

12 - Sistemas ternários isomorfos

- * Sistemas ternários => 3 componentes
- * 4 variáveis termodinâmicas independentes (P,T,X1,X2)
- * $X_1 + X_2 + X_3 = 1$

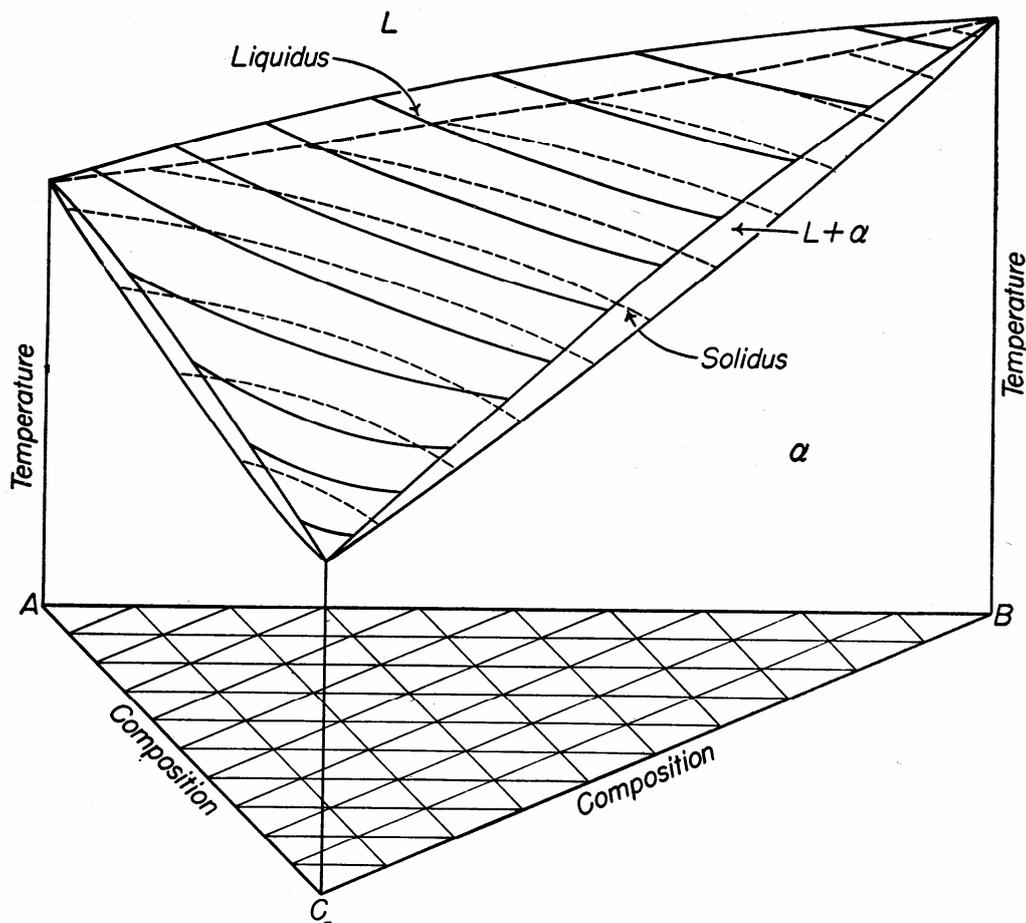


FIG. 12-4. Temperature-composition space diagram of a ternary isomorphous system.

- * linha liquidus => superfície liquidus
- * linha solidus => superfície solidus
- * área de estabilidade de fase => volume de estabilidade

12.1 - O triângulo de Gibbs

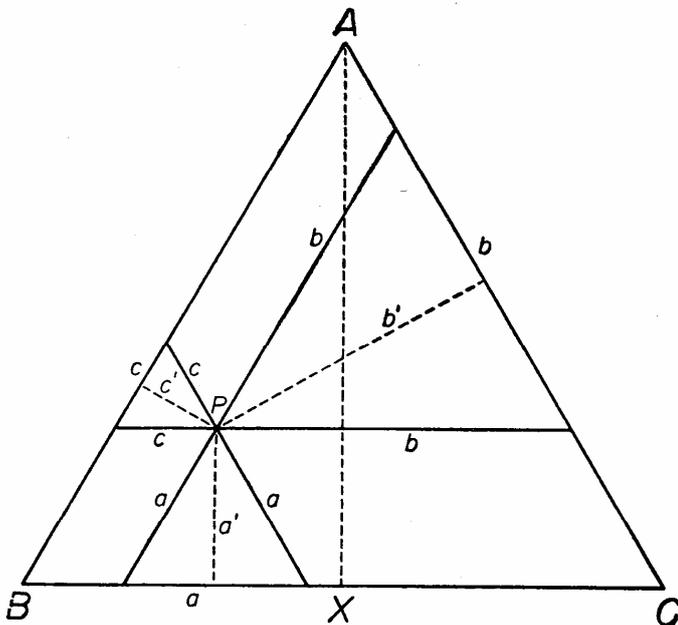


FIG. 12-1. The Gibbs triangle.

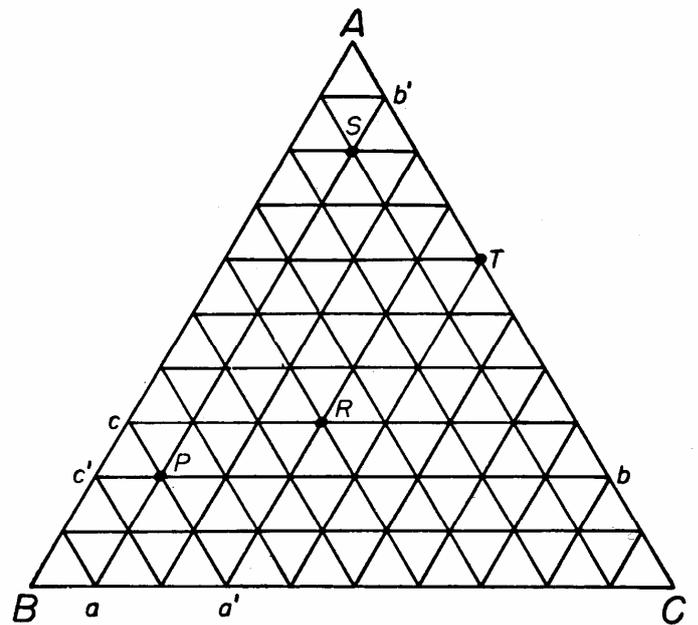


FIG. 12-2

$$a + b + c = AB = AC = BC = 1 \text{ (100\%)}$$

12.2 - As linhas de ligação (tie-lines)

- * tie-lines => isobáricas e isotérmicas
- * As tie-lines não estão confinadas em uma seção TxX. Elas ocorrem como um conjunto de linhas de direções variáveis preenchendo o espaço bifásico tridimensional.
- * Duas tie-lines nunca podem se cruzar.
- * Elas devem ser medidas experimentalmente.

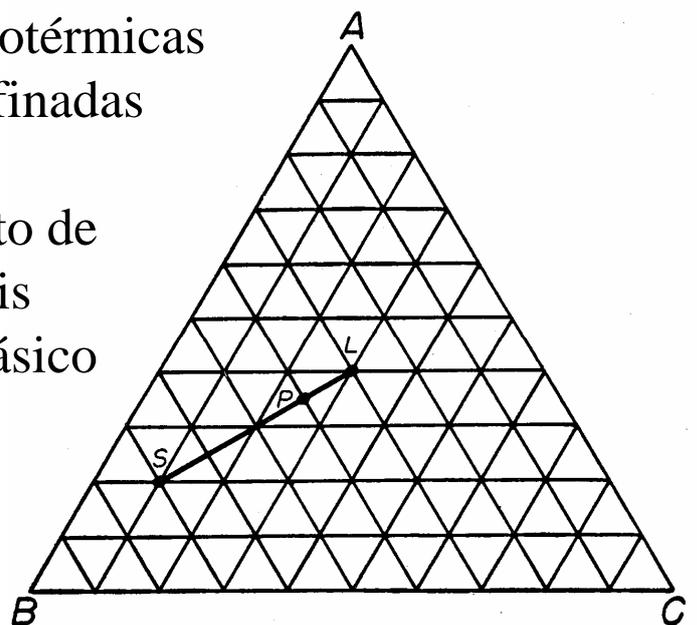


FIG. 12-3

12.3 - Seções isotérmicas

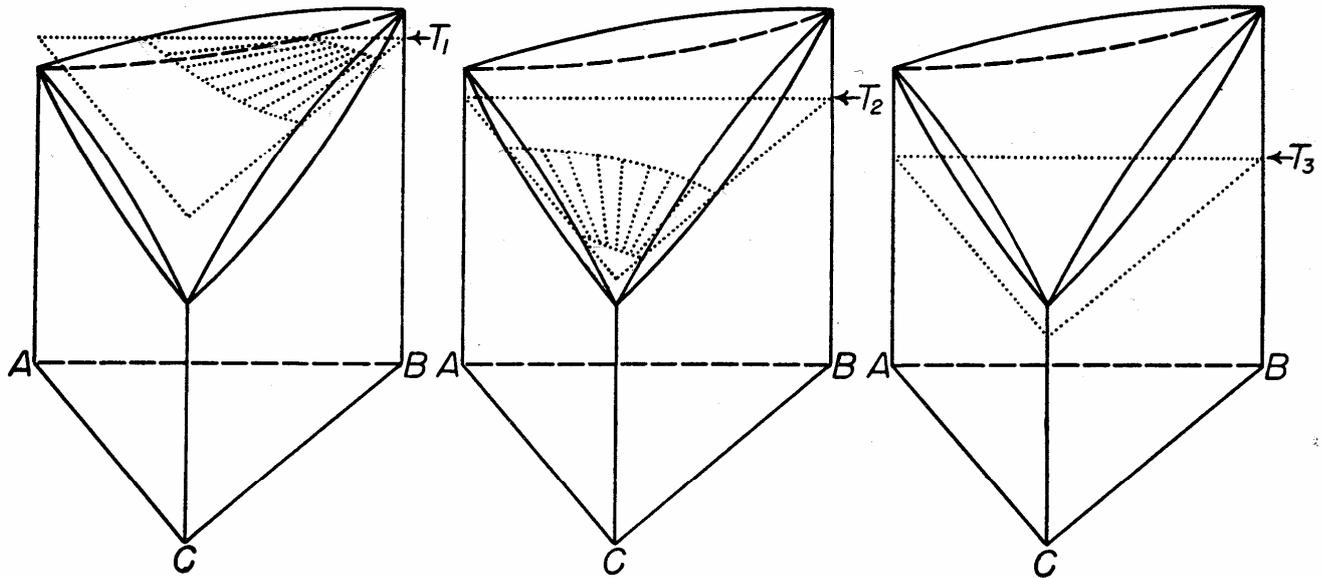


FIG. 12-5. Development of isotherms shown in Fig. 12-6.

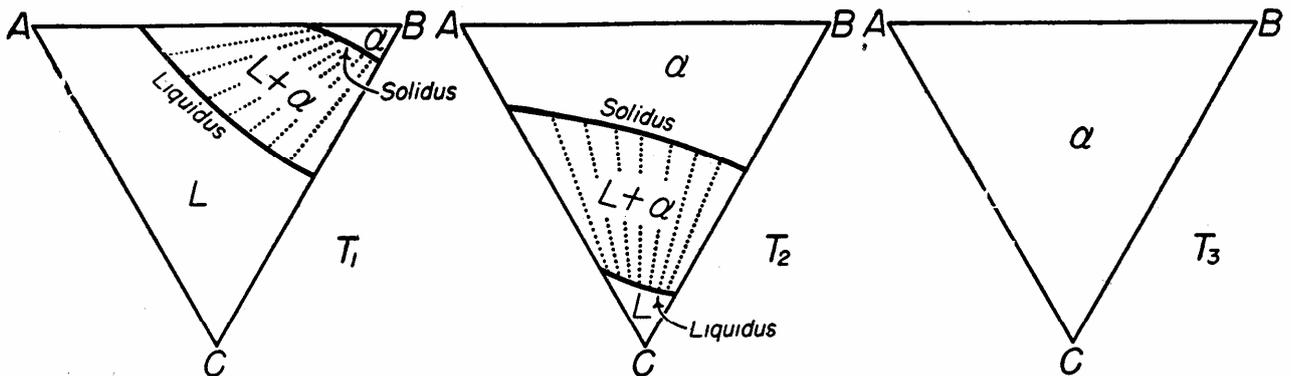


FIG. 12-6. Isotherms through the ternary isomorphous phase diagram, as derived from Fig. 12-5.

- * A forma mais comum de representar diagramas ternários é através de seções isotérmicas.
- * Uma seqüência de seções isotérmicas podem ser sobrepostas em um plano, dando origem a projeções de superfícies tais como a projeção liquidus ao lado.

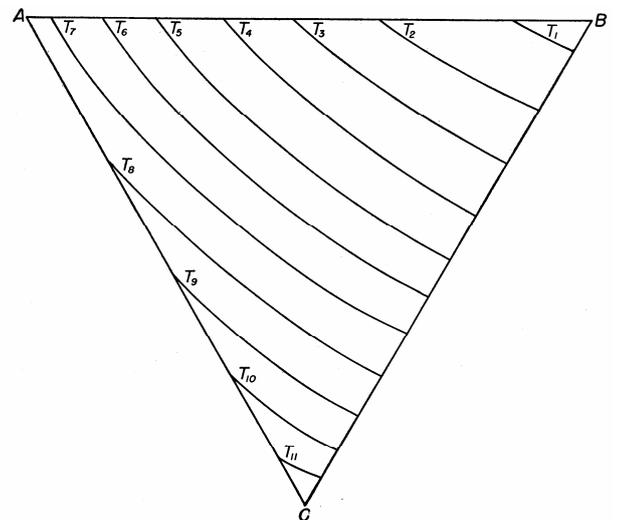


FIG. 12-7. Liquidus projection of the diagram shown in Fig. 12-4.

12.4 - Seções verticais (isopleths)

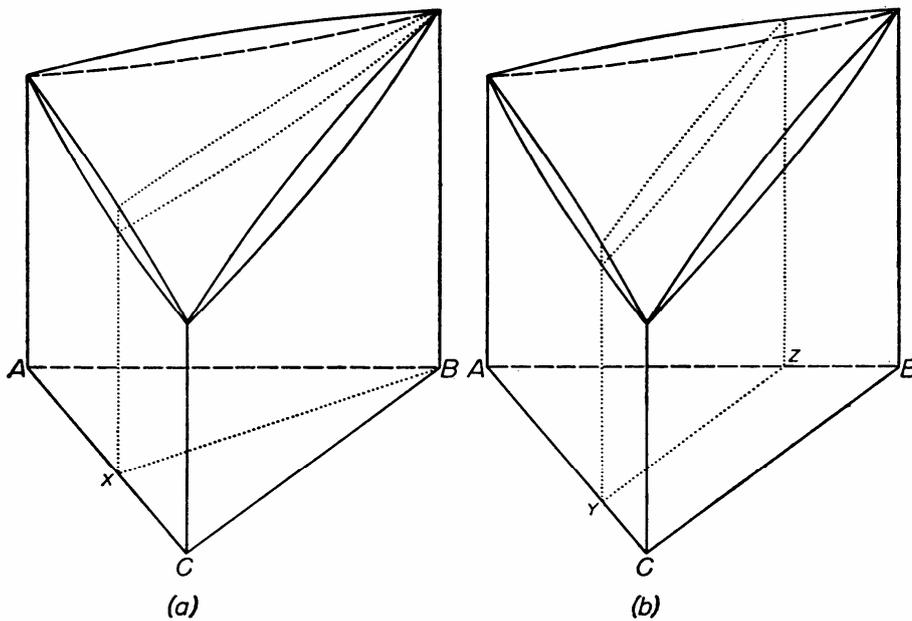


FIG. 12-8. Development of the isopleths shown in Fig. 12-9.

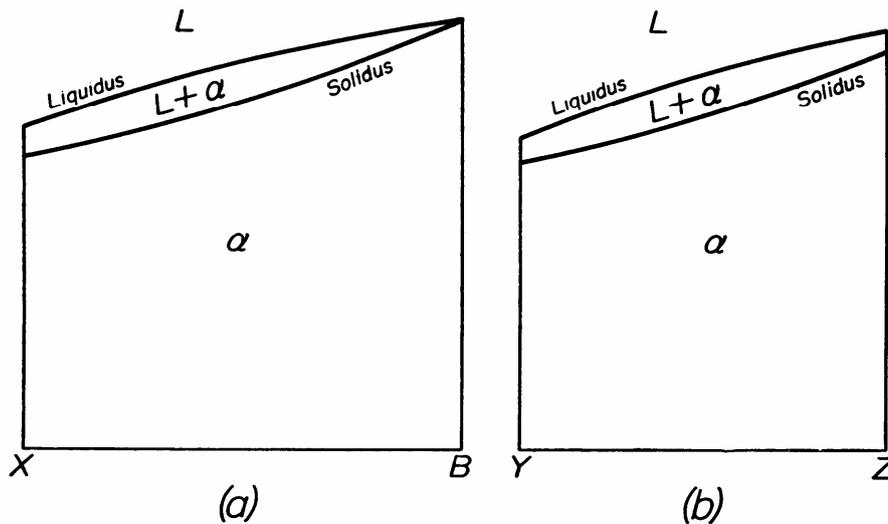


FIG. 12-9. Isopleths through an isomorphous system, derived from Fig. 12-8.

- * Linhas xB e $yz \Rightarrow$ lugares geométricos de ligas com constantes: (a) relação C/A ; e (b) teor do componente A .
- * Podem ser lidas as temperaturas liquidus e solidus de qualquer liga, mas não podem ser registrados os equilíbrios das fases uma vez que as tie-lines não estão contidas no plano de corte (caso especial \Rightarrow seções quase-binárias).

12.5 - Aplicação da regra das fases

$$P + F = C + 1$$

(pressão constante)

- regiões monofásicas:
 $P = 1; C = 3; F = 3$

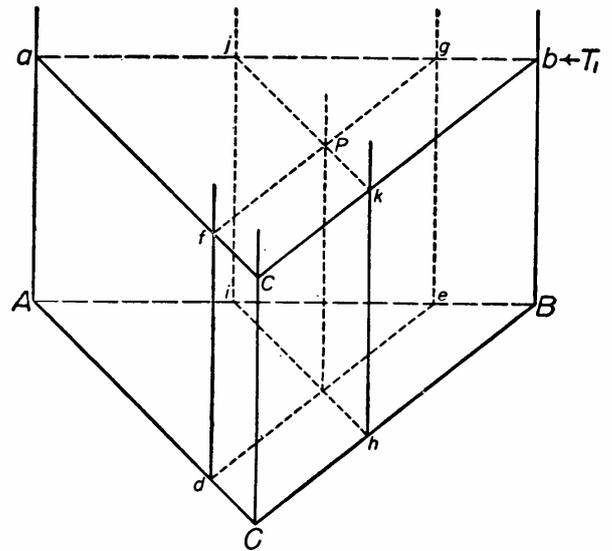


FIG. 12-10

- regiões bifásicas:
 $P = 2; C = 3; F = 2$

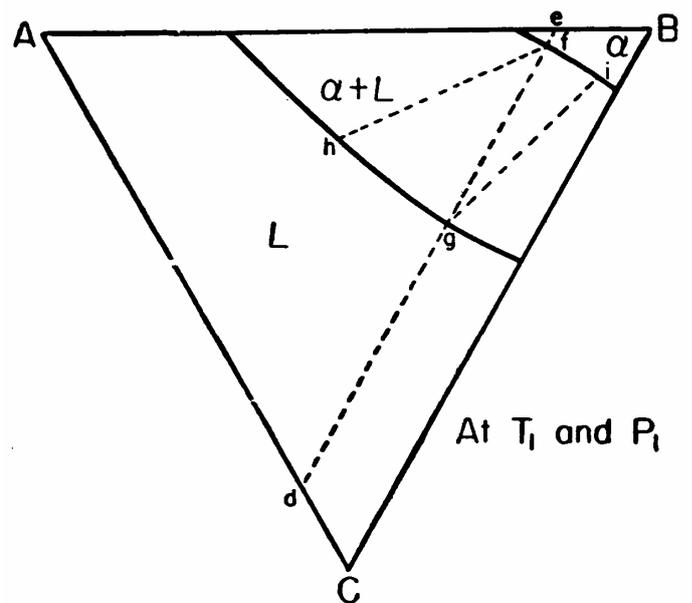


FIG. 12-11

12.6 - Máximos e mínimos

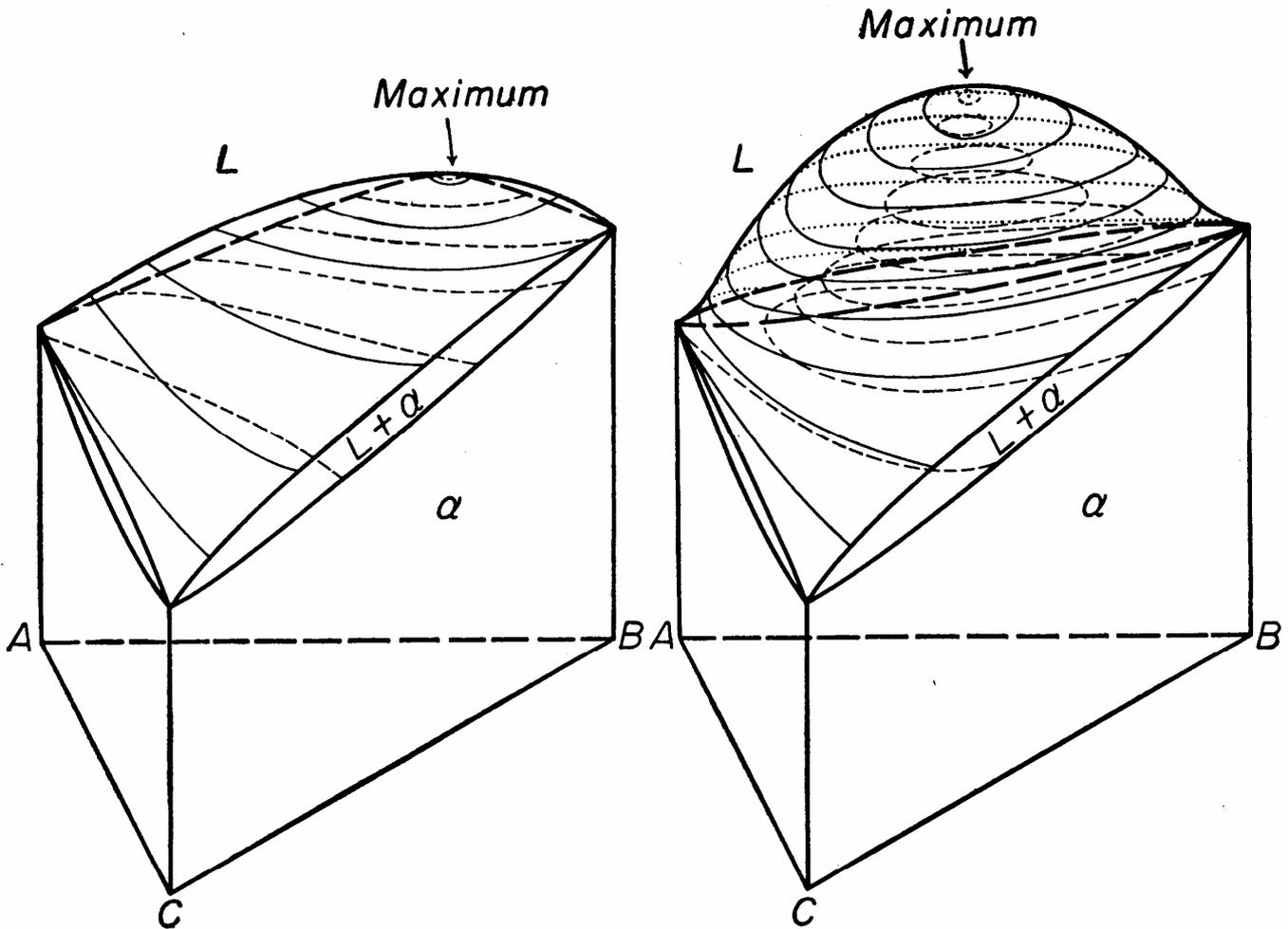


FIG. 12-17. Isomorphous ternary system with a maximum melting point in the binary system AB .

FIG. 12-18. Isomorphous ternary system with a maximum melting point in ternary space.

Exercícios:

- 1 - Desenhe esquematicamente seções isotérmicas correspondentes às temperaturas dos contornos da superfície liquidus nas figuras acima.
- 2 - Desenhe seções verticais esquemáticas correspondentes à figura 12-17: (a) à partir de C passando pelo máximo no binário AB ; (b) de $50\%B + 50\%C$ até o máximo no binário AB ; (c) ao longo da linha de B constante e igual a 50% ; (d) ao longo da linha C/A constante e igual a 1 .

12.7 - Resfriamento em equilíbrio

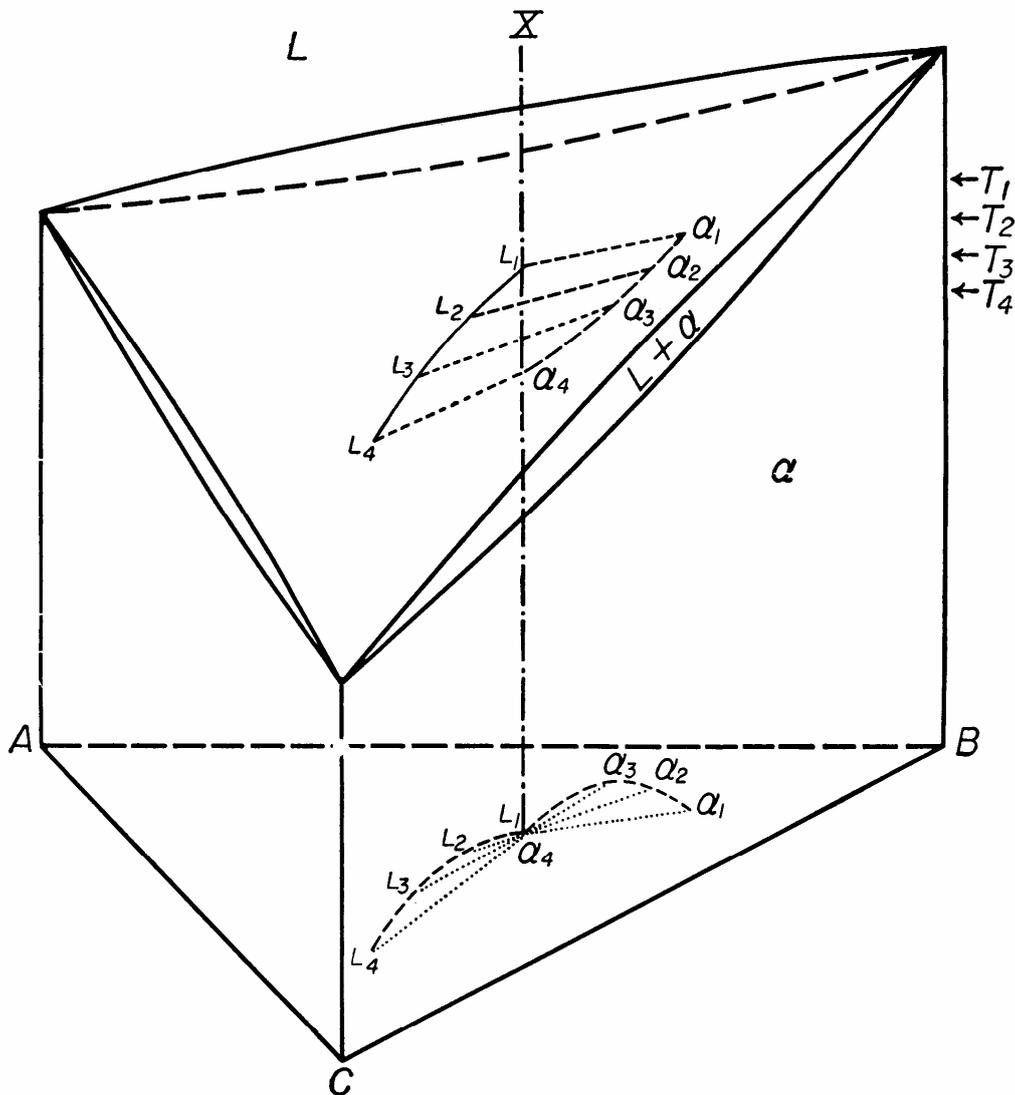


FIG. 12-13. Path of composition change of the liquid L and solid α phase during the freezing of a solid-solution alloy.

todas as tie-lines passam por X

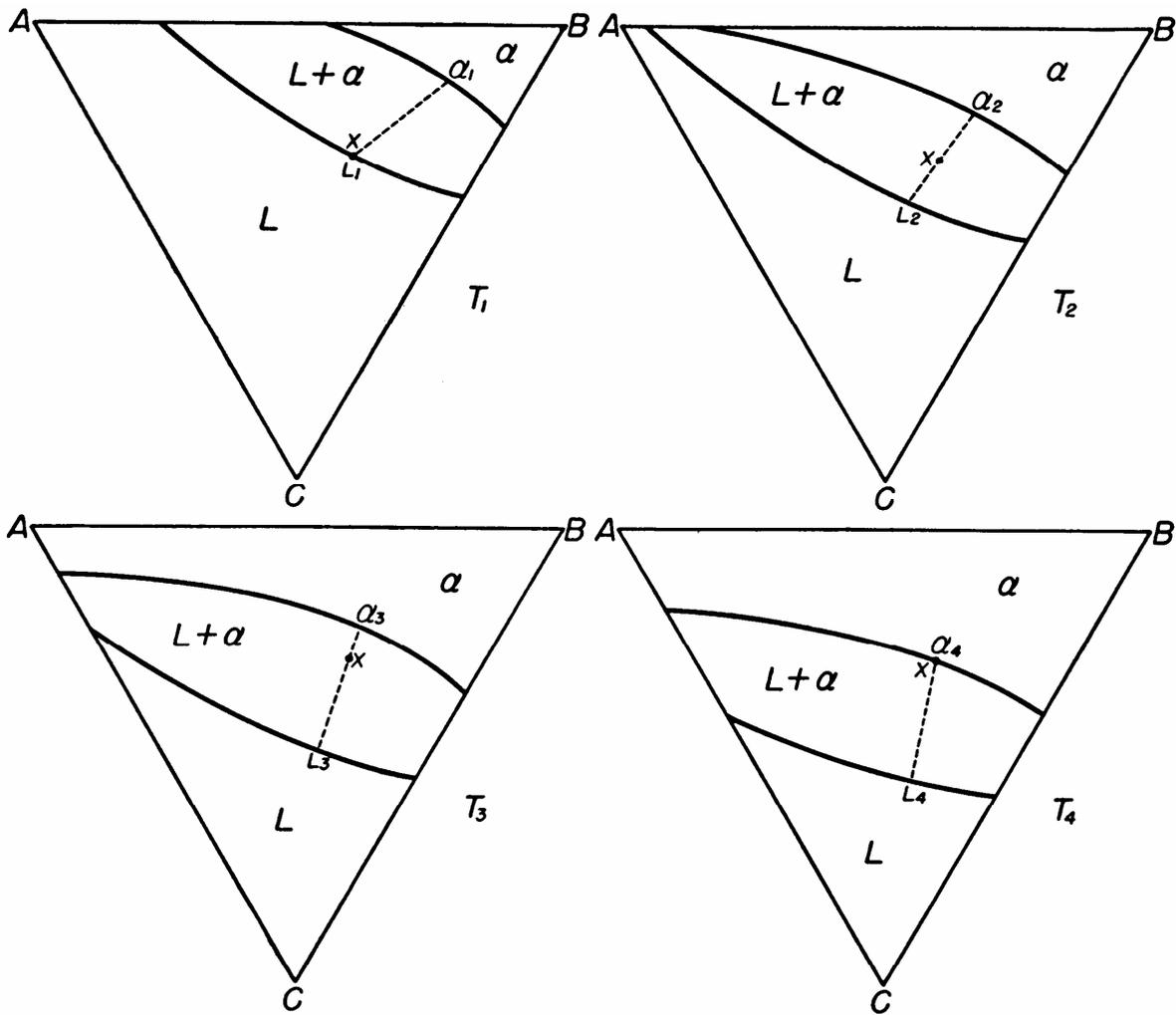


FIG. 12-14. Illustrating the progress of the "equilibrium freezing" of a ternary isomorphous alloy.

13 - Equilíbrio ternário de três fases

$$P + F = C + 1$$

(pressão constante)

regiões trifásicas:

$$P = 3; \quad C = 3; \quad F = 1$$

13.1 - Triângulos de equilíbrio (tie-triangles)

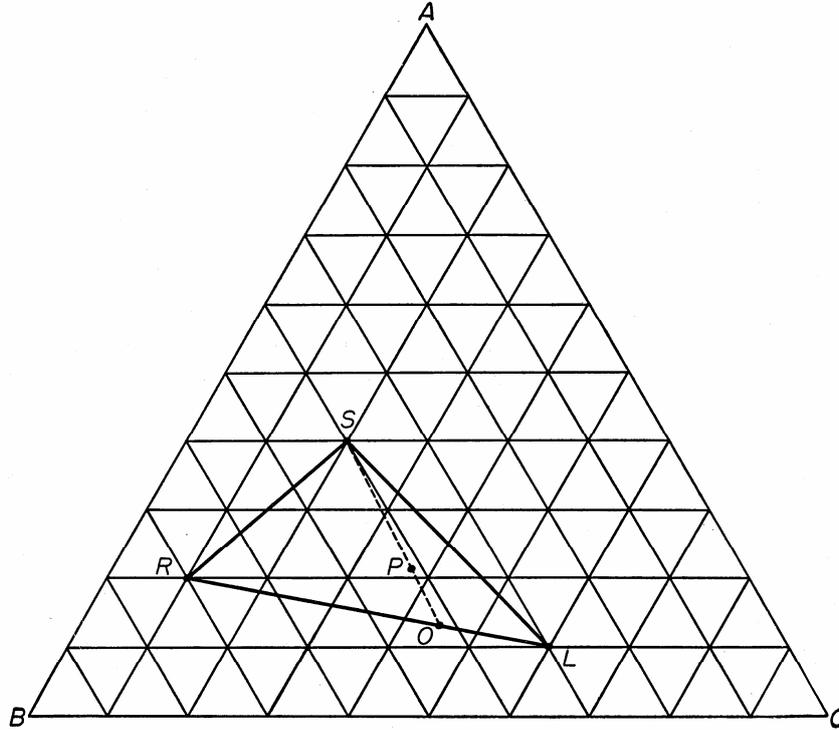


FIG. 13-1. Analysis of a tie-triangle.

- * Toda mistura de três fases resultará em uma liga cuja composição global estará localizada no interior do triângulo formado pela união entre os pontos que designam as composições das fases em equilíbrio.
- * Aplicação da regra da alavanca: a alavanca é o triângulo de equilíbrio e o apoio (ponto de fulcro) é o ponto P correspondente à composição global da liga.

$$\% S = \frac{PO}{SO} \times 100$$

$$\% O = \frac{SP}{SO} \times 100$$

$$\% R = \frac{OL}{RL} \frac{SP}{SO} \times 100$$

$$\% L = \frac{RO}{RL} \frac{SP}{SO} \times 100$$

13.2 - Equilíbrio de 3 fases no modelo 3D

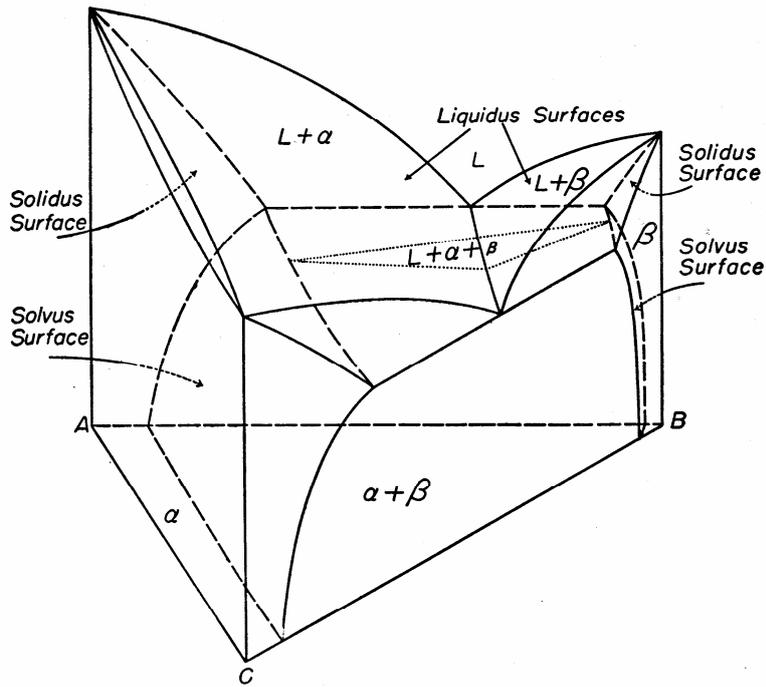


FIG. 13-2. Occurrence of three-phase equilibrium in a simple ternary system.

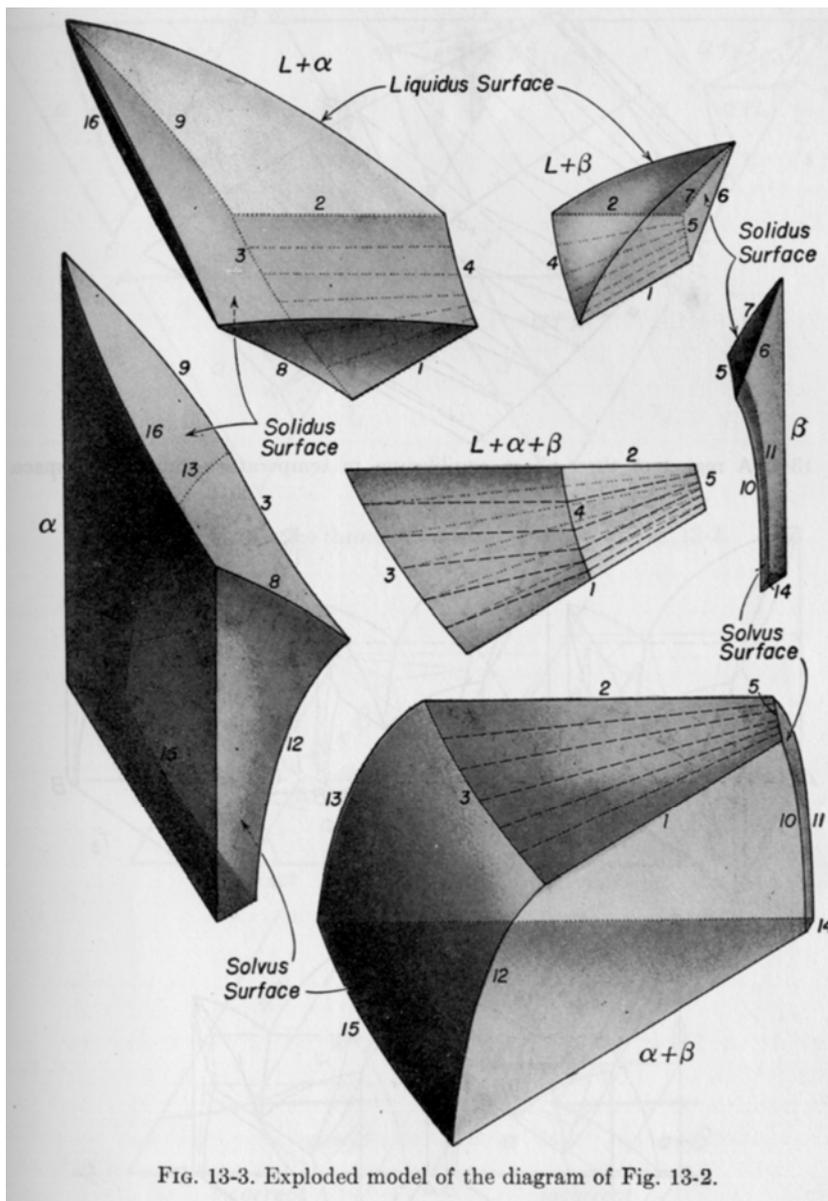


FIG. 13-3. Exploded model of the diagram of Fig. 13-2.

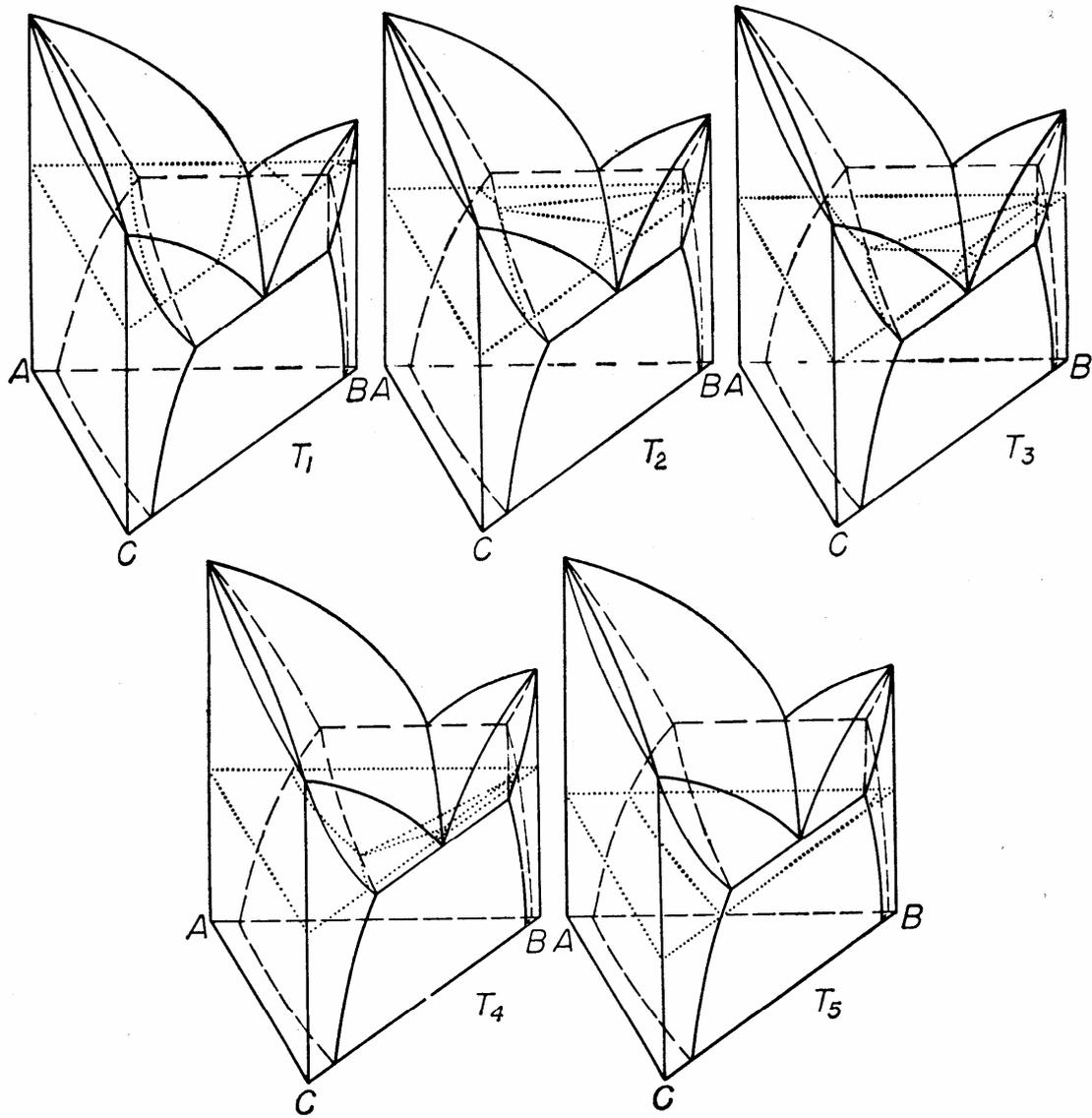


FIG. 13-5. Development of isotherms shown in Fig. 13-6.

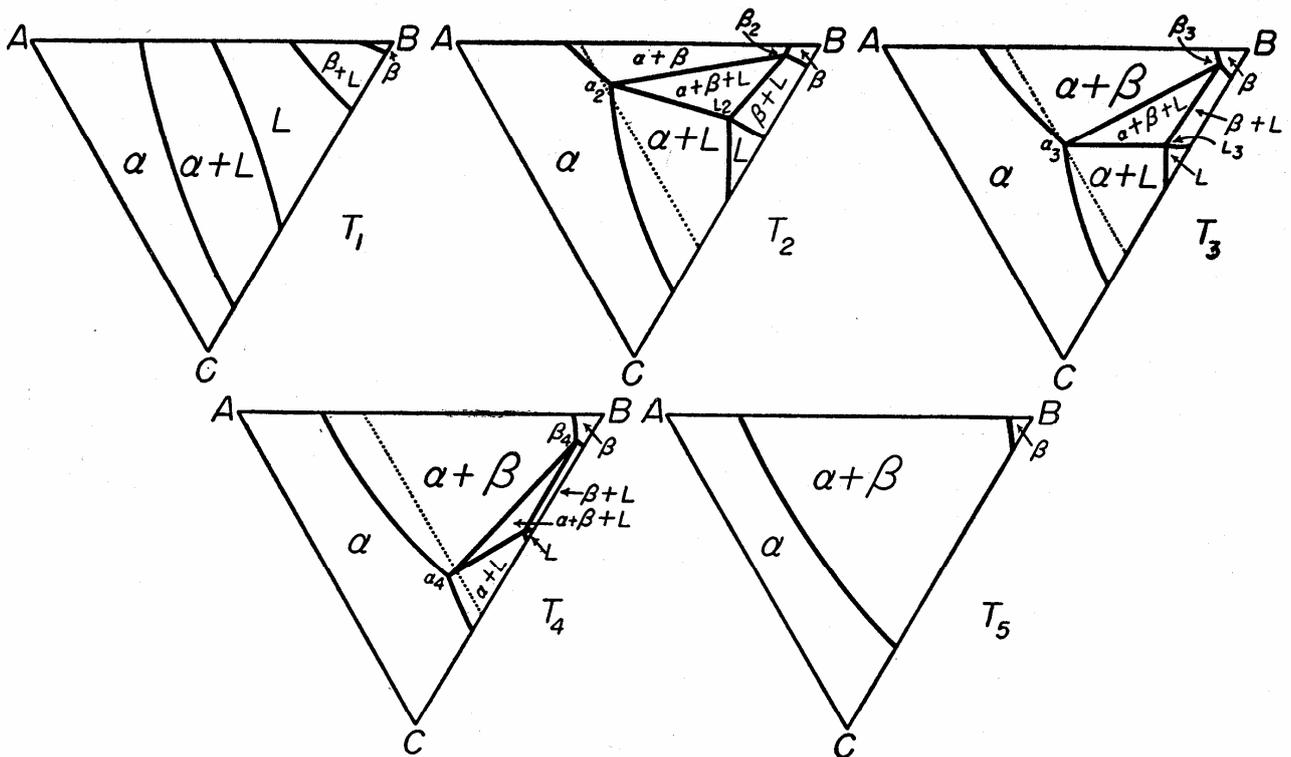


FIG. 13-6. Isotherms through the space diagram of Fig. 13-2.

13.3 - Resfriamento em equilíbrio

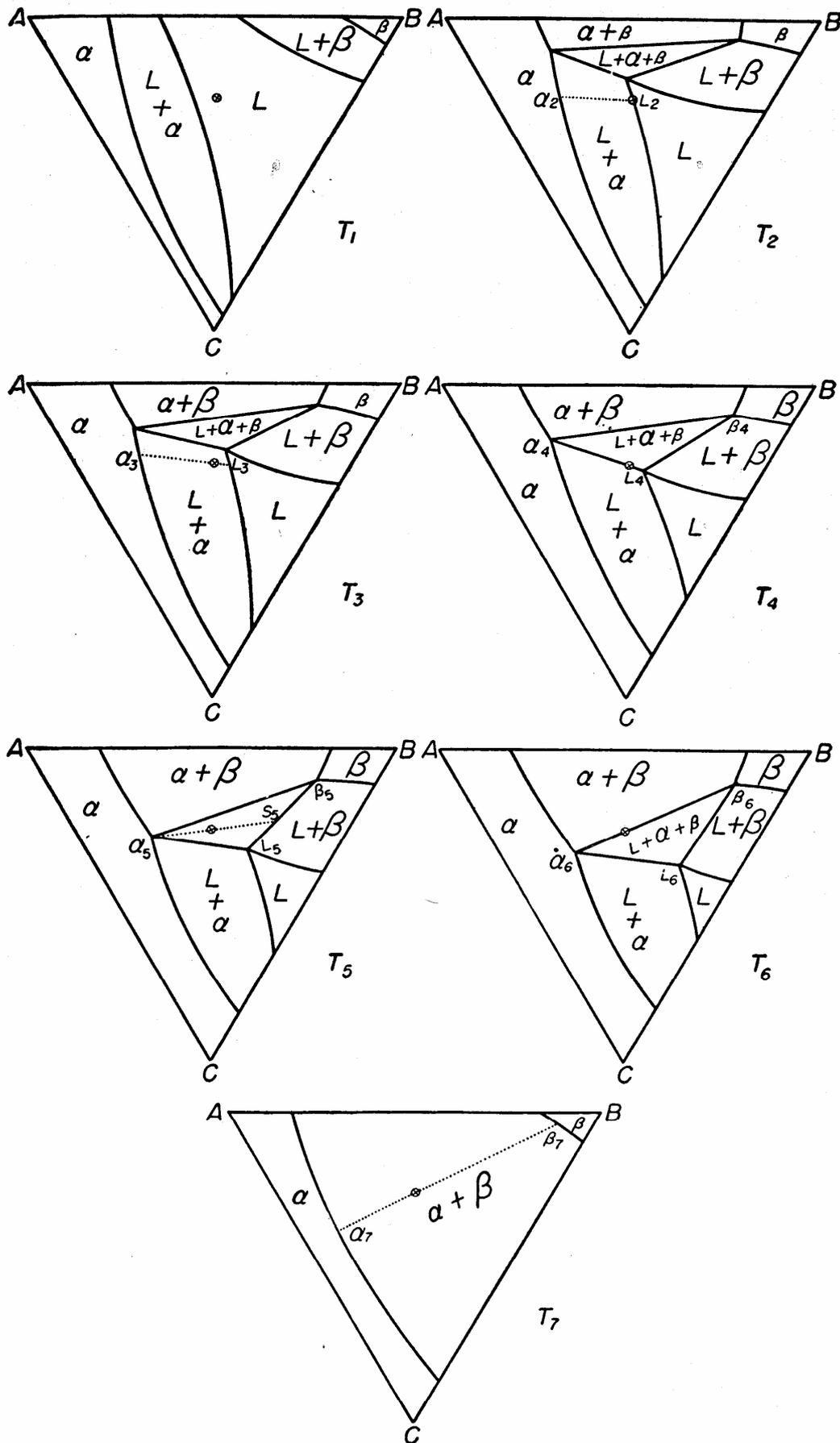


FIG. 13-8. Illustrating the sequence of equilibria involved in the freezing of an alloy whose gross composition is indicated by the circled cross in each isotherm.

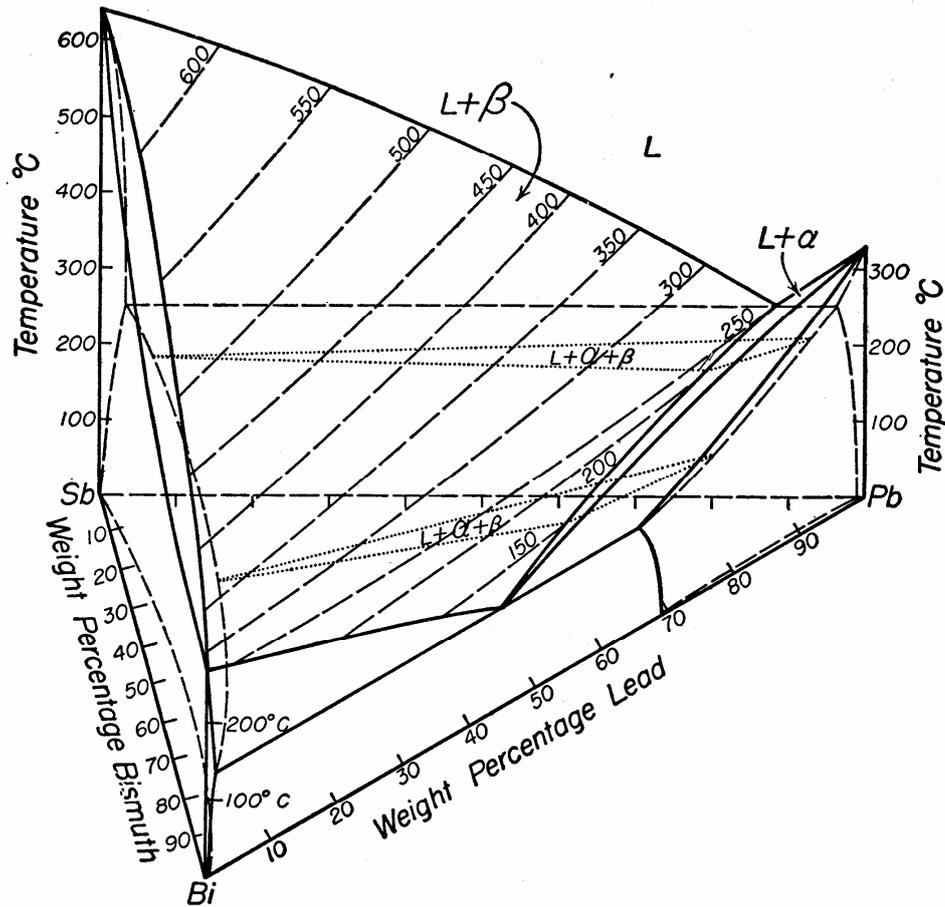


FIG. 13-10. Temperature-composition diagram of the system lead-bismuth-antimony.

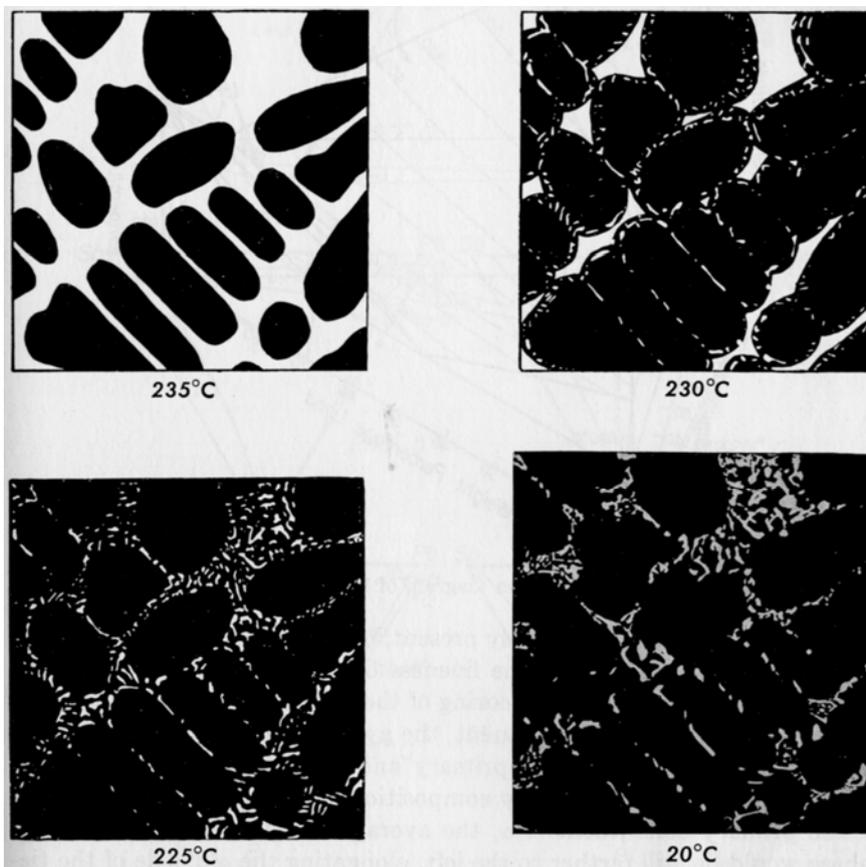


FIG. 13-9. Schematic representation of the progress of freezing of an alloy composed of 90% Pb + 5% Bi + 5% Sb, indicated by point *x* in Fig. 13-11. The first five pictures of the series are idealized sketches; the sixth picture is an actual photomicrograph of the alloy at room temperature. Magnification 100.

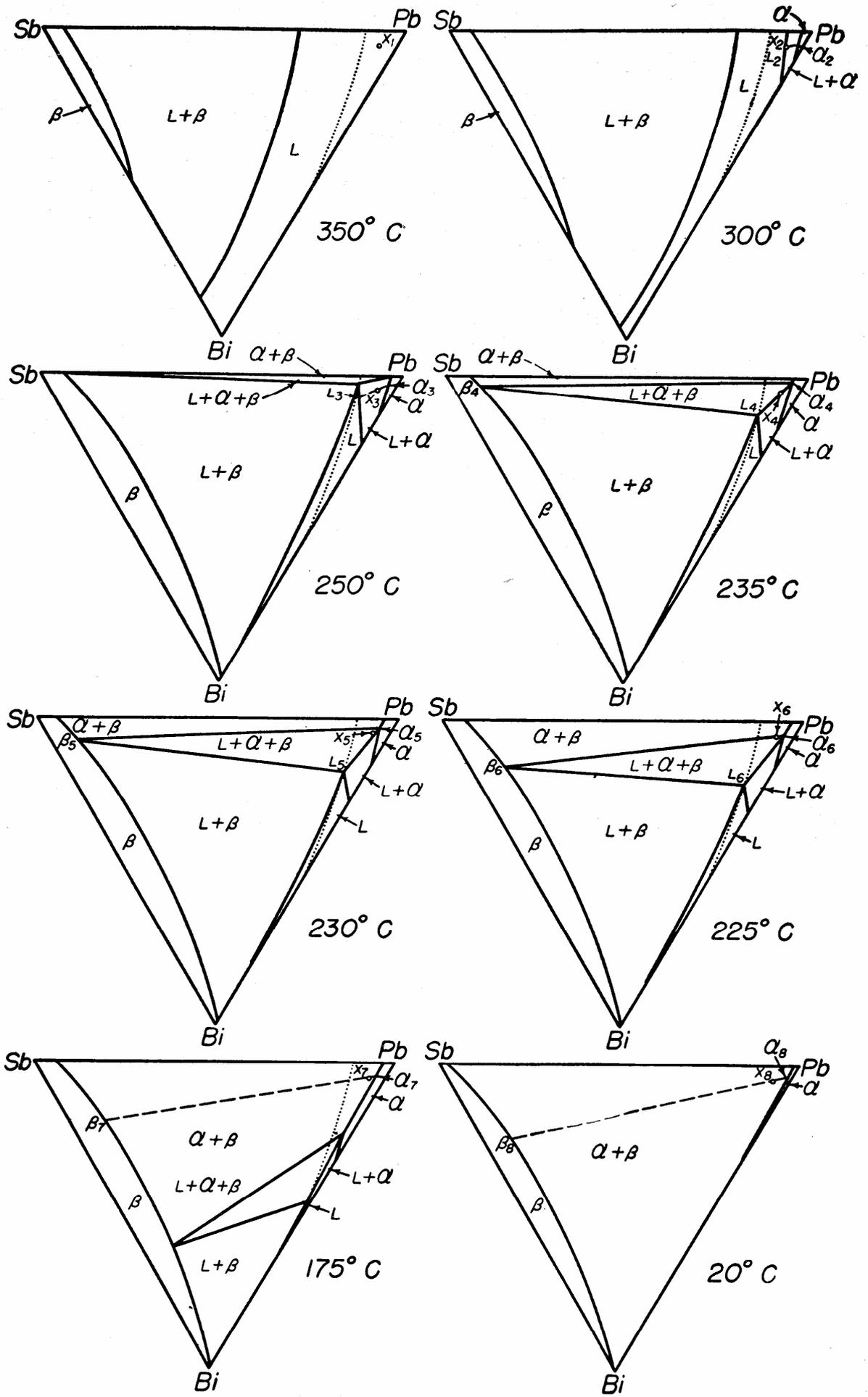


FIG. 13-11. Isotherms of the system lead-bismuth-antimony (see Fig. 13-10).

13.4 - Outro sistema envolvendo equilíbrio de 3 fases

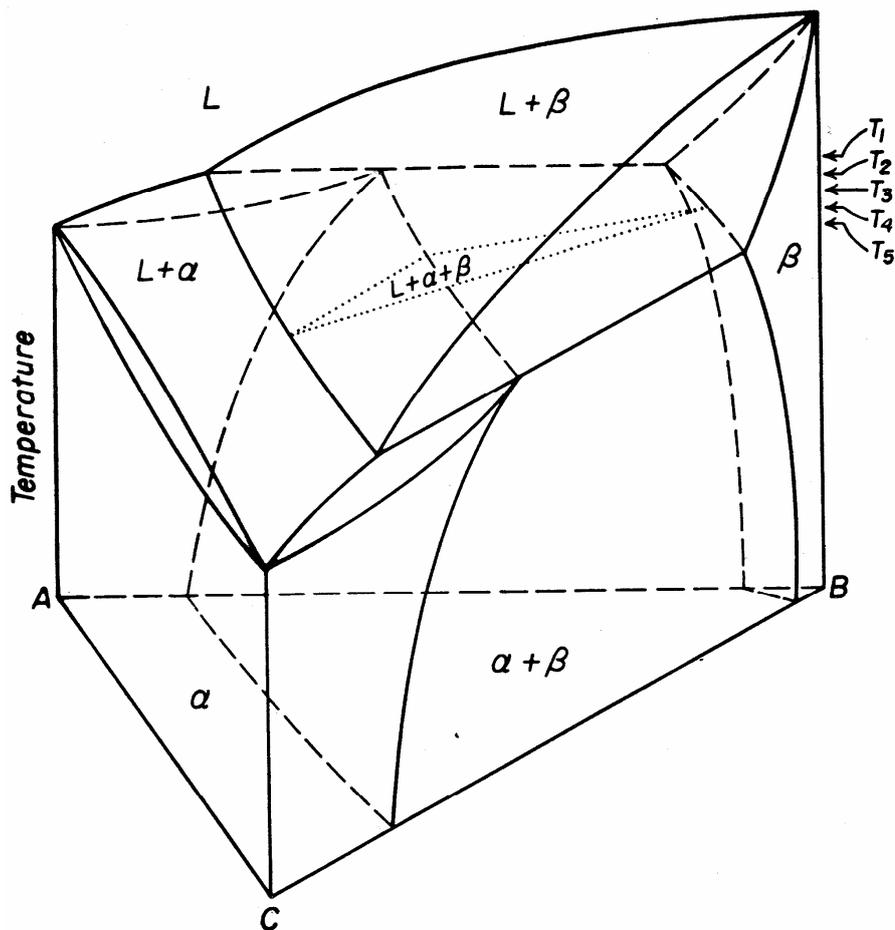


FIG. 13-13

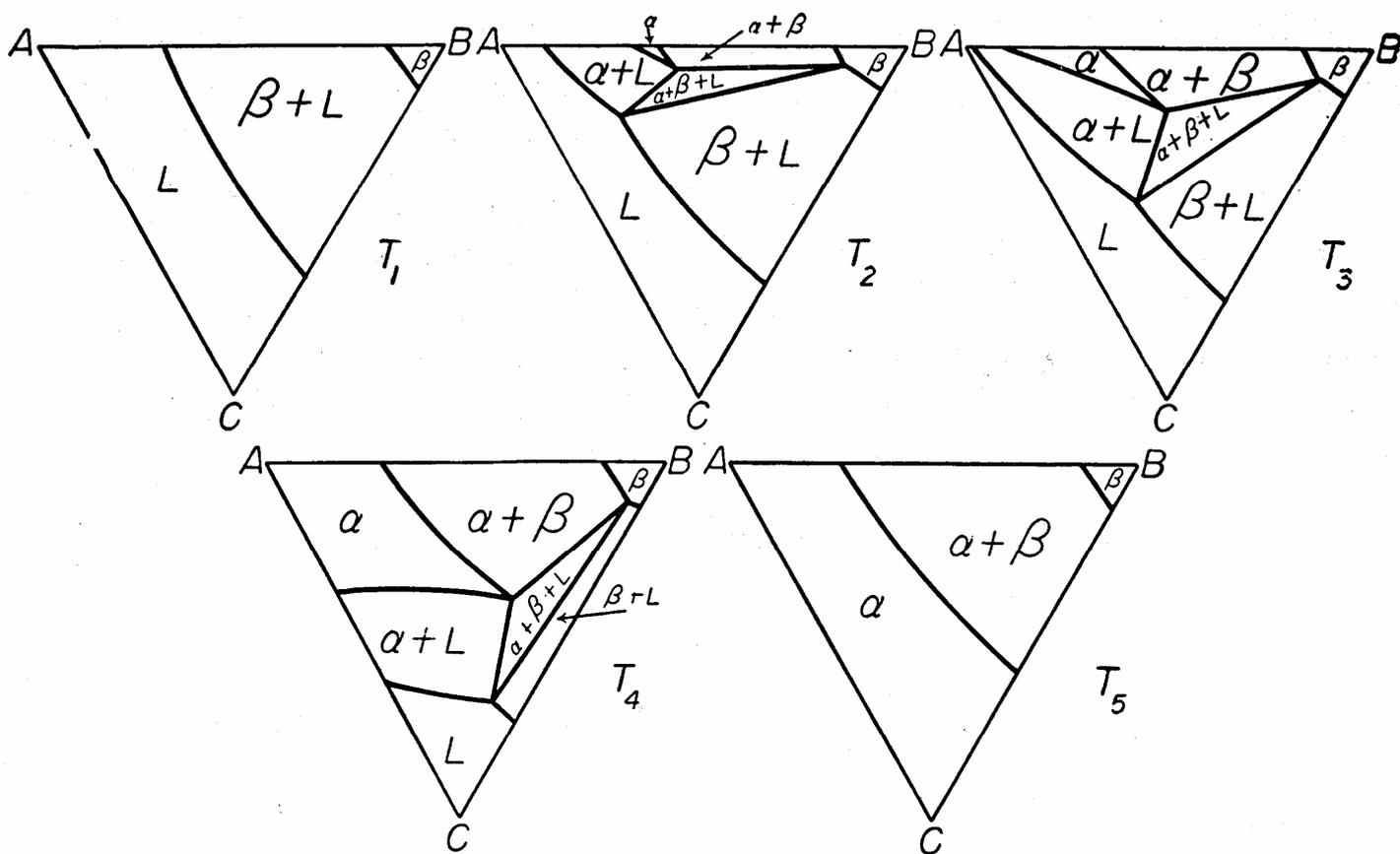


FIG. 13-15. Isotherms through the space diagram of Fig. 13-13.

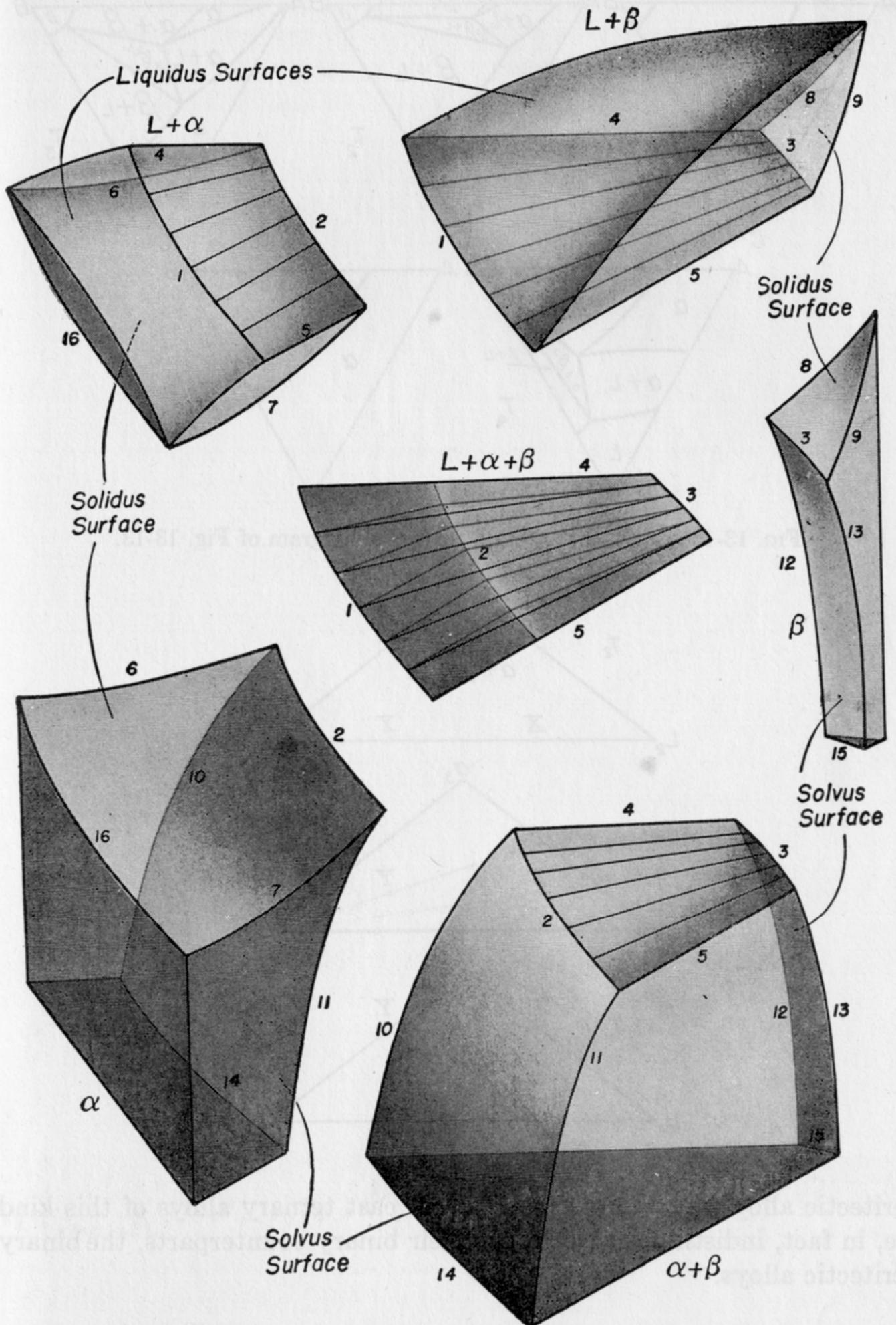


FIG. 13-14. Exploded model of the diagram of Fig. 13-13.

EQUILÍBRIO TERNÁRIO DE QUATRO FASES

$$P + F = C + 1$$

(pressão constante)

regiões de 4 fases:
 $P = 4; C = 3; F = 0$

14 - EQUILÍBRIO DE CLASSE I (EUTÉTICO)

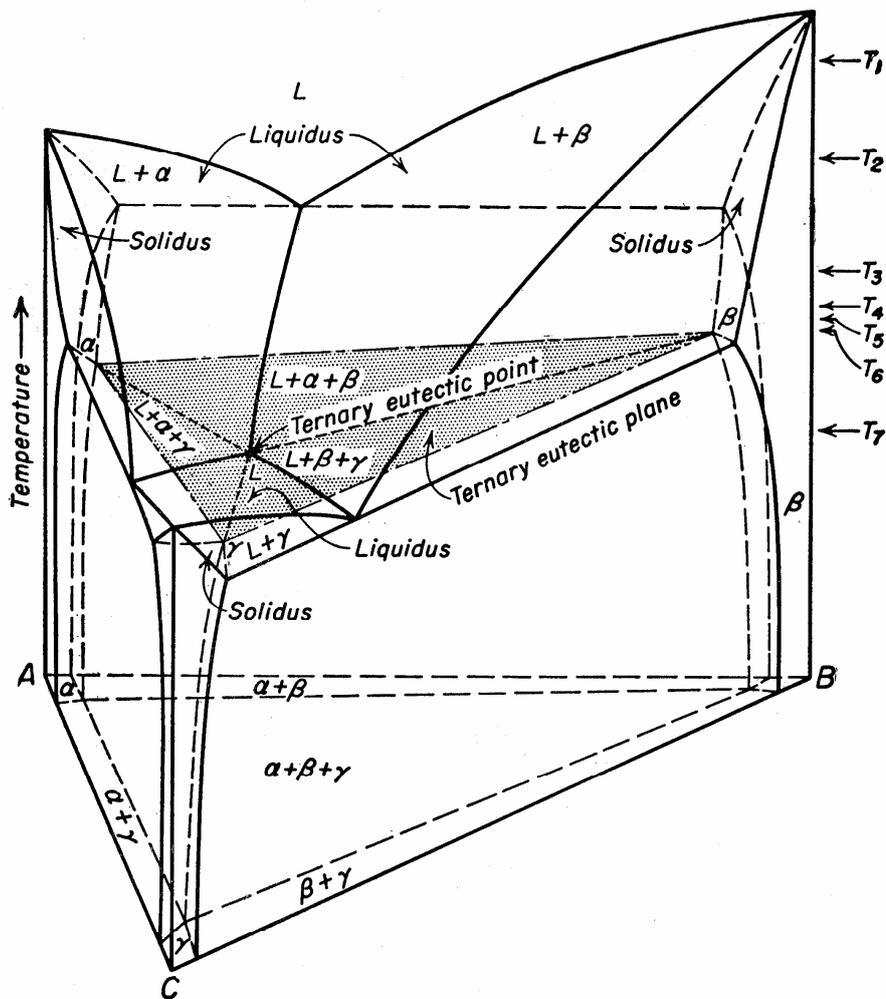
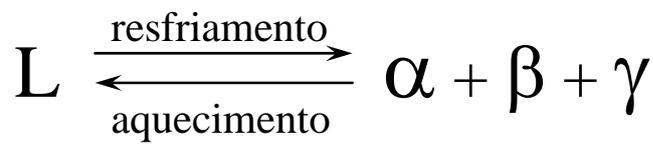


FIG. 14-1. Temperature-composition space diagram of a ternary eutectic system, illustrating class I four-phase equilibrium.

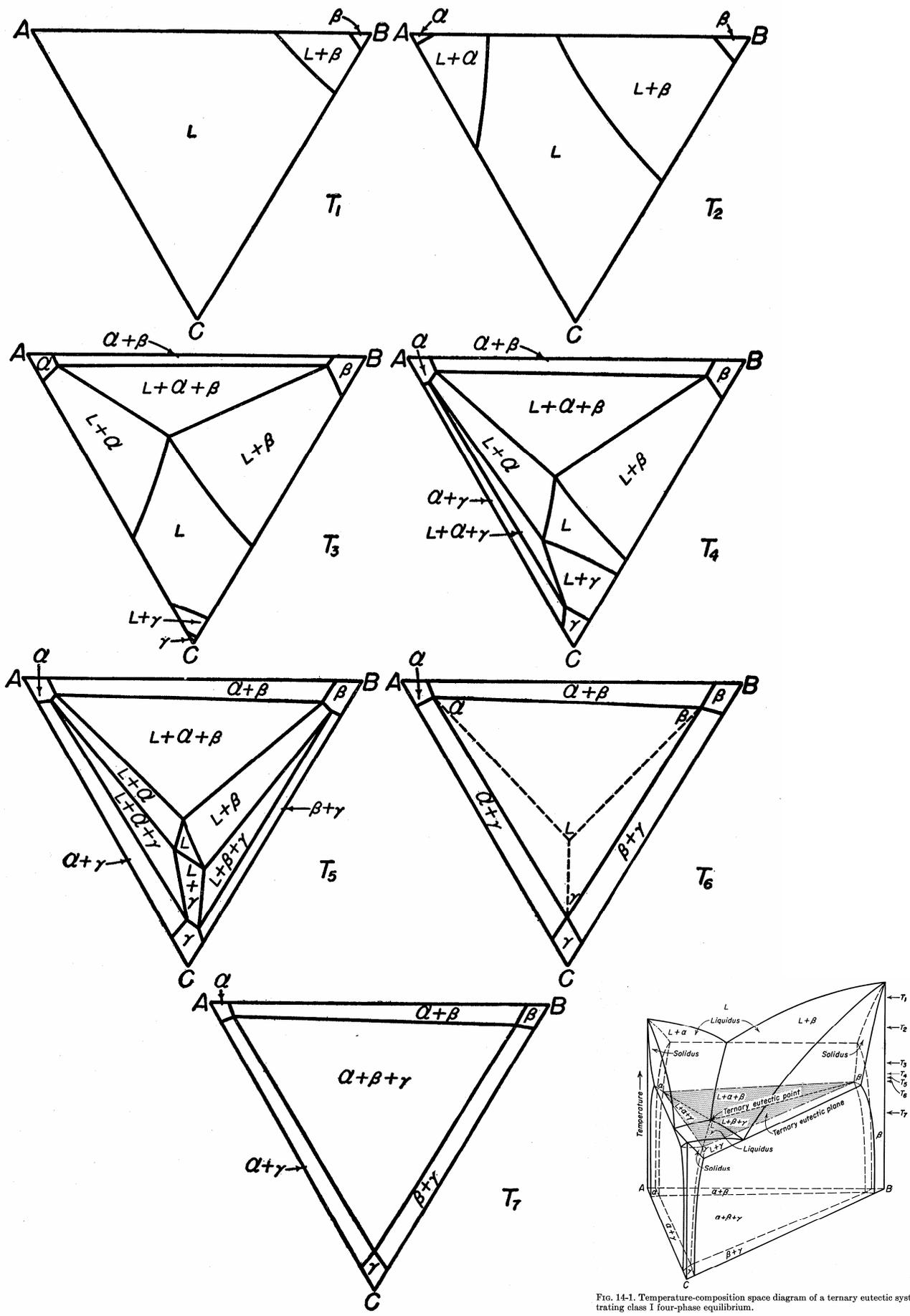


FIG. 14-1. Temperature-composition space diagram of a ternary eutectic system, illustrating class I four-phase equilibrium.

FIG. 14-3. Isotherms through the space diagram of Fig. 14-1.

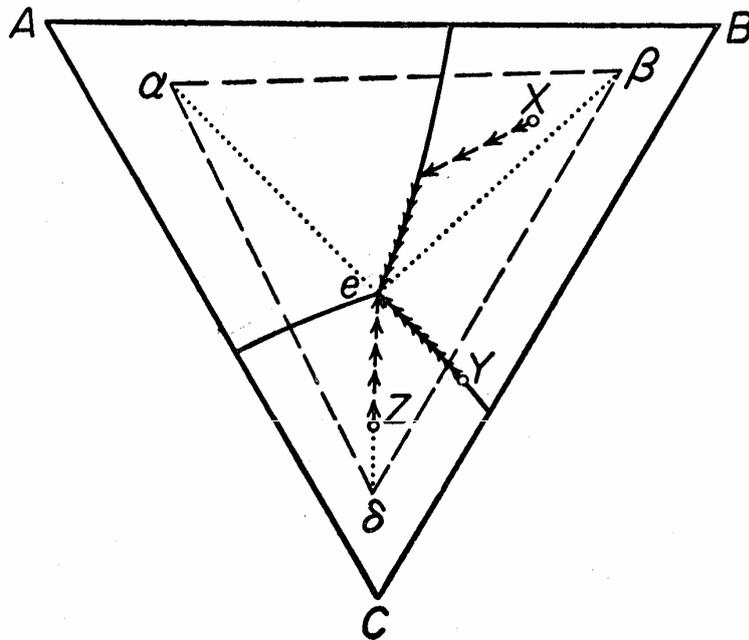


FIG. 14-10. Diagram showing by arrows the progress of composition change of the liquid phase during the freezing of alloys X, Y, and Z.

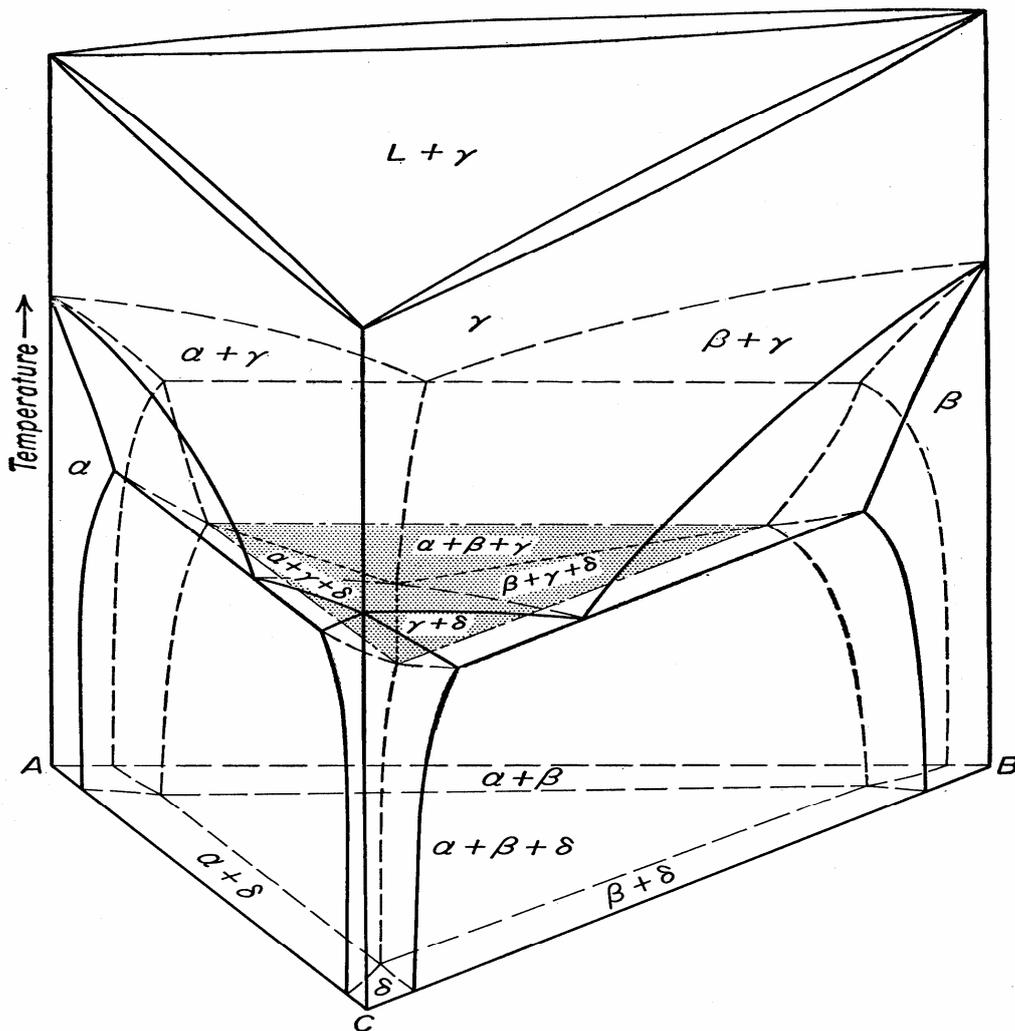


FIG. 14-12. Space diagram of an idealized ternary eutectoid system.

15 - EQUILÍBRIO DE CLASSE II

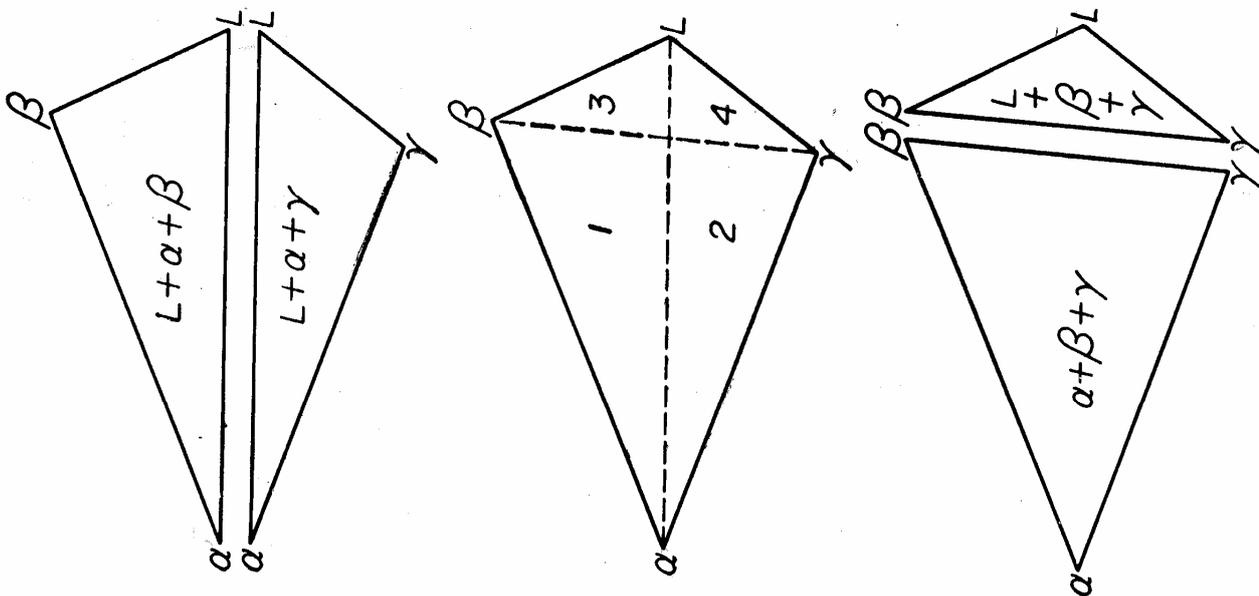
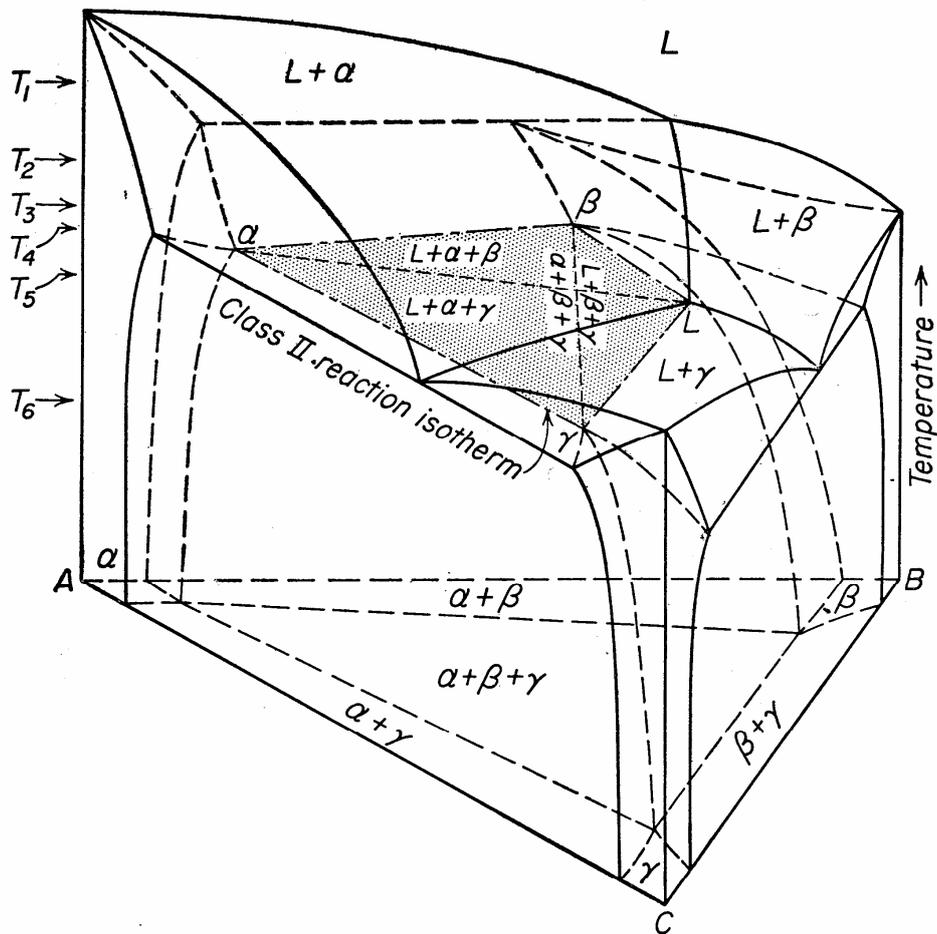
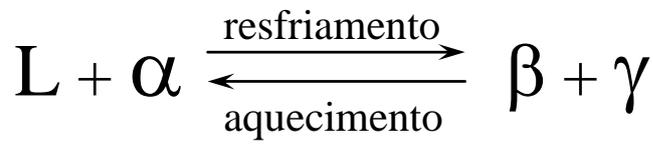


Fig. 15-4

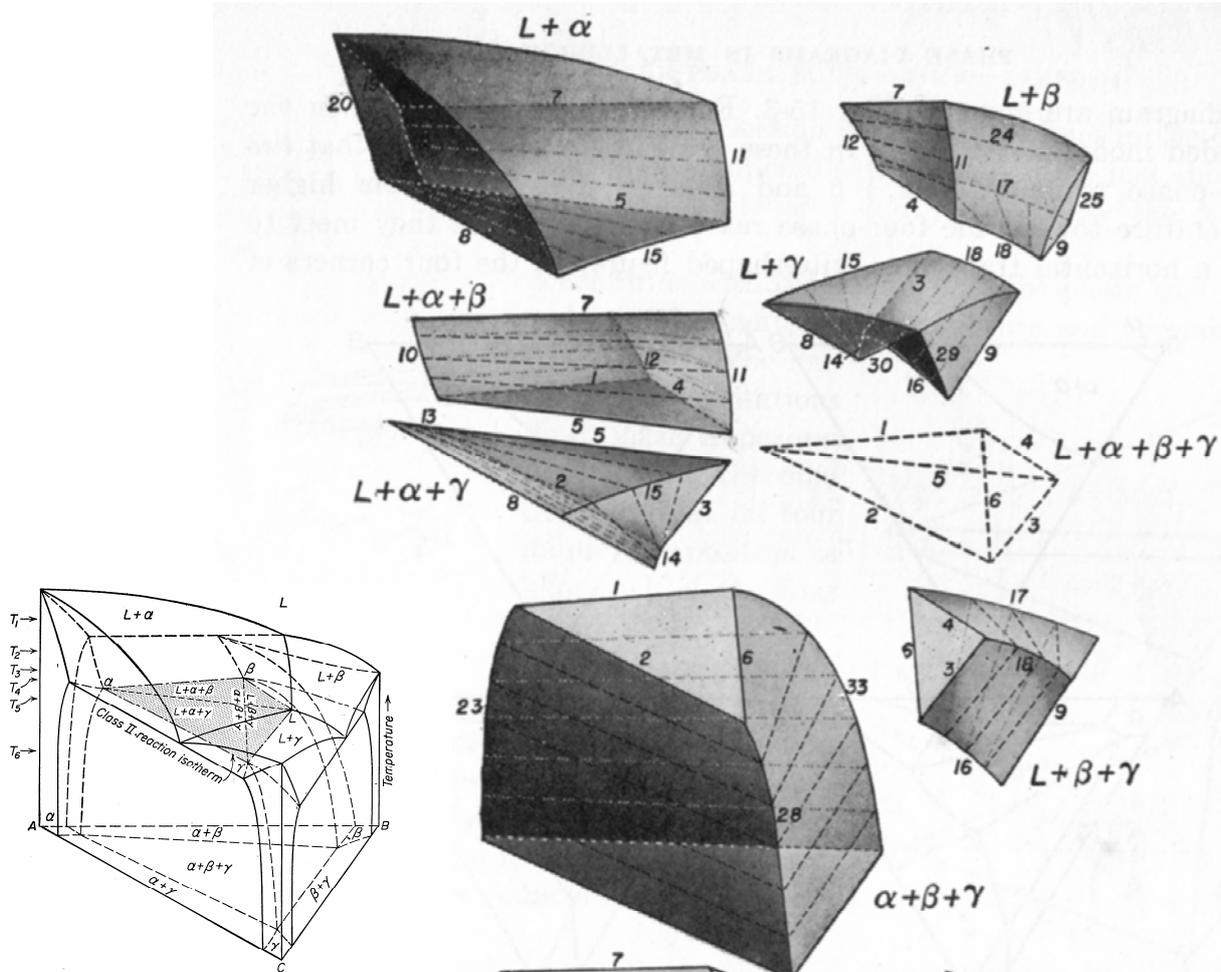


FIG. 15-1. Temperature-concentration diagram illustrating class II four-phase equilibrium.

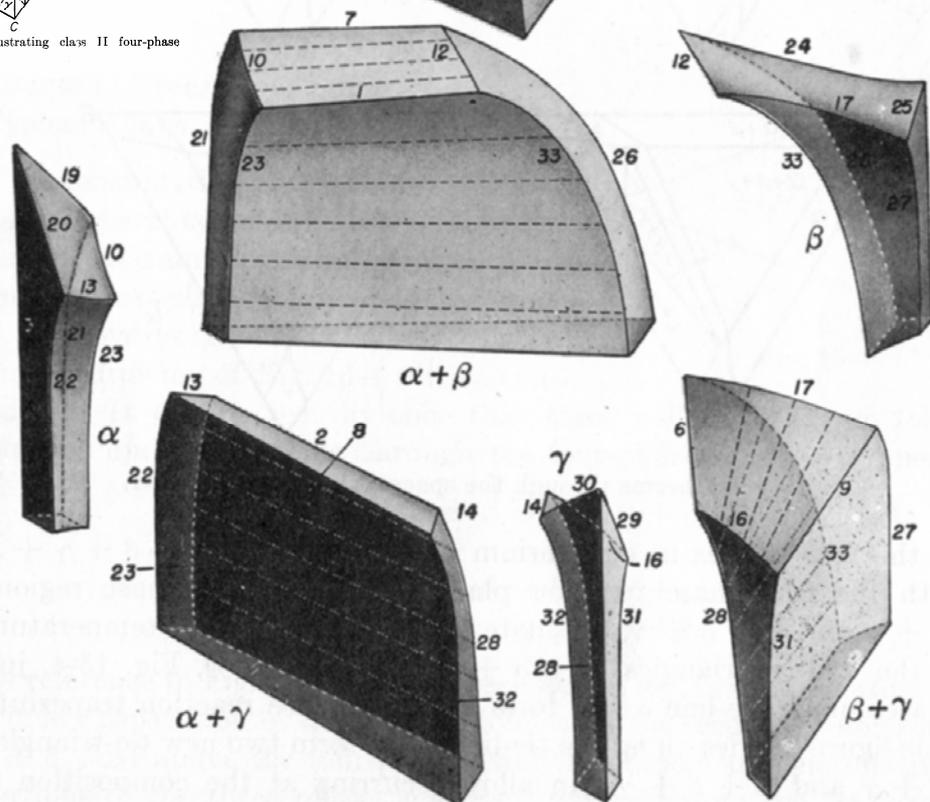


FIG. 15-2. Exploded model of the phase diagram of Fig. 15-1. The inscribed numbers identify edges that are identical lines on different segments of the model.

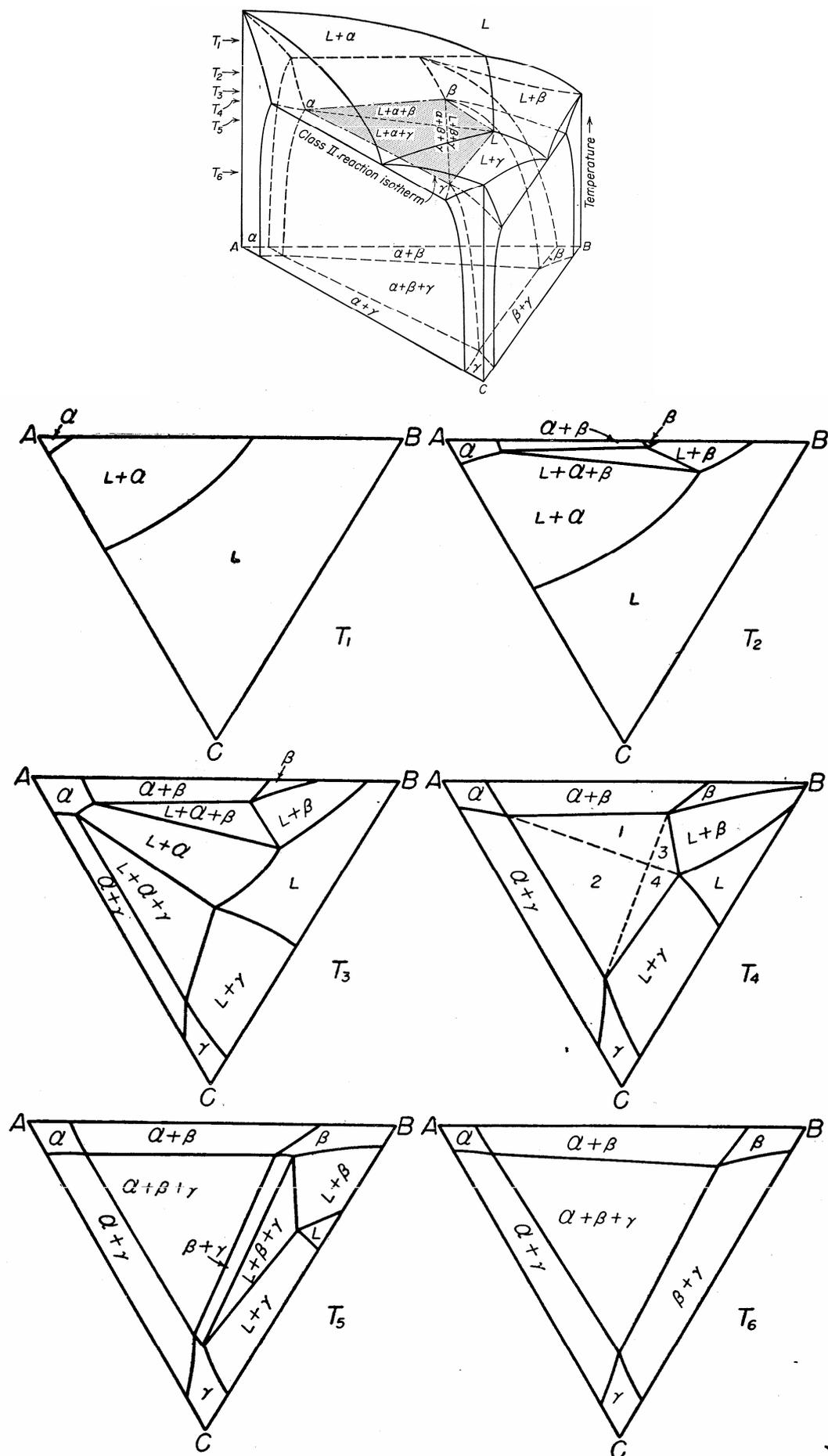


FIG. 15-3. Isotherms through the space diagram of Fig. 15-1.

16 - EQUILÍBRIO DE CLASSE III (PERITÉTICO)

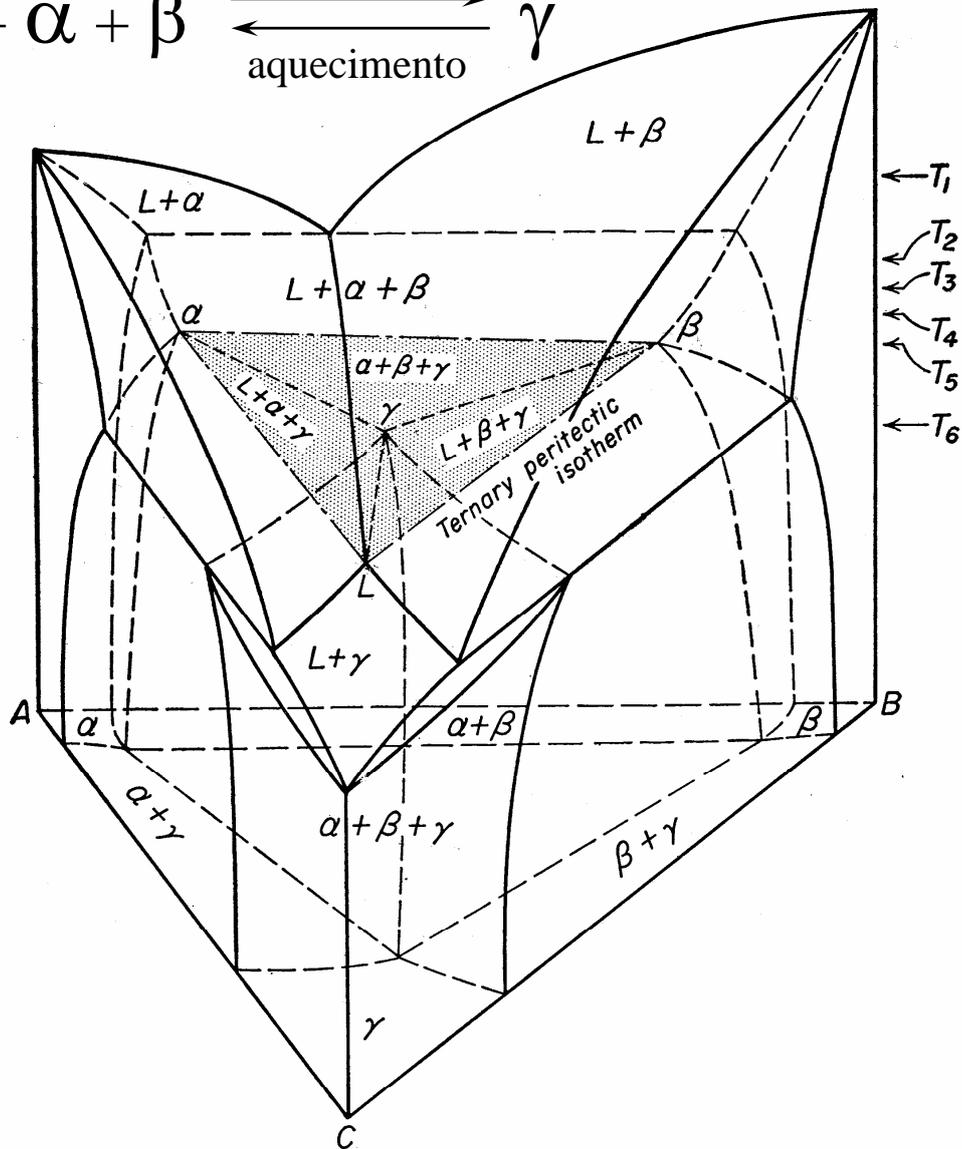
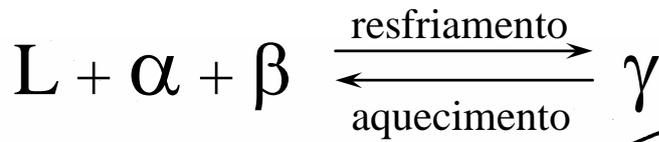


FIG. 16-1. Temperature-composition diagram of an ideal ternary peritectic system, class III.

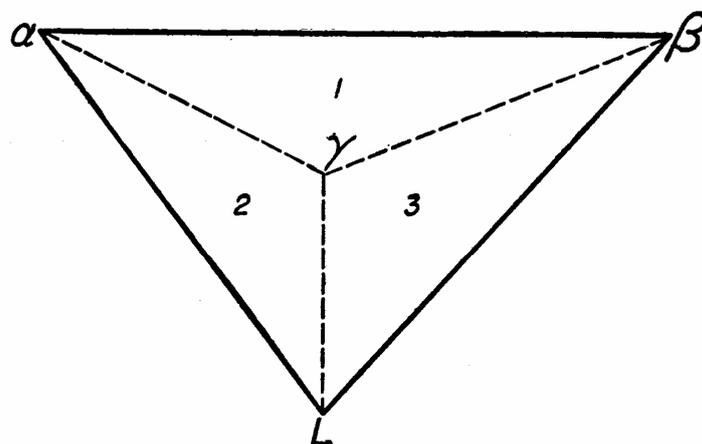


FIG. 16-4

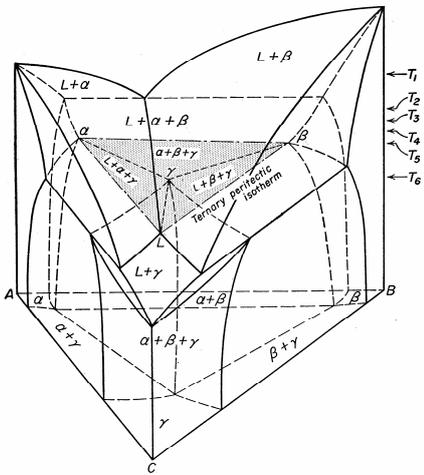


FIG. 16-1. Temperature-composition diagram of an ideal ternary peritectic system, class III.

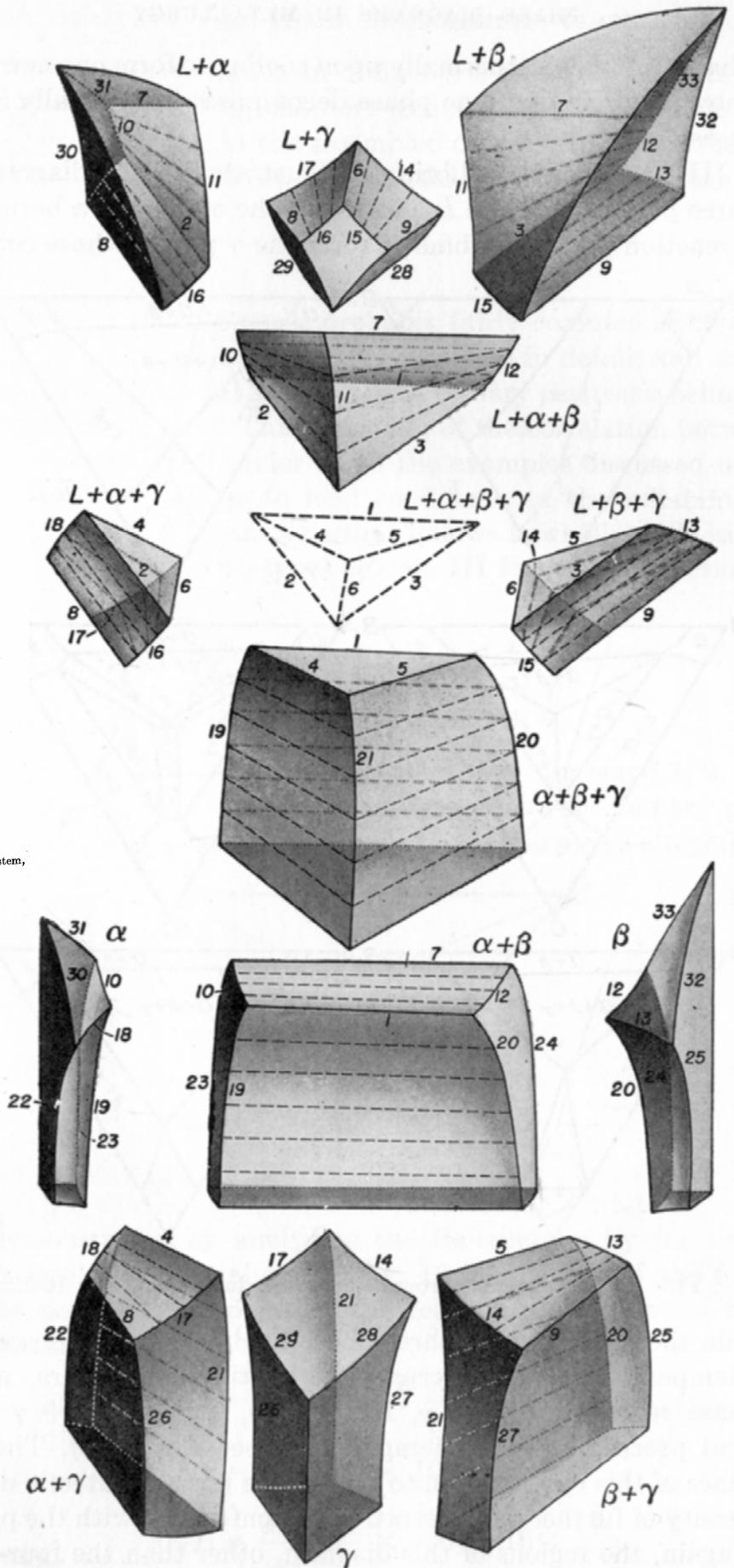


FIG. 16-2. Exploded model of the phase diagram shown in Fig. 16-1.

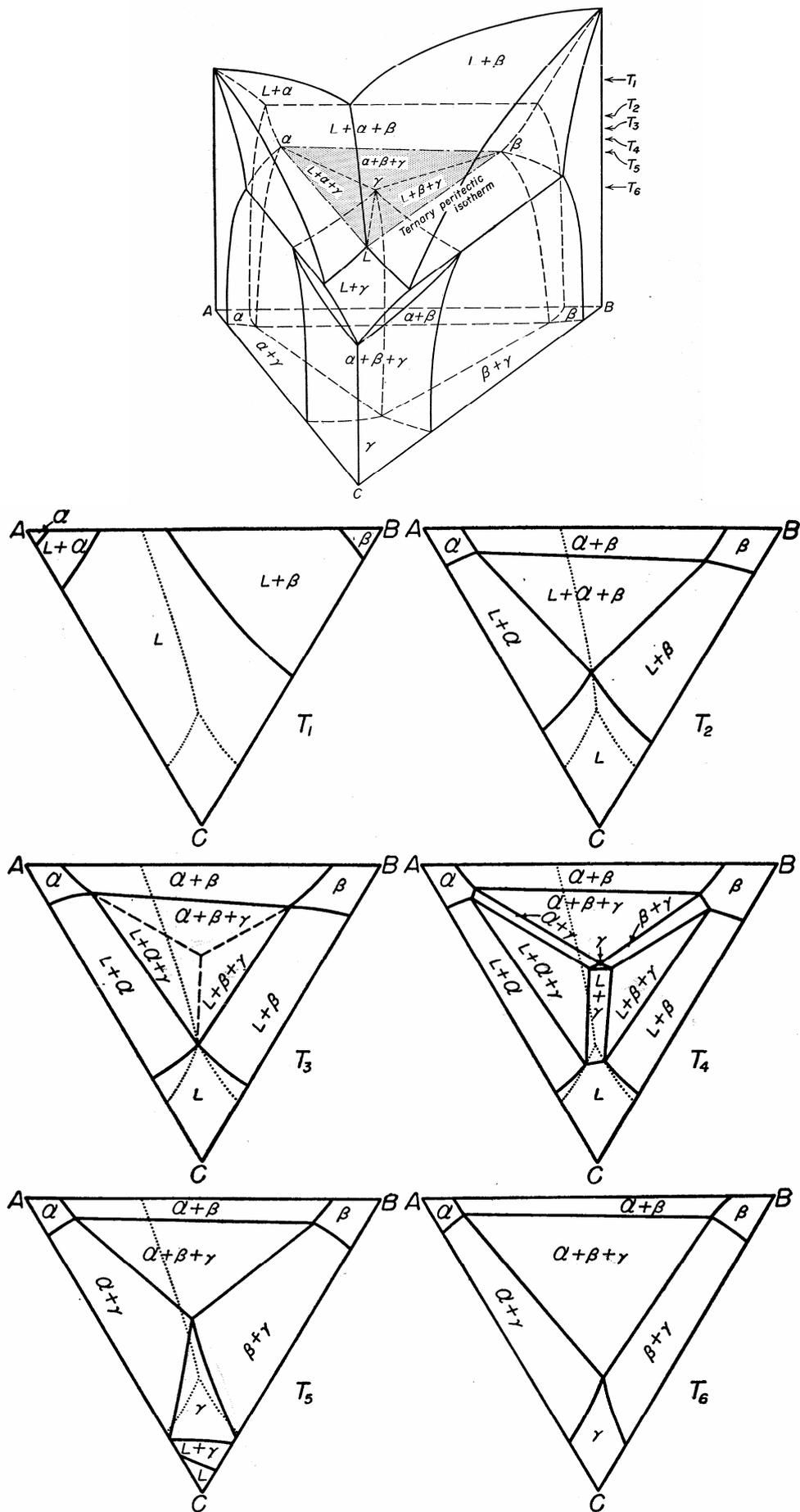


FIG. 16-3. Isotherms through the space diagram of Fig. 16-1.

17 - TRANSFORMAÇÃO CONGRUENTE EM SISTEMAS TERNÁRIOS

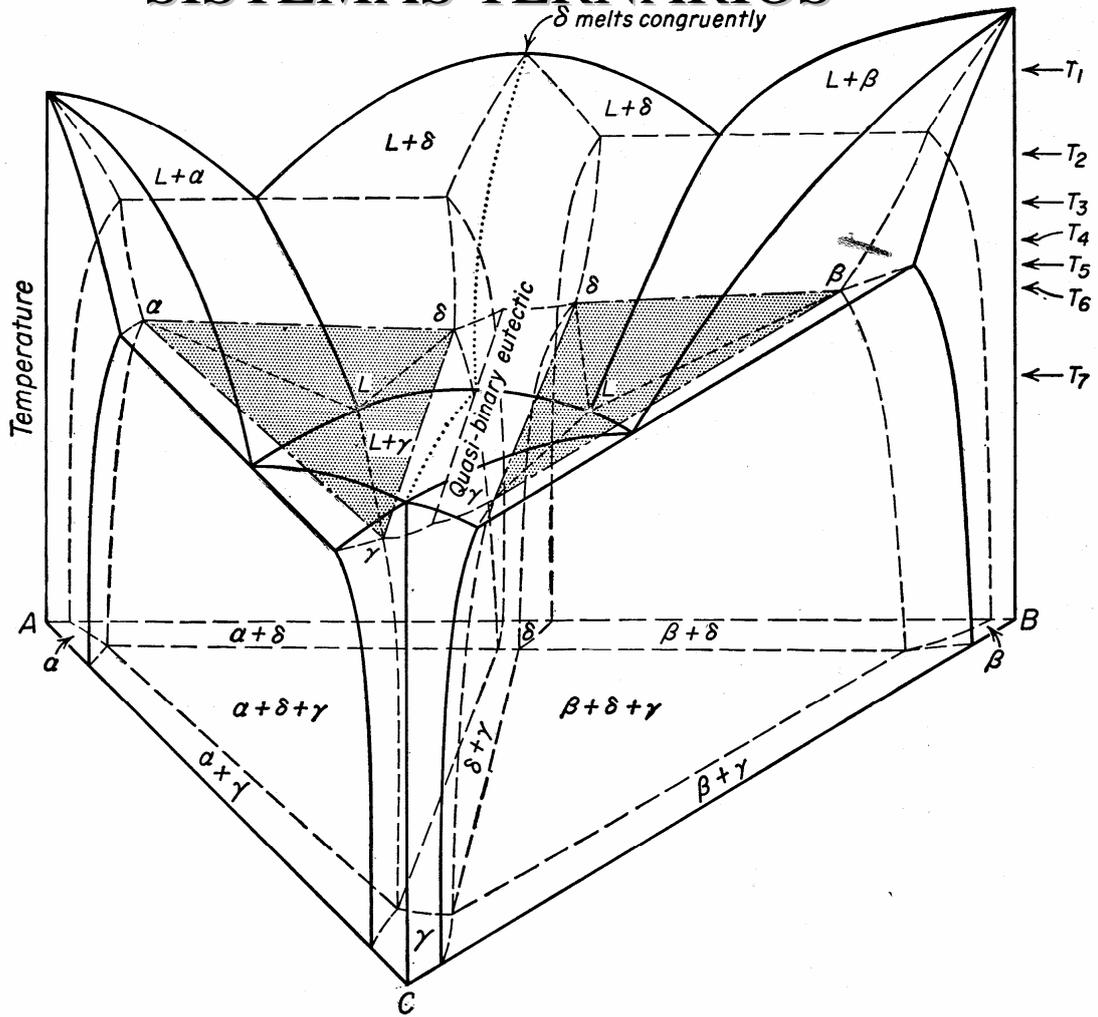


FIG. 17-1. Temperature-composition diagram of a ternary alloy system displaying a quasi-binary section in the vertical plane between the C component and the congruently melting binary δ phase.

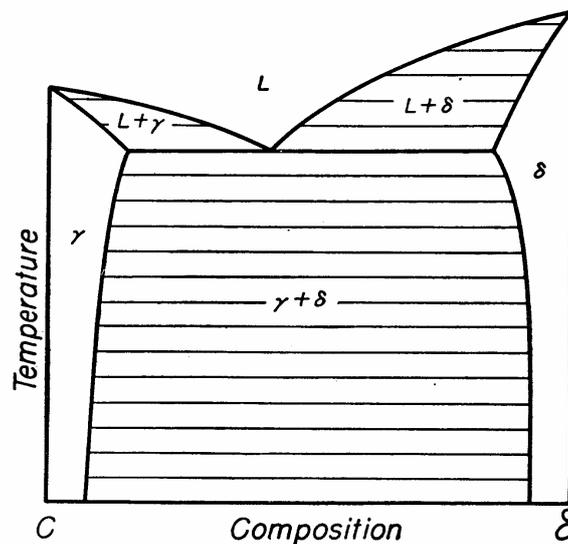


FIG. 17-2. A quasi-binary section from Fig. 17-1 has tie-lines in the plane of the section in all two-phase regions.

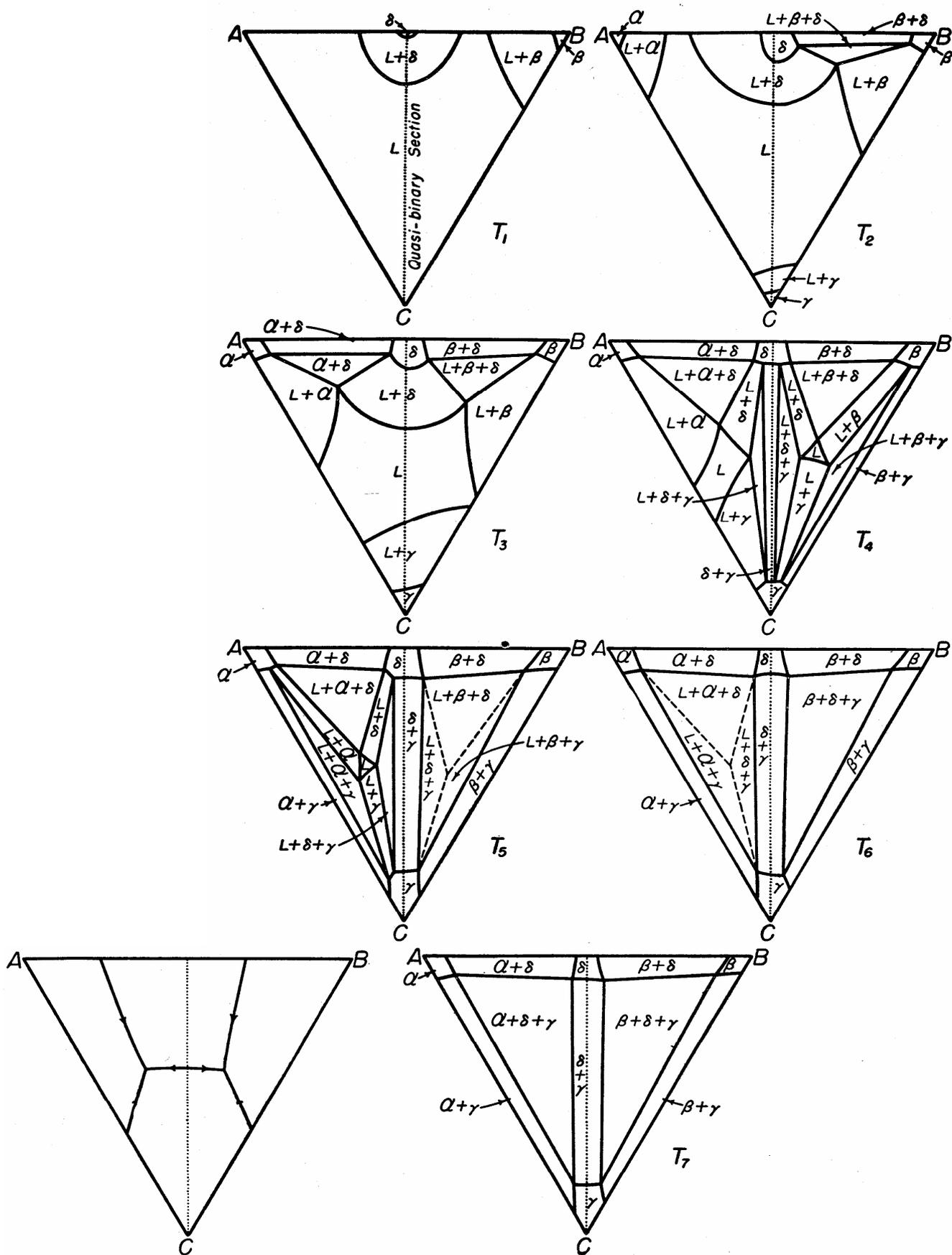


FIG. 17-3. Isotherms through the space diagram of Fig. 17-1.

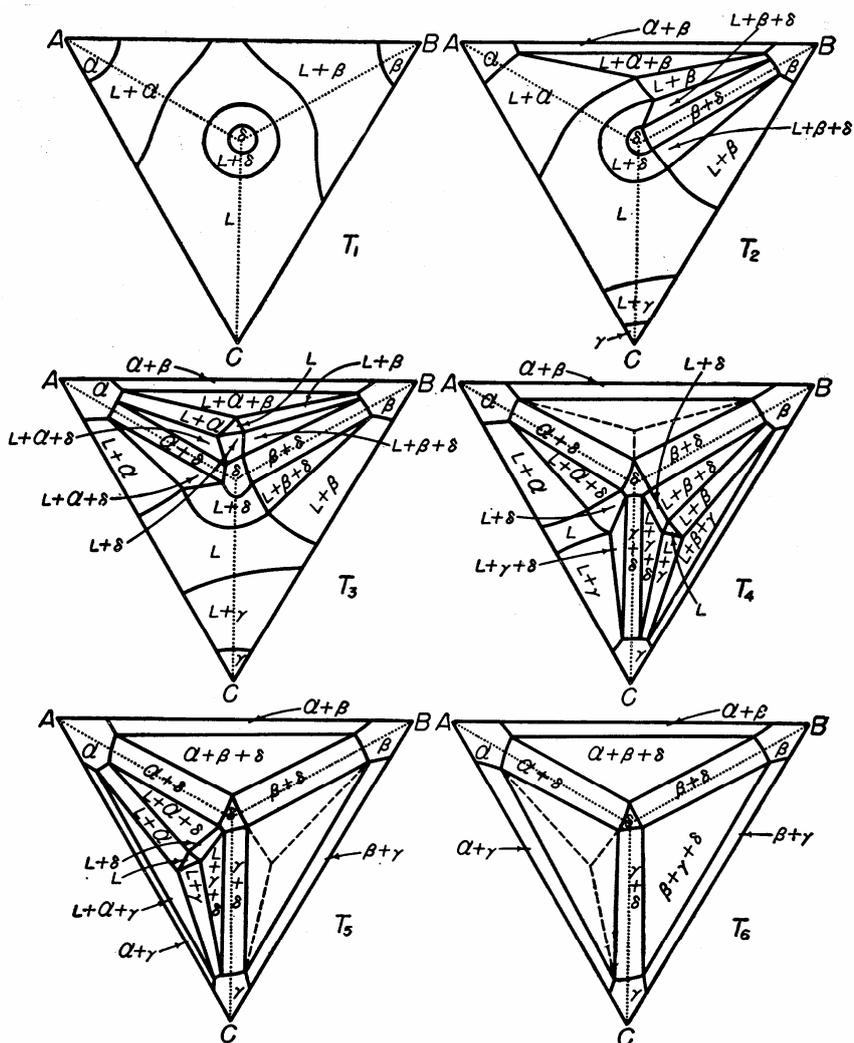
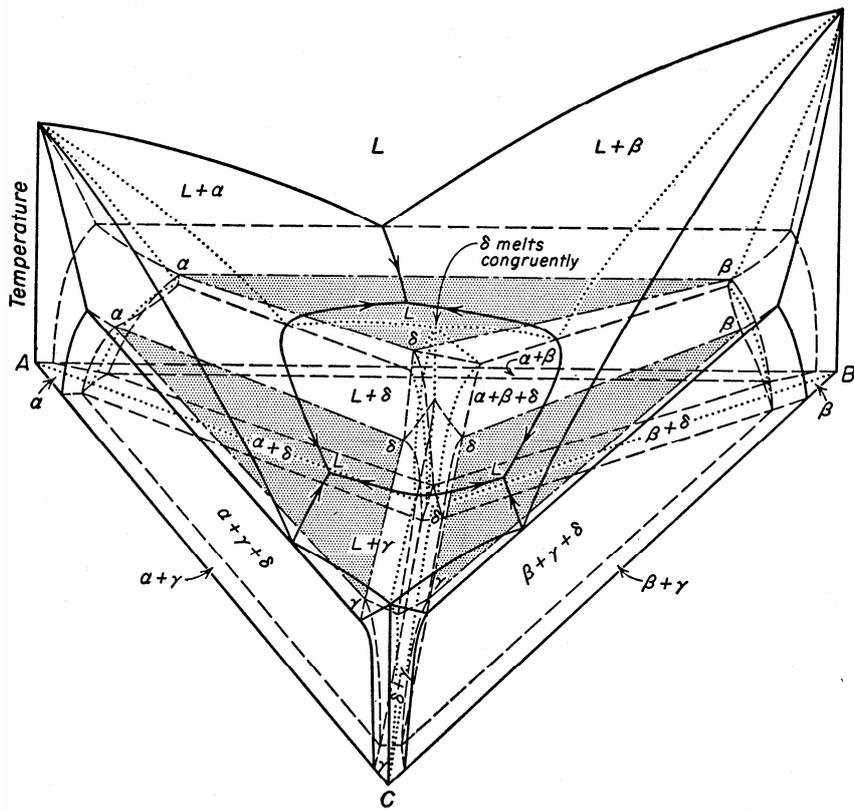


FIG. 17-10. Isotherms through the space diagram of Fig. 17-9.

18 - SISTEMAS TERNÁRIOS COMPLEXOS

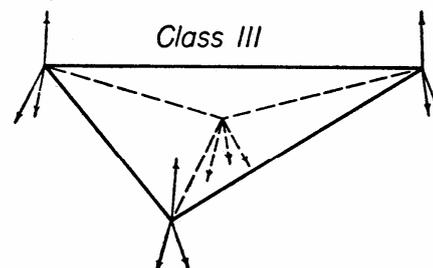
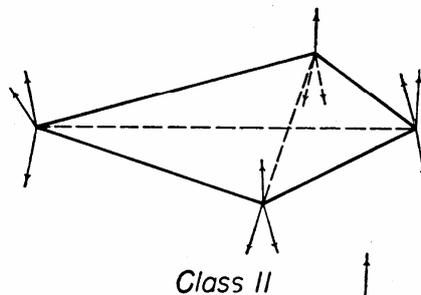
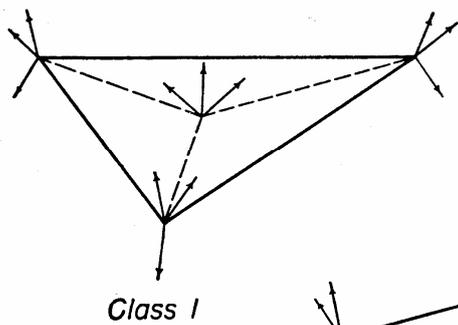
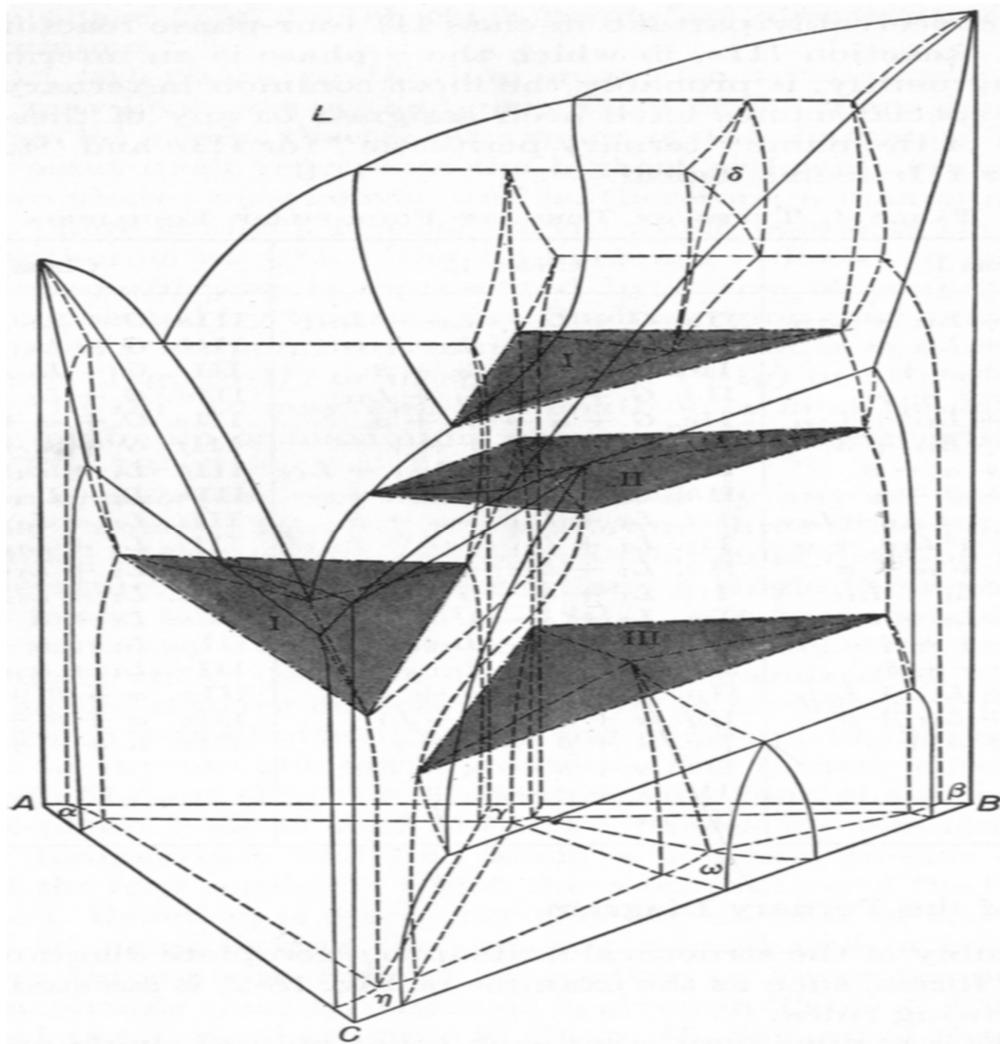
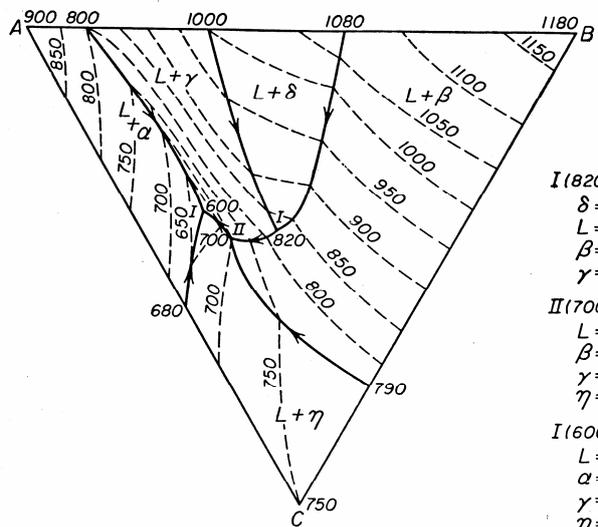
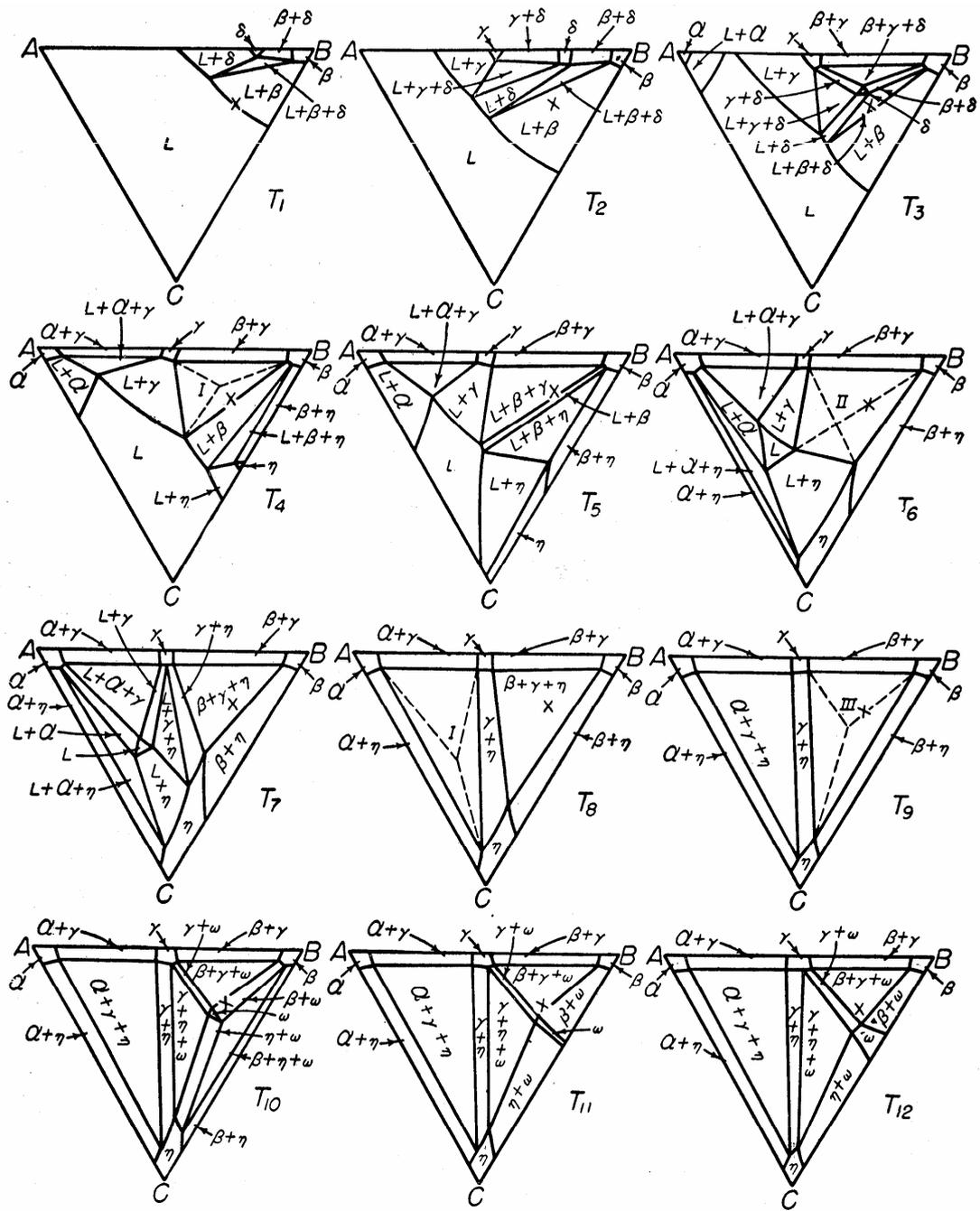


FIG. 18-3

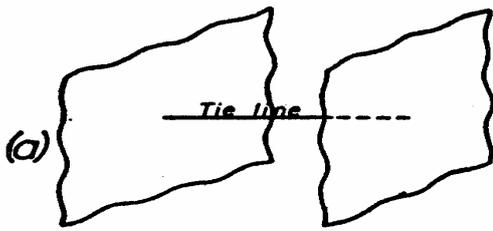


I (820°C) $\delta \rightarrow L + \beta + \gamma$
 $\delta = 30\%A + 60\%B + 10\%C$
 $L = 35\%A + 30\%B + 35\%C$
 $\beta = 12\%A + 83\%B + 5\%C$
 $\gamma = 45\%A + 50\%B + 5\%C$

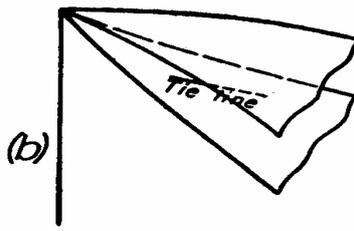
II (700°C) $L + \beta \rightarrow \gamma + \eta$
 $L = 42\%A + 18\%B + 40\%C$
 $\beta = 12\%A + 83\%B + 5\%C$
 $\gamma = 46\%A + 49\%B + 5\%C$
 $\eta = 5\%A + 25\%B + 70\%C$

III (600°C) $L \rightarrow Q + \gamma + \eta$
 $L = 47\%A + 17\%B + 35\%C$
 $Q = 90\%A + 5\%B + 5\%C$
 $\gamma = 50\%A + 45\%B + 5\%C$
 $\eta = 5\%A + 5\%B + 90\%C$

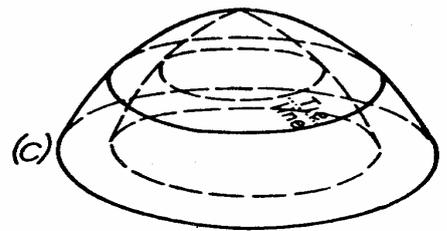
FIG. 18-9. Liquidus projection of the space diagram of Fig. 18-2.



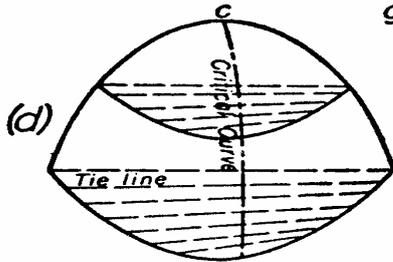
(a) Two-phase equilibrium
General case



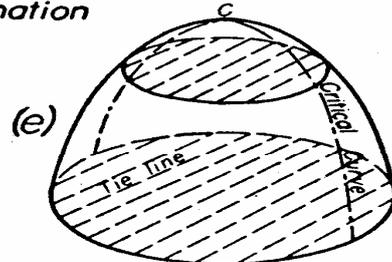
(b) Two-phase equilibrium
Bounding surfaces meet
at composition of component or binary
congruent transformation



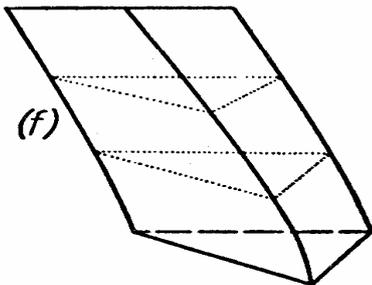
(c) Two-phase equilibrium
Bounding surfaces meet
at point of ternary
congruent transformation



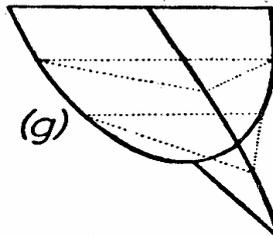
(d) Two-phase equilibrium
With temperature maximum
in binary space



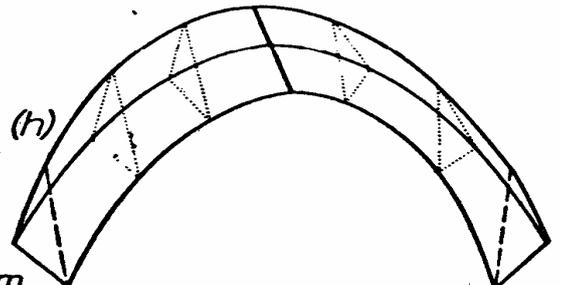
(e) Two-phase equilibrium
With temperature maximum
in ternary space



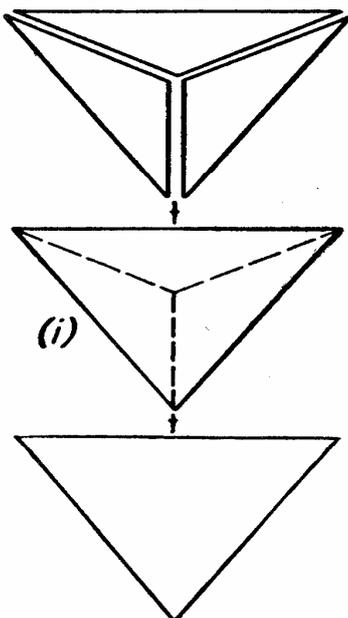
(f) Three-phase equilibrium,
terminating at a binary
isotherm and at a four-
phase reaction isotherm



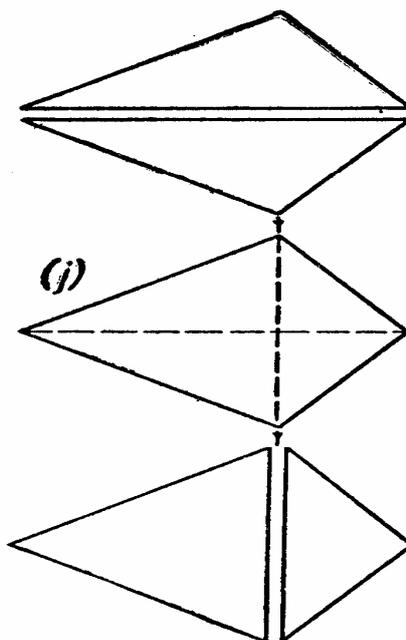
(g) Three-phase equilibrium,
terminating at a binary
isotherm and at a
critical point



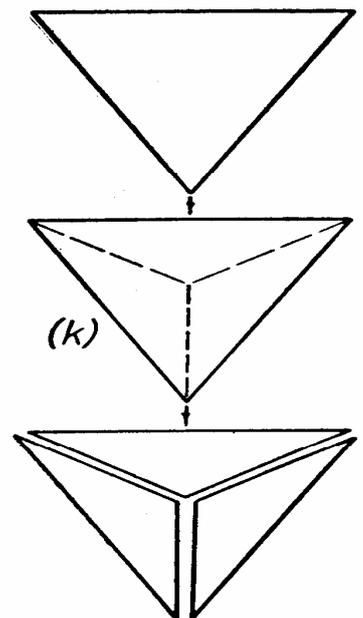
(h) Three-phase equilibrium,
passing through a
temperature maximum



(i) Class I Four-phase
equilibrium



(j) Class II Four-phase
equilibrium



(k) Class III Four-phase
equilibrium