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Al-Ta-Ti (Aluminum-Tantalum-Titanium)

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The previous work on this system by [1966Ram] and [1983Sri] presented isothermal sections at 1000 and 1100 °C, respectively. More recently, using updated binary information, several isothermal sections have been reported between 1450 and 1100 °C. In this review, a schematic liquidus projection, a reaction table down to 1100 °C, full isothermal sections at 1440, 1350, 1330, and 1100 °C, and partial isothermal sections at 1300 and 1200 °C are presented.

Binary Systems

The Al-Ta system [1990Sub] depicts four intermediate phases: Ta_2Al (σ) has the $D8_b$, σCrFe-type tetragonal structure, with a homogeneity range of 20-47 at.% Al. TaAl (denoted ε; monoclinic), $TaAl_2$ (denoted δ; complex bcc with $a = 1.93$ nm), and $TaAl_3$ ($D0_{22}$, $TiAl_3$-type tetragonal) are stoichiometric phases. According to [1993Jew], TaAl (ε) does not come into equilibrium with the liquid. It probably forms through a peritectoid reaction [1993Jew] tentatively placed around 1300 °C. The updated version of the Al-Ti phase diagram [2005Rag] depicts a number of intermediate phases. $TiAl_3$ has two crystal modifications: $TiAl_3$ (HT) ($D0_{22}$-type tetragonal) forms peritectically at 1387 °C and decomposes eutectoidally at 735 °C. $TiAl_3$ (LT) (tetragonal) forms at ~950 °C and is stable at low temperatures. Ti_5Al_{11} is a superstructure based on the AuCu-type tetragonal phase. It forms peritectically at 1416 °C and decomposes eutectoidally at 995 °C to $TiAl_2$ and $TiAl_3$ (HT). $TiAl_2$ ($HfGa_2$-type tetragonal) forms congruently at 1215 °C from Ti_5Al_{11} and is stable at low temperatures. $Ti_{1-x}Al_{1+x}$ (AuCu-type tetragonal) is stable between 1445 and 1170 °C. Ti_3Al_5 is a low-temperature phase stable below 810 °C. TiAl, often designated γ, has the $L1_0$, AuCu-type tetragonal structure and forms peritectically at 1460 °C. (βTi) (bcc, also denoted β) and liquid undergo a peritectic reaction at 1490 °C to yield (αTi) (cph, also denoted α). Ti_3Al, commonly labeled α_2, has the $D0_{19}$, Ni_3Sn-type hexagonal structure and forms congruently from (αTi) at 1176 °C. In the Ta-Ti system [Massalski2], there are no intermediate phases. Ta and βTi form a continuous bcc solid solution. Ta lowers the βTi → αTi transformation temperature.

Ternary Phases

Around the composition ~Ti_2TaAl, an island-like ternary phase was reported, which was identified as the ordered bcc (*B*2) phase [1991Das, 1991McC, 1991Wea]. [1993Jew] suggested that ordering in the bcc phase to the *B*2 structure occurs around 1200 °C. The ternary phase forms directly from the bcc phase. On further cooling, it undergoes decomposition to ω-related phases, as in the Al-Nb-Ti system [1991Das]. The occurrence of an island-like *B*2 region could result from a miscibility gap in the bcc (*B*2) phase, as in the Al-Nb-Ti and Al-Cr-Ti systems. However, the isothermal section determined by [1993Jew] at 1100 °C shows no island-like phase, but a part of the bcc phase as *B*2 with a second-order phase boundary between bcc and *B*2.

The isostructural compounds $TaAl_3$ and $TiAl_3$ form a $D0_{22}$-type continuous solid solution below 1387 °C (denoted η) [1966Ram, 1983Sri, 1993Jew]. The lattice parameters of this tetragonal structure reported by [1983Sri] vary linearly from $a = 0.3850$ nm at $TiAl_3$ to $a = 0.3837$ nm at $TaAl_3$ and $c = 0.8602$ nm at $TiAl_3$ to $c = 0.8550$ nm at $TaAl_3$.

Liquidus Projection

Using starting metals of 99.99% Al, 99.99% Ta, and high-purity Ti (with 200 ppm of oxygen impurity), [1991McC] and [1992McC] arc-melted under Ar atm about 15 ternary alloys. The as-cast and annealed samples were characterized by scanning and transmission electron microscopy and x-ray diffraction. The composition of the phases was determined by the energy-dispersive x-ray spectroscopy. The liquidus lines for the three-phase equilibria of L + bcc + (αTi) and L + (αTi) + γ were determined. Both these lines descend toward the Al-Ti binary, pointing to the formation of (αTi) and γ phases in the ternary region at a temperature higher than the corresponding binary peritectic temperature. Unpublished calculations of Kattner quoted by [1991Boe] refer to two four-phase equilibria of L + (αTi) + (βTi) + σ and L + (αTi) + γ + σ. These results taken together indicate the existence of two ternary peritectic reactions P_1 and P_2 on the liquidus surface, which yield (αTi) and γ respectively. No data are available on the solidification features in the other parts of the surface, except for the reference by [1992McC] to the existence of three-phase equilibrium between L, γ, and η. Using these scanty data and the reported isothermal sections as a guide, a schematic liquidus surface is drawn in Fig. 1. Only the P_1p_4 and P_2p_5 lines in Fig. 1 are known experimentally [1991McC].

Isothermal Sections

With starting metals of 99.999% Al, 99.98% Ta, and 99.8% Ti, [1993Jew] arc-melted about 5 alloy compositions under Ar atm. The samples were annealed at 1440 and 1100 °C for 24-72 h and quenched in brine solution. The phase equilibria were studied with optical and electron microscopy, x-ray diffraction, electron microprobe analysis and differential thermal analysis. Using their own results and the literature data, [1993Jew] constructed an isothermal

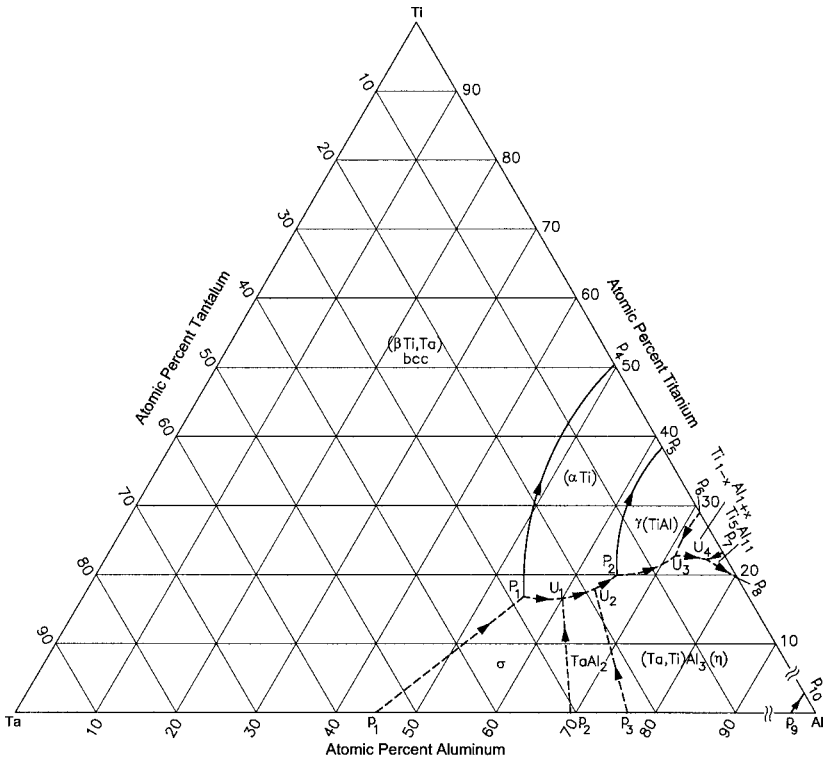


Fig. 1 Al-Ta-Ti schematic liquidus projection

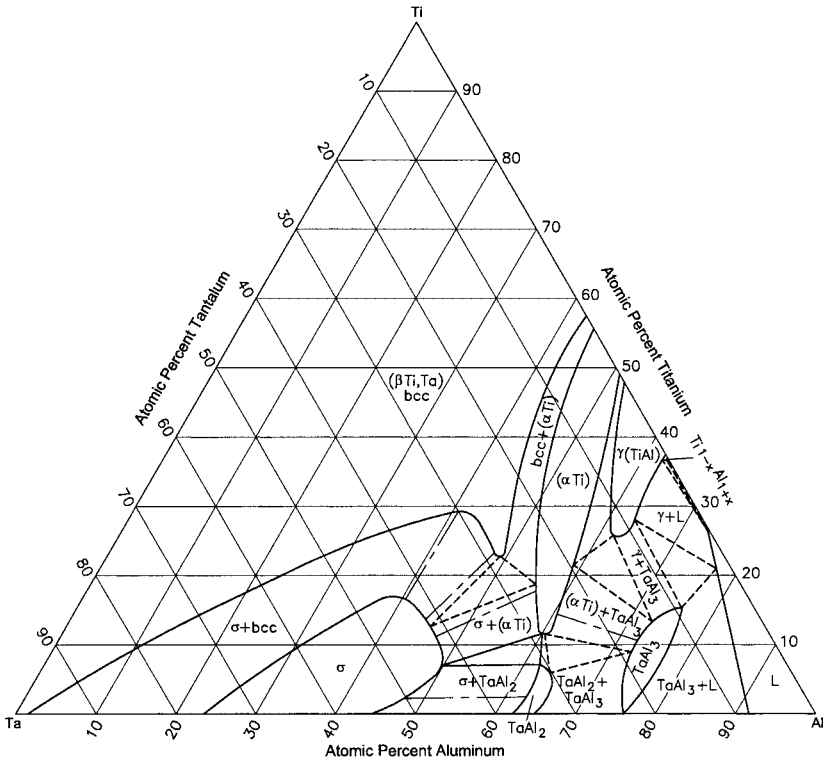


Fig. 2 Al-Ta-Ti isothermal section at 1440 °C [1993Jew]

section at 1440 °C, which is redrawn in Fig. 2 to agree with the accepted binary data. The bcc (βTi,Ta) phase occupies a large area. (αTi) penetrates deep into the ternary region. $TaAl_2$ (δ) dissolves about 7 at.% Ti at this temperature. TaAl (ε) is not present at 1440 °C. [1993Jew] pointed out that TaAl forms peritectoidally at a lower temperature.

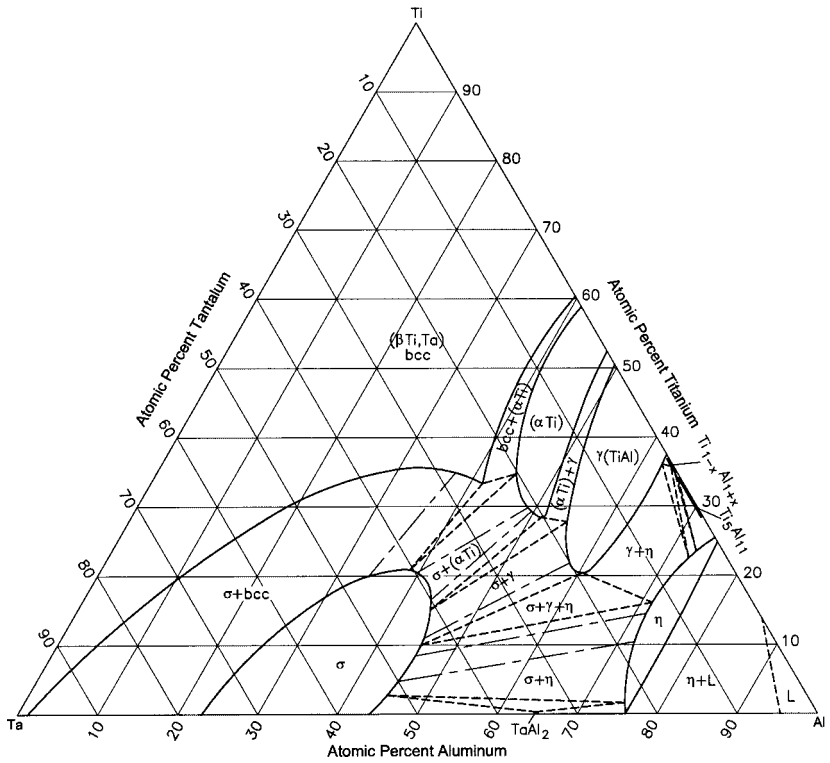


Fig. 3 Al-Ta-Ti isothermal section at 1350 °C [1995Wea]

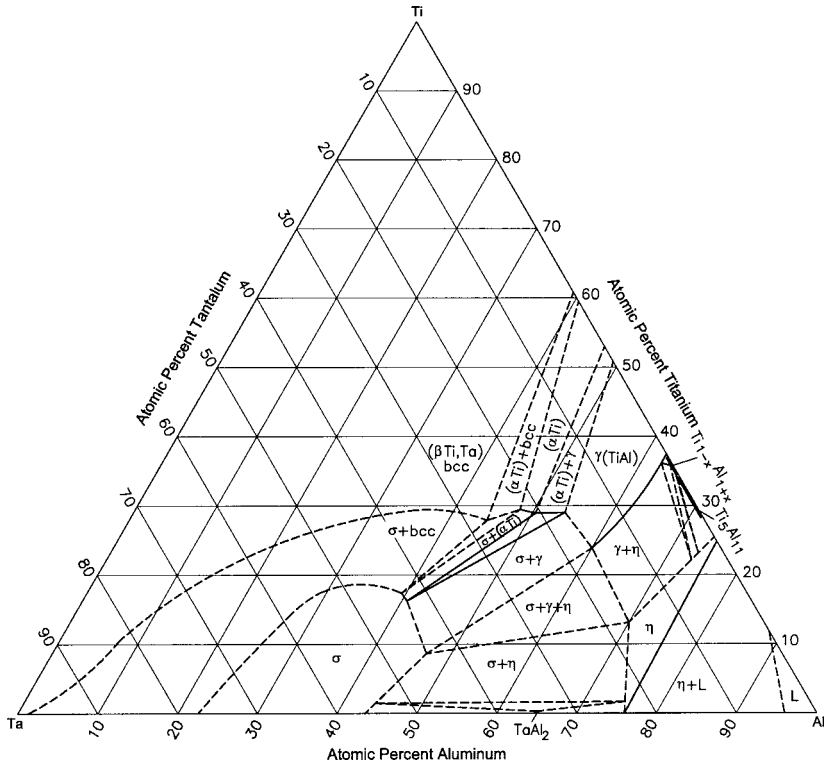


Fig. 4 Al-Ta-Ti isothermal section at 1330 °C [after 1991Boe]

With starting metals of 99.999% Al, 99.985% Ta, and 99.985% Ti, [1995Wea] arc-melted under Ar atm 27 ternary alloys. The alloy samples were annealed at 1550, 1450, and 1350 °C for 1-72 h and water quenched. The phase equilibria were studied by optical and electron metallography, x-ray diffraction, and electron probe microanalysis. Differ-

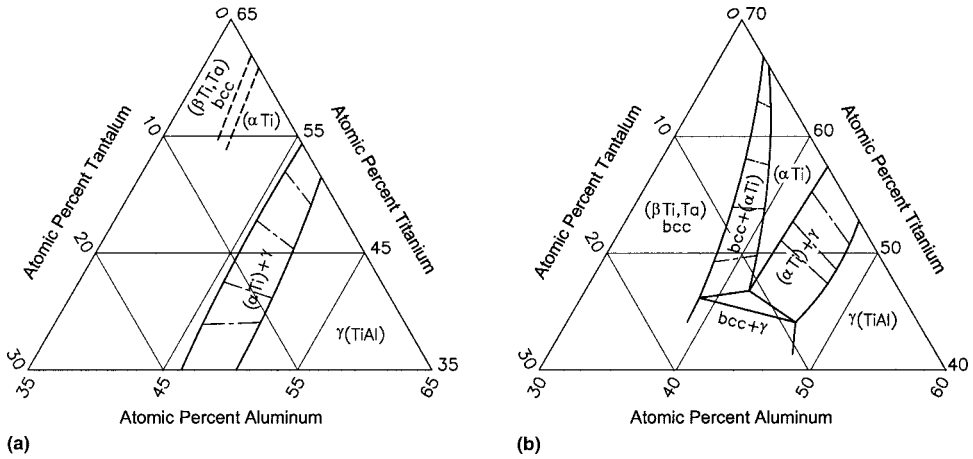


Fig. 5 Al-Ta-Ti partial isothermal sections at (a) 1300 °C and (b) 1200 °C [2000Kai]

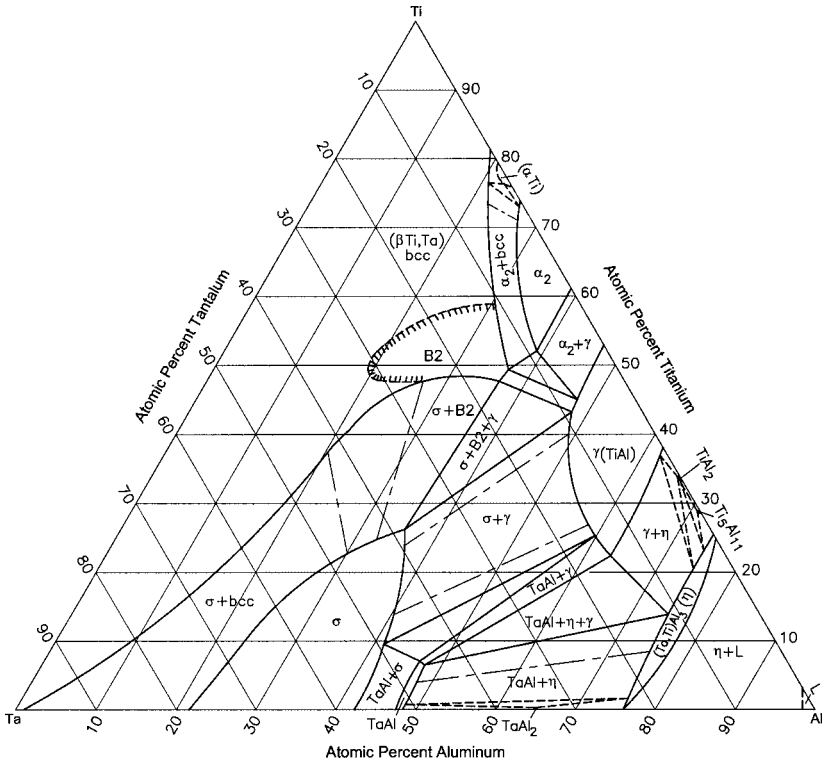
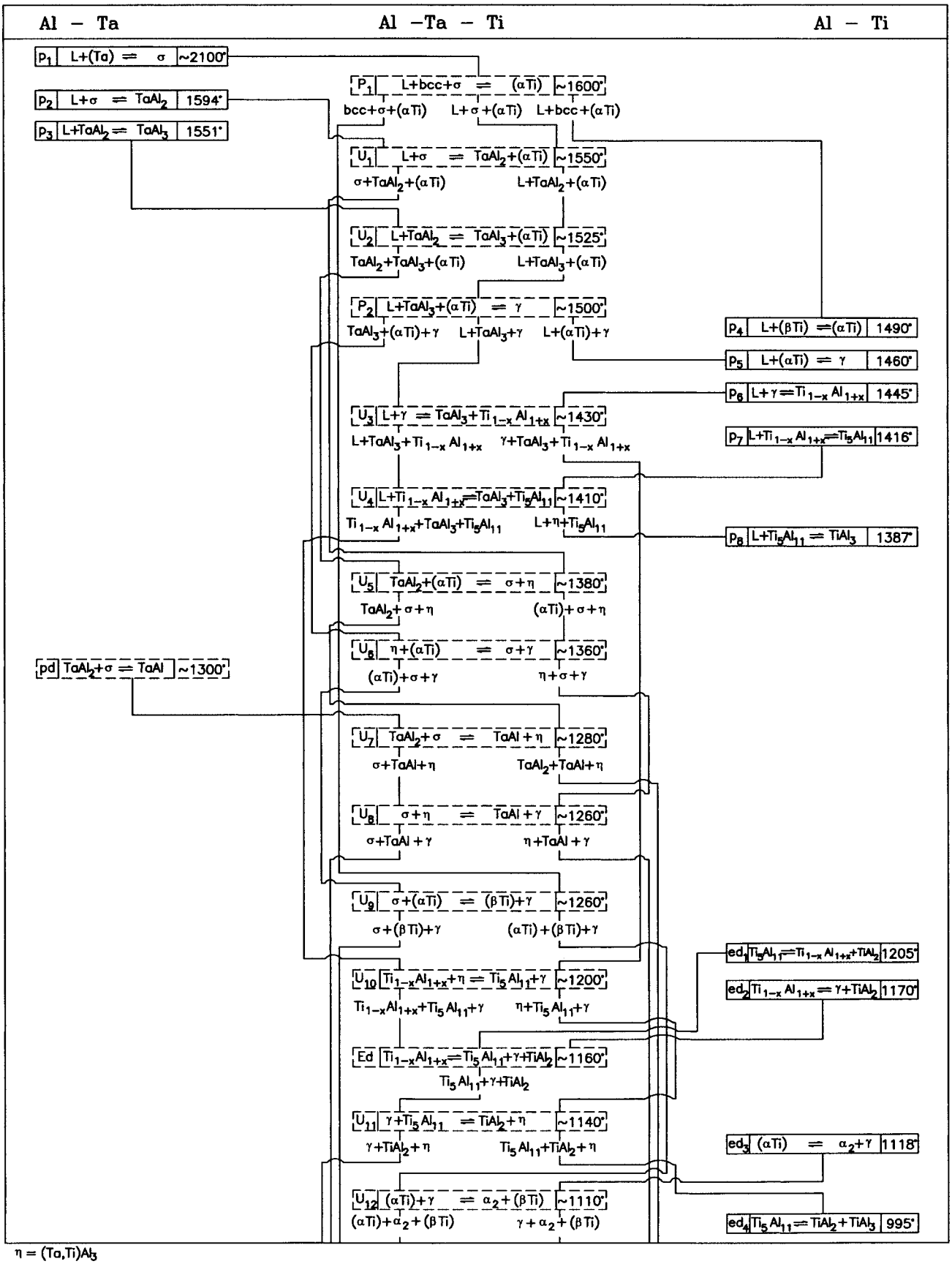


Fig. 6 Al-Ta-Ti isothermal section at 1100 °C [1993Jew]

ential thermal analysis was done at a heating/cooling rate of 10-30 °C/min. Using their own experimental results and the literature data, [1995Wea] constructed isothermal sections at 1450 and 1350 °C. The section at 1450 °C shows an island-like γ phase, consistent with the conclusion of [1992McC] that the γ phase nucleates peritectically in the ternary region. However, the temperature of this section has to be somewhat higher than that of the binary peritectic reaction L ↔ (αTi) + γ (1460 °C) [2005Rag]. The isothermal section of [1995Wea] at 1350 °C is redrawn in Fig. 3 to agree with the accepted binary data. The solubility of Ta in (αTi) is smaller than that at 1440 °C (Fig. 2), but still more than 20 at.%. The solubility of Ta in γ is, however, larger at 1350 °C at 20 at.% as compared with 12 at.% at 1440 °C. $TaAl_3$ and $TiAl_3$ form a continuous solid solution (η) below 1387 °C. This solid solution is present at 1350 °C (Fig. 3).

Figure 4 shows an isothermal section at 1330 °C from the results of [1991Boe]. The section is schematically extended to the Ta-rich region. The triangulations here are the same as those at 1350 °C. Figure 5 shows partial isothermal sections at 1300 and 1200 °C for Ta-poor alloys from the results of [2000Kai]. The full isothermal section constructed by [1993Jew] at 1100 °C is redrawn in Fig. 6. The ordered *B*2 phase is present in the Al-rich end of the bcc phase,

Table 1 Al–Ta–Ti tentative reaction sequence down to 1100°C



separated by a second-order phase boundary. TaAl dissolves up to ~7 at.% Ti. The solubility of Ti in $TaAl_2$ is negligible at this temperature.

A tentative reaction scheme, consistent with the liquidus projection (Fig. 1) and the isothermal sections (Fig. 2-6), is given in Table 1. No distinction is made between the ordered and disordered bcc forms. All invariant reactions are placed in broken boxes. The temperatures of these reactions are notional values. They merely indicate their likely sequence with falling temperature. The scheme extends down to about 1100 °C and does not include the temperature range of the formation of the ω-related phases.

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