Geometrical Construction of Liquidus Phase Relations in Tetrahedrons: A Case Study of a Fo-Wo-An-Qtz System at Atmospheric Pressure

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A graphical approach is one of the most powerful techniques of modern petrologic investigations for predicting liquidus phase equilibria. The current situation with this approach is, however, such that ample experimental results on liquidus equilibria for petrologically important quaternary systems are presented only in the form of projections of compositional data from within the tetrahedron to one of the bounding or interior ternary planes. Meanwhile, in many instances currently available information on liquidus phase relations in ternary systems scattered over various sources is quite enough for graphical constructions of volume phase relationships in tetrahedrons. To demonstrate the potential of the volume representtation we took advantage of experimental results for isoplethic section Ol-Cpx-Pl-Qtz (Grove et al., 1982, 1983) and two subsystems of the quaternary system CaO-MgO-Al_2O_3-SiO_2 (CMAS) - Fo-Wo-An-Qtz (Longhi 1987) and Sp-Fo-An-Ak (O'Hara and Biggar, 1969; Schairer and Yoder, 1969; Yang et al., 1972, etc.). The standard approach for graphical analysis of phase equilibria described by Schreinemakers (1965) was applied in our constructions.

As a result three new tetrahedron phase diagrams (Ol-Cpx-Pl-Qtz, Fo-Wo-An-Qtz and Sp-Fo-An-Ak) have been constructed using available information on liquidus phase relations in several bounding and interior ternary planes. By way of illustration only one of these diagrams - Fo-Wo-An-Qtz is discusses here. The most comprehensive study of this system has been carried out by Longhi (1987) and incorporates results of all previous investigations. In this system, Longhi determined 20 divariant surfaces, 24 univariant boundary curves and 7 invariant points. Three projected planes, Wo-Fo-Qtz, Wo-En-An and Qtz-Fo-An, have been employed to present the compositional data of the study and to portray liquidus phase boundaries. The overall comprehension of the topology of this rather complex liquidus system is hampered by the fact that it is impossible to portray the relationship among all divariant surfaces, univariant lines and invariant points on a certain single plane. Therefore, an attempt has been made to compensate for this deficiency by constructing a tetrahedral phase diagram of the system Fo-Wo-An-Qtz (Fig. 1a), which is subdivided by a thermal barrier Qtz-Di-An into two independent subsystems Fo-Di-An-Qtz and Di-An-Qtz-Wo (Fig. 1b). The main advantage of the diagram (Fig. 1a) is that the relationships among all topological elements of the system (surfaces, lines and points) can be observed on one diagram. Two important points following from a volume analysis of the diagram are worthy of notice here. First, the analysis confirms that the invariant points 4 and 6 are distributive (Longhi, 1987) rather than peritectic as was deduced by Libourel et al. (1989). This conclusion follows from the fact that the Alkemade's Theorem requires the temperature on the univariant lines pr+oen+an+l and oen+pig+di+l to decrease in the direction from the invariant points involved toward a Qtz apex rather than the reverse (Fig. 1). Second, two new invariant points have been identified within the subsystem Di-An-Qtz-Wo (8 – wo+pswo+di+an+l and 9 – qtz+wo+pswo+di+l). Their existence stems from the fact that on the boundary faces Qtz-Di-Wo (Levin et al., 1964) and Di-An-Wo (Osborn, 1942) the liquidus fields of diopside and pseudowollastonite are separated by that of wollastonite, whereas, within a tetrahedron, these phases occur together in invariant association qtz+pswo+di+an (Longhi, 1987).

This study suggests that the volume representation in combination with plane projections may give much more penetrating insight into phase equilibria relations, the nature of topological elements (surfaces, lines, points) and understanding of experimental and natural trends of crystallizations. Together with an algebraic method (Presnall, 1986; 1991) the volume representation of phase equilibria can facilitate the determination of equilibrium crystallization paths in multicomponent systems. The constructed volume diagrams can potentially be used by concerned investigators for prediction and explanation of low-pressure

crystallization sequences in their experimental investigations and study of igneous complexes (e.g., Irvine, 1970, Dubrovskii, 1998; Latypov et. al., 2001).

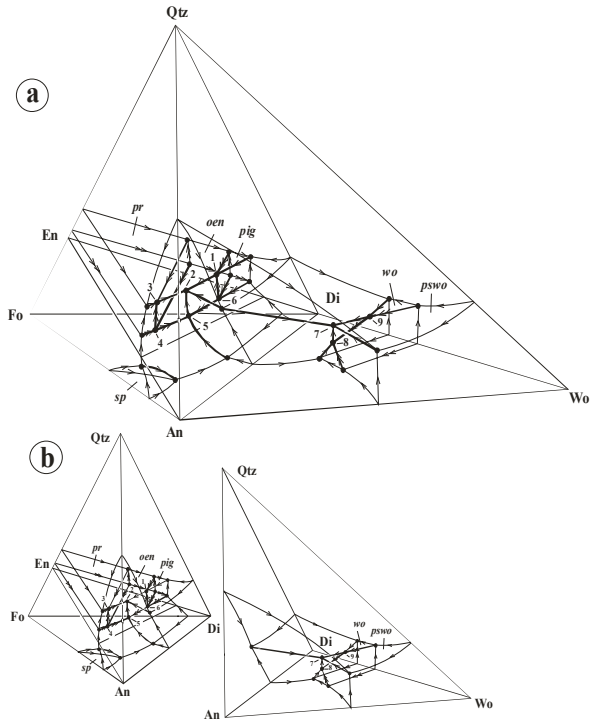

Figure 1. *Liquidus phase relations in the tetrahedron Fo-Wo-An-Qtz (à) at atmospheric pressure (wt. %) constructed mainly from data of Longhi (1987). The relative position of 9 invariant points is illustrated. Bounding ternary faces are taken from the following sources: Fo-Di-Qtz (Kushiro, 1972; Longhi and Boudreau, 1980), An-Fo-Qtz (Andersen, 1915), An-Di-Qtz (Clark et al., 1962) An-Fo-Di (Osborn and Tait, 1952), Qtz-Di-Wo (Levin et al., 1964), Di-An-Wo (Osborn, 1942), and An-Wo-Qtz (Osborn and Muan, 1960; Gentile and Foster, 1963). The tetrahedron is subdivided by a thermal barrier Qtz-Di-An into two subtetrahedra Fo-Di-An-Qtz and Di-An-Qtz-Wo (b). Heavy liquidus lines are in the interior, and fine dotted liquidus lines are on the faces of the tetrahedron. One and two arrows indicate cotectic and reaction lines, respectively. Arrows point towards decreasing temperature. Invariant points in the interior of the tetrahedron are shown as open circles. Ternary points on the faces of the tetrahedron are shown as solid circles. The explanations to all invariant equilibria are summarized in the Table.*

Table 1. *Phase equilibria to subsystems Fo-Di-An-Qtz and Di-An-Qtz-Wo (Fig. 1) Abbreviations Ol (ol) – olivine, Cpx (cpx) – clinopyroxene, Pl (pl) – plagioclase, Qtz (qtz) – quartz, Fo (fo) – forsterite, Di (di) – diopside, An (an) – anorthite, En (en) – enstatite, Wo (wo) – wollastonite, Ak (ak) – akermanite, Sp (sp) – spinel, pr – protoenstatite, oen - orthoenstatite, pswo – pseudowollastonite, l – liquid. Capital and lower case letters denote components and phases, respectively.*

Notation	Phase equilibria
1	qtz+oen+di=l+pig
2	qtz+oen+di+an=l
3	qtz+oen+an=l+pr
4	oen+pl=l+fo+pr
5	oen+di+an=l+fo
6	oen+di=l+fo+pig
7	pswo+di=l+qtz+wo
8	pswo+di+an=l+wo
9	qtz+pswo+di+an=l