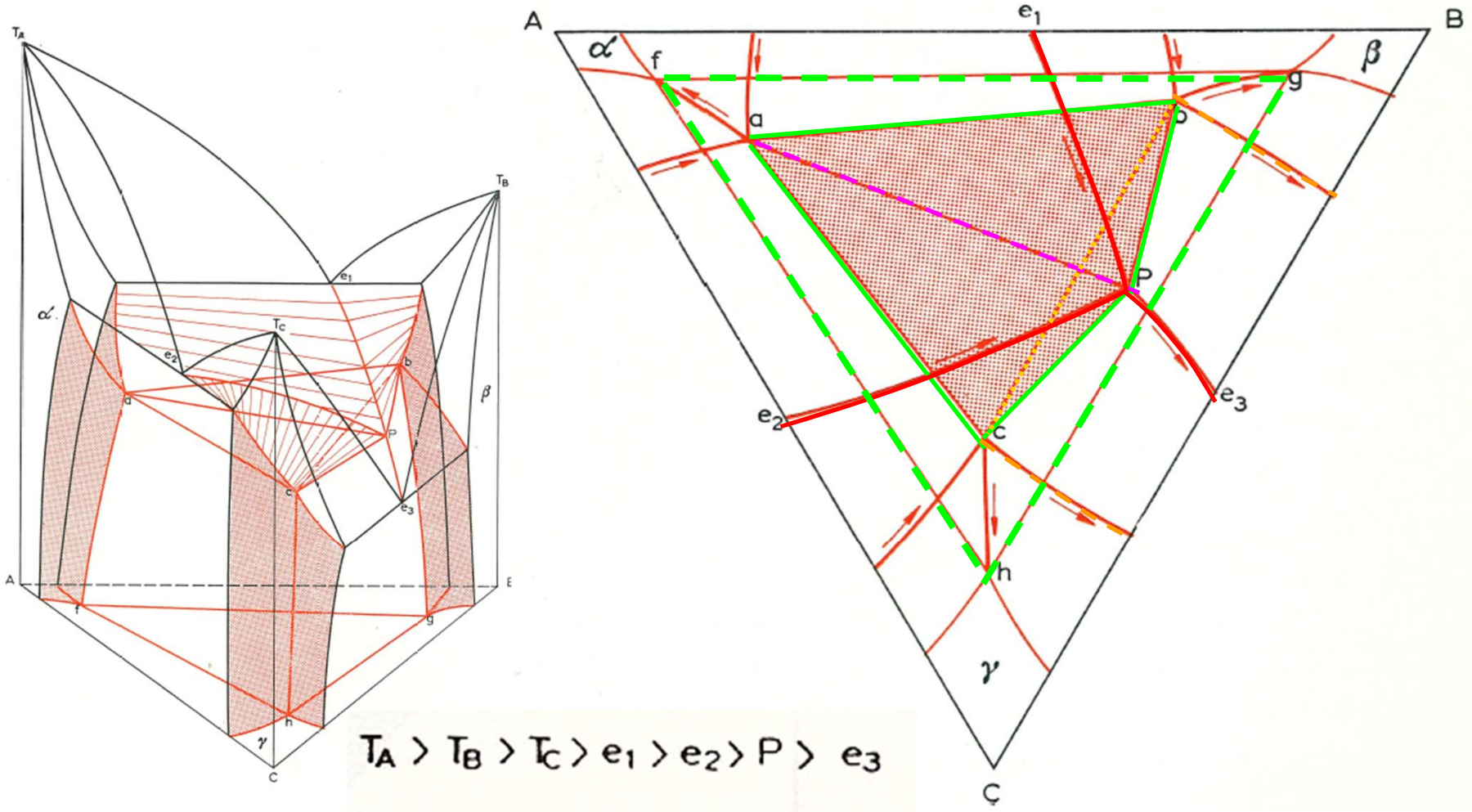


Vertical section **which intersects point d1 on the AB binary, the tie lines db and Pc, and proceeds to the C corner**

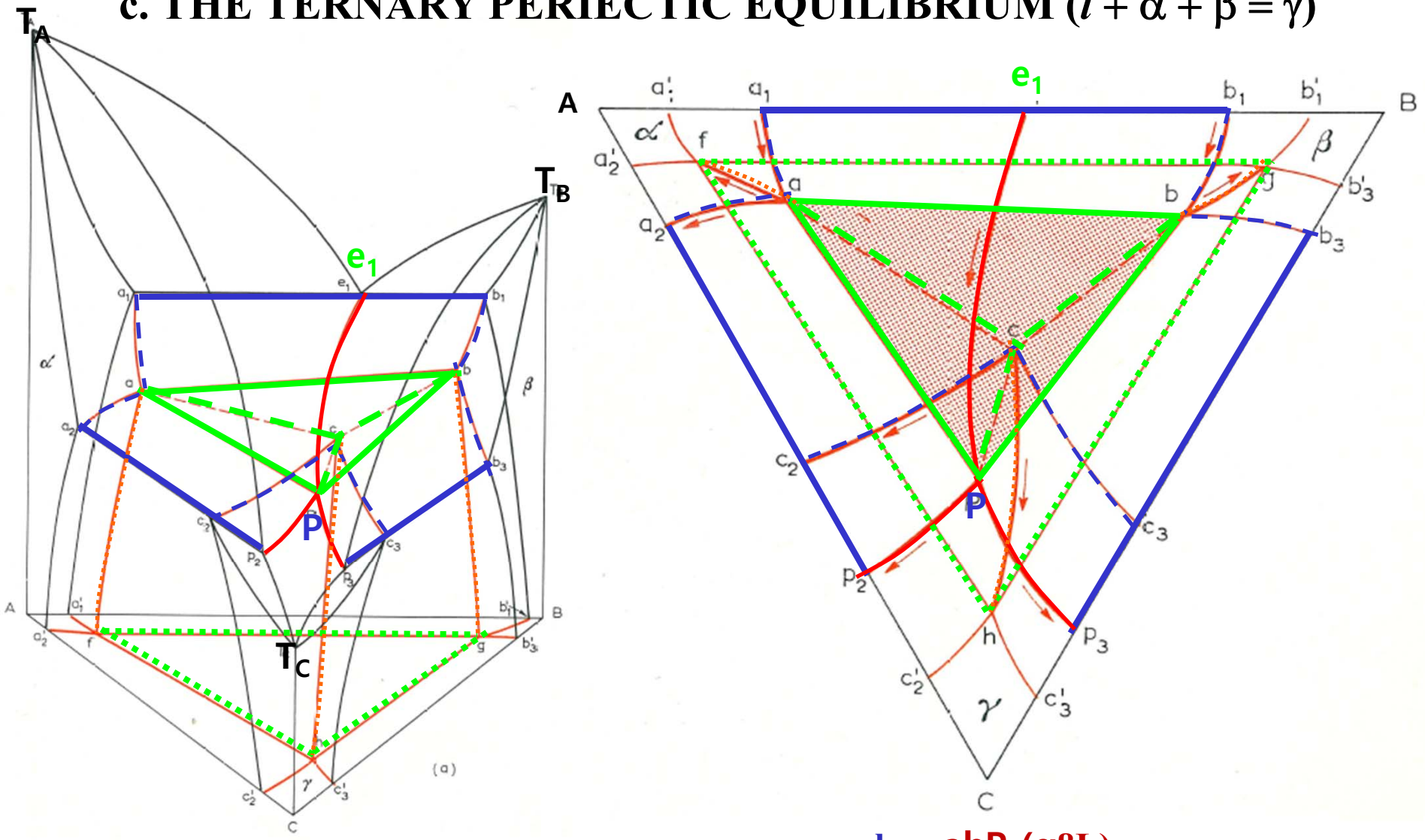


10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

Fig. 191. The ternary quasi-peritectic system formed when all three binaries are eutectics. (a) Space model; (b) projection on the concentration triangle.



c. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)

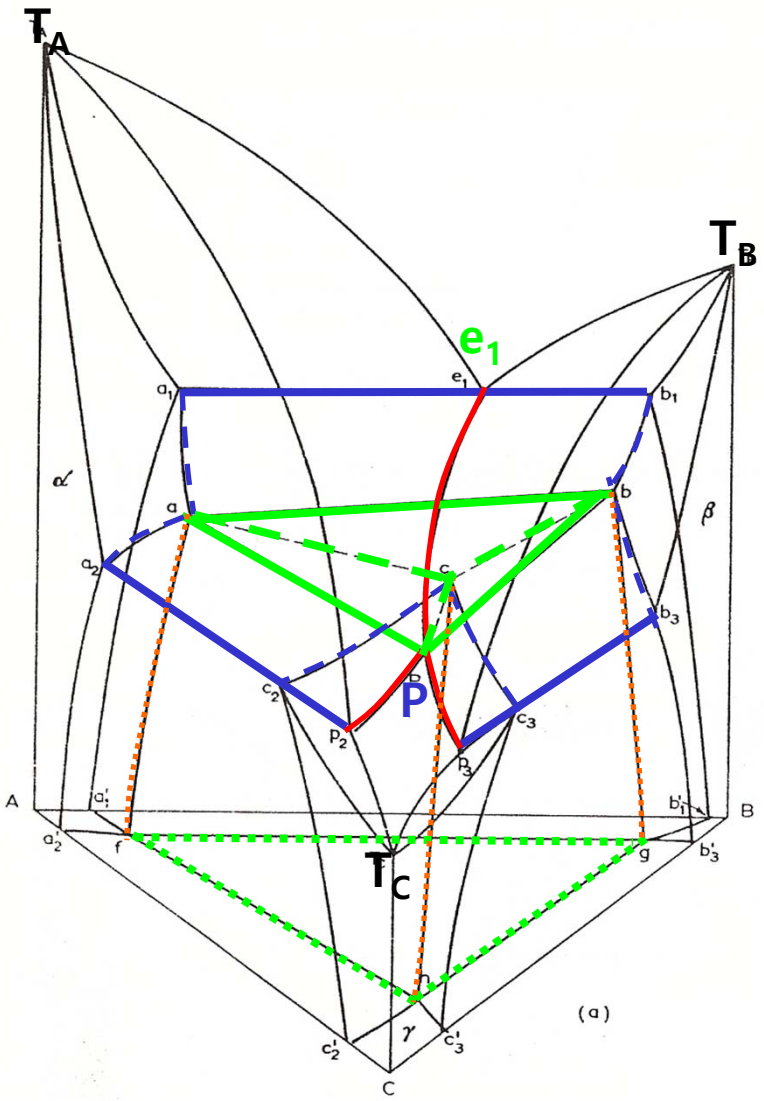


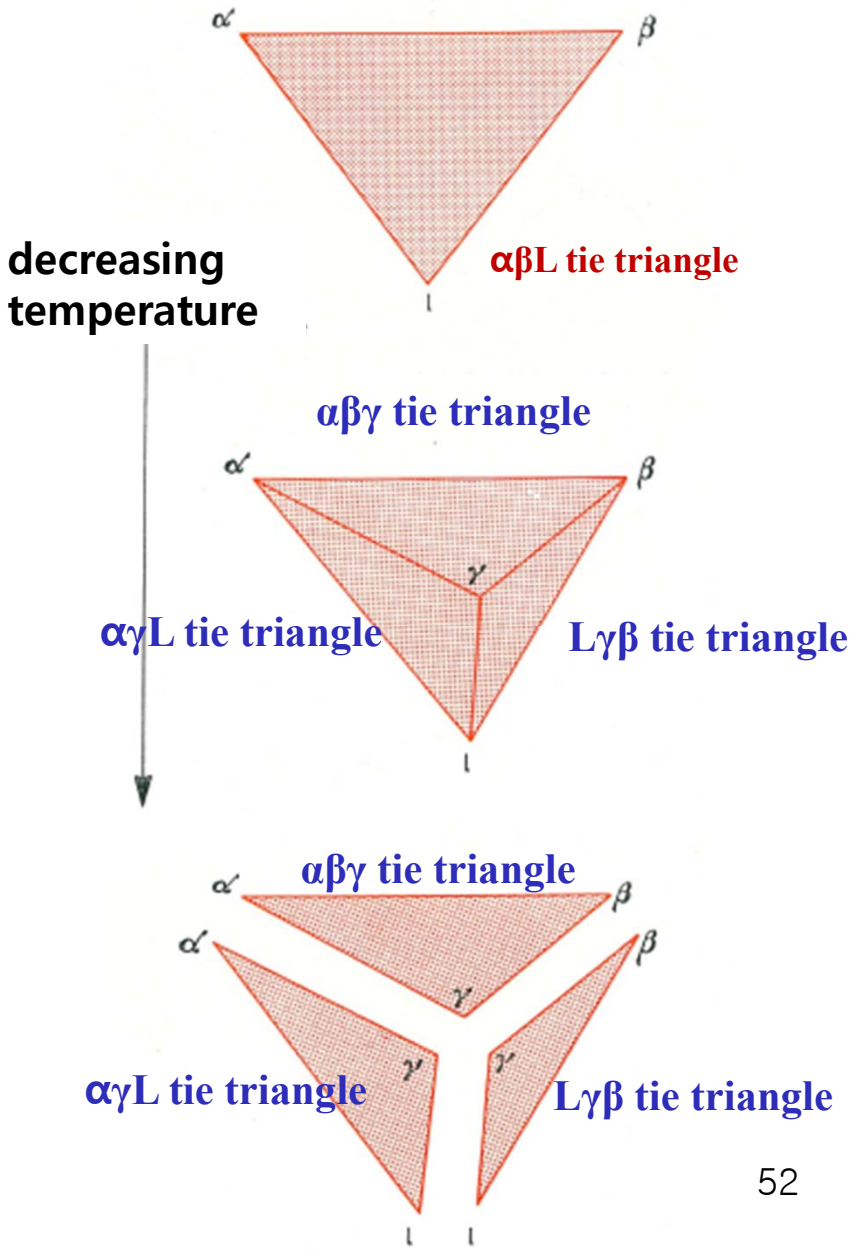
$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

$\underline{a_1 e_1 b_1} \rightarrow abP\ (\alpha\beta L)$

$aPc(\alpha\gamma L) \rightarrow \underline{a_2 c_2 P_2}\ /\ Pcb(L\gamma\beta) \rightarrow \underline{P_3 c_3 b_3}\ /\ abc(\alpha\beta\gamma) \rightarrow fgh\ (\alpha\beta\gamma)$

10.4. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)



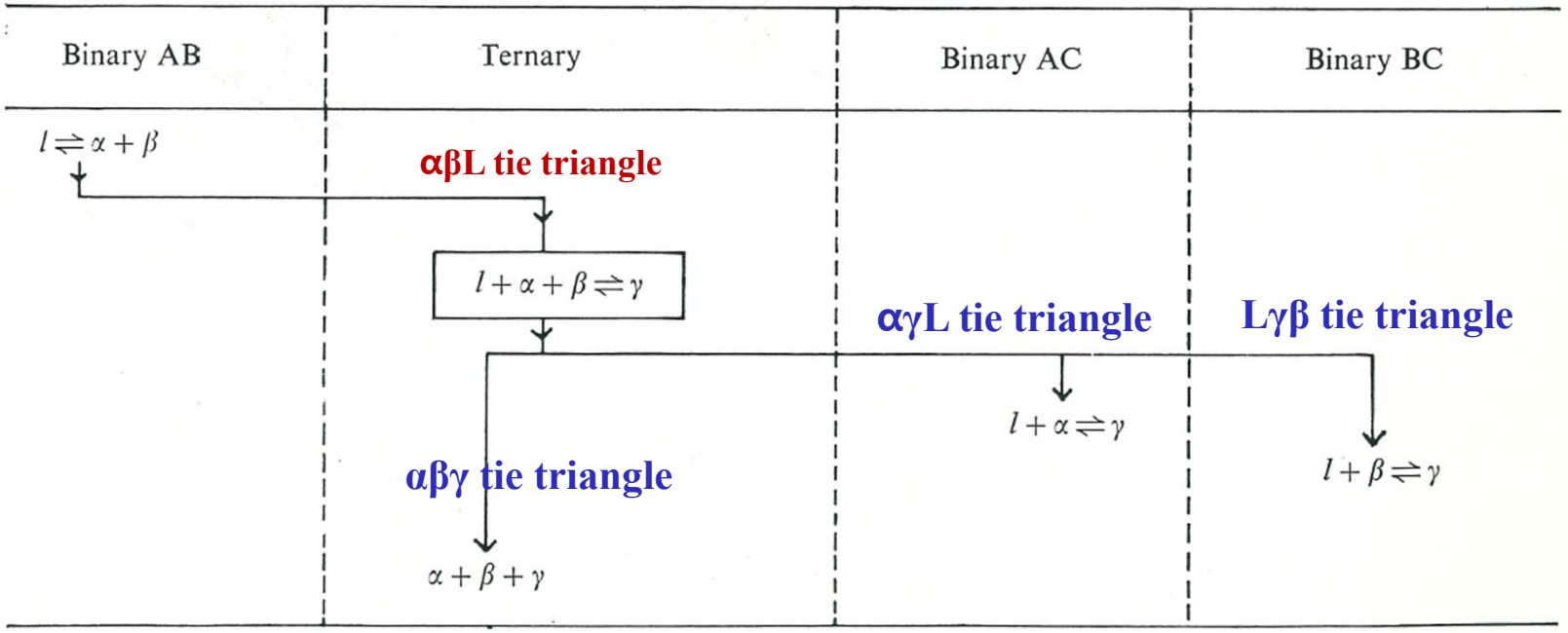


$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

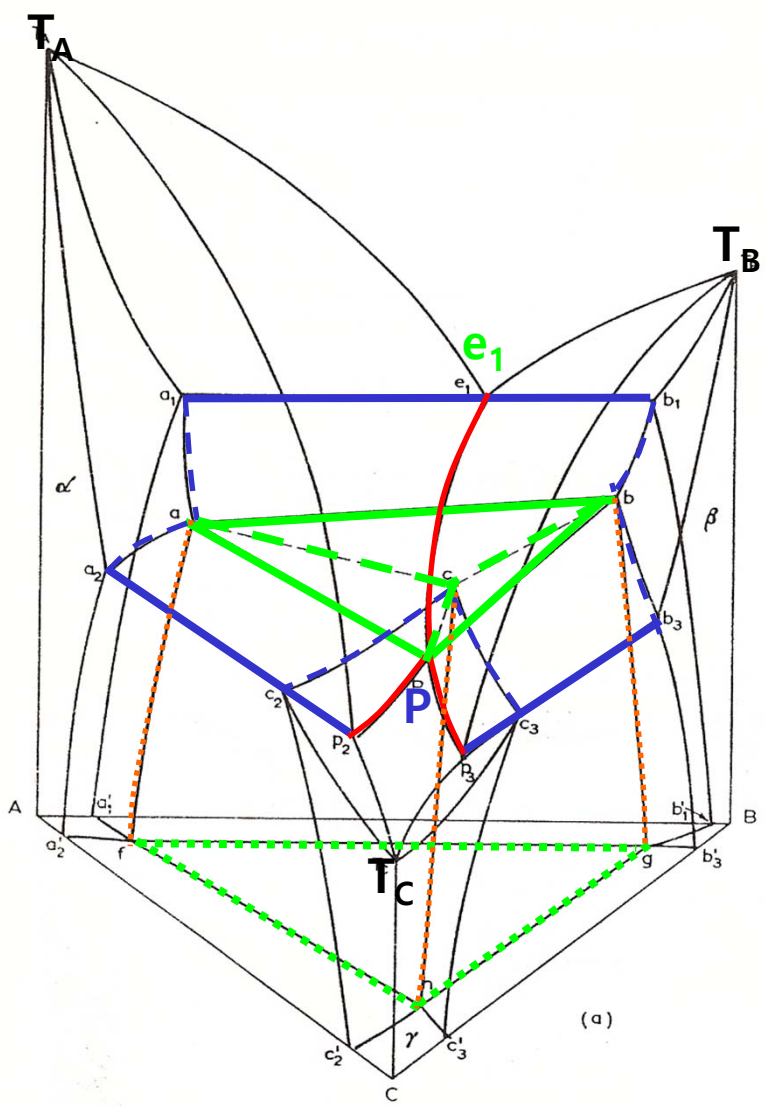
Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

TERNARY PERITECTIC EQUILIBRIUM $l+\alpha+\beta \rightleftharpoons \gamma$

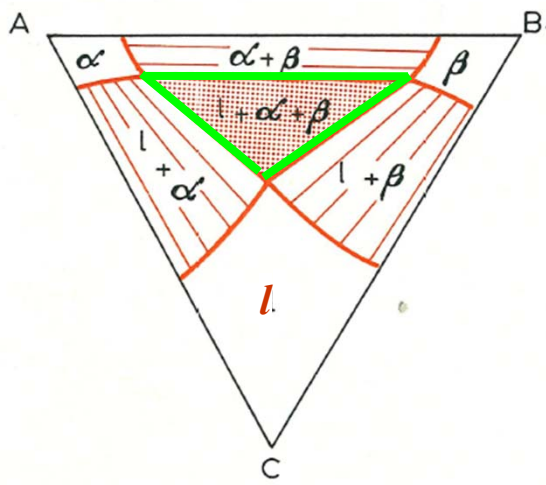


10.4. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)

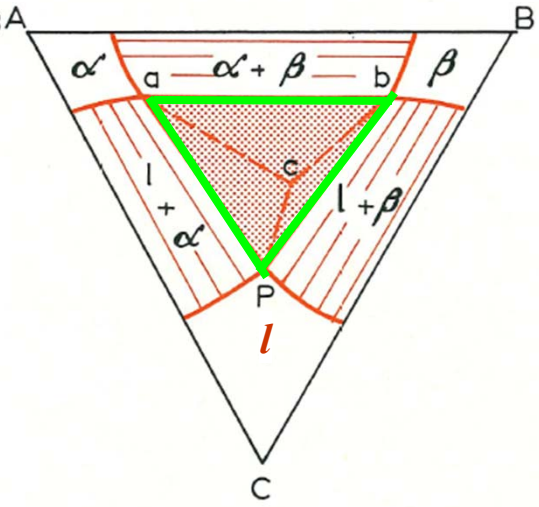


$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

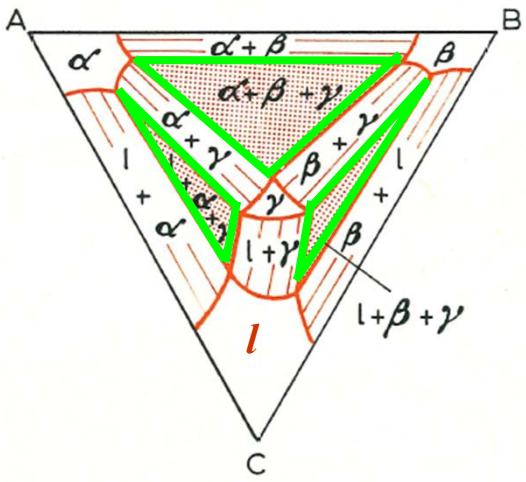
Isothermal section



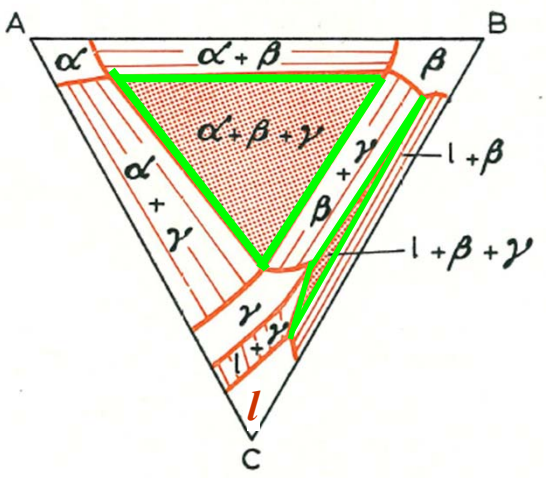
$e_1 > T > P$



$T = P$

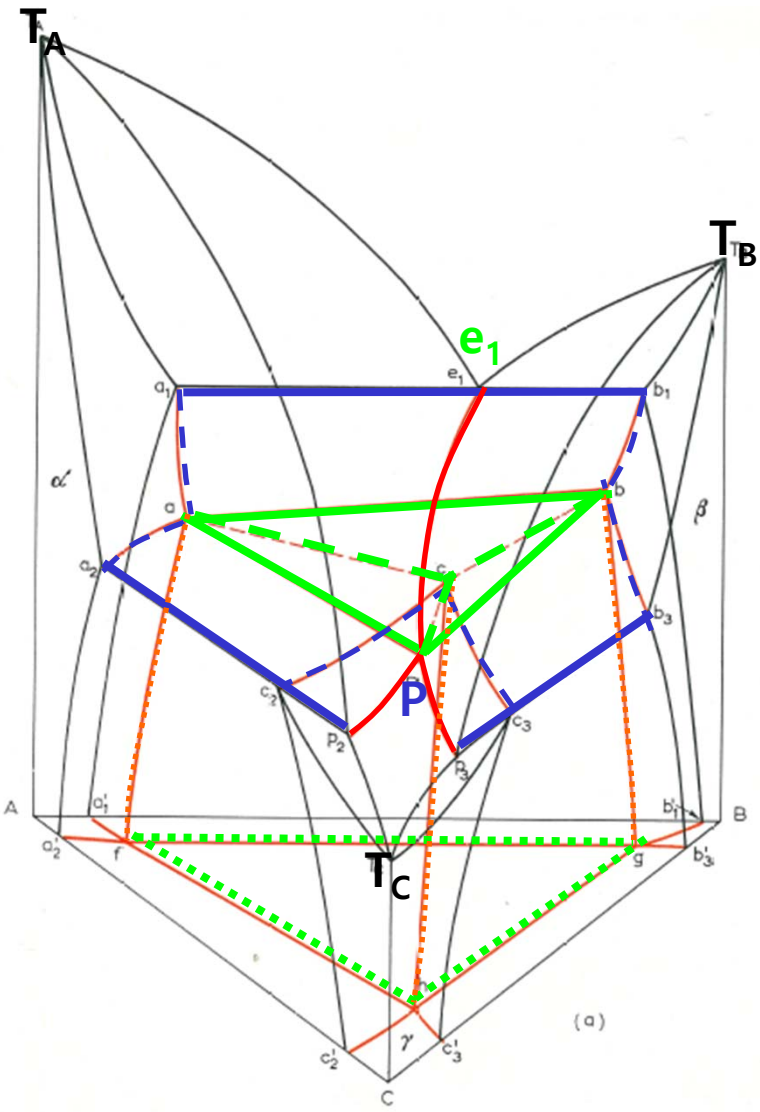


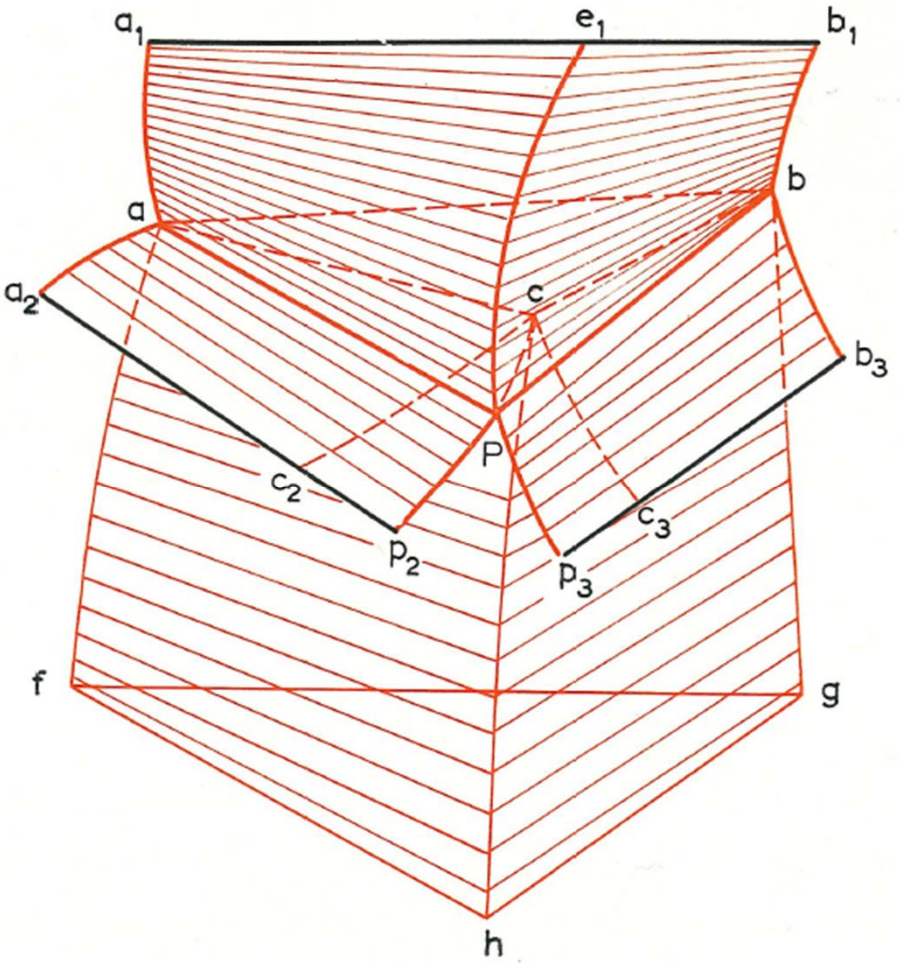
$P > T > P_2$



$P_2 > T > P_3$

10.4. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)





$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

The ternary peritectic four-phase plane as the junction of four tie triangles

10.4. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)