

THE ARCHITECTURE OF THE OL-PL-QTZ PSEUDOTERNARY LIQUIDUS DIAGRAM; J. Longhi and V. Pan, Dept. Geology & Geophysics, Yale Univ., P.O. Box 6666, New Haven, CT 06511.

The Ol-An-Qtz(SiO_2) pseudo-ternary diagram in mole units (Fig. 1a) developed by (1) has been widely used among lunar petrologists working with highlands compositions to portray bulk compositions and predict crystallization sequences of liquids. Two important restrictions to observe are that the liquidus boundaries are appropriate only for liquids with a limited range of Mg [$=Mg/(Mg+Fe)$], i.e. 0.7-0.5, and with low concentrations of alkalis similar to those in KREEP-basalts. Appropriate modifications of this diagram have been employed in studies of high-Ti mare basalts and eucrites (2,3). New experimental data (4) allow the compositional dependence of the liquidus boundaries to be mapped out as functions of Mg and An (the normative plagioclase composition). In addition, there are compelling reasons for changing the units of the diagram from moles to oxygen units.

Fig. 1b illustrates the pseudo-ternary diagram replotted in terms of oxygen units after (5). Comparison of Figs. 1a and 1b demonstrates that oxygen units reproduce volume proportions of minerals more faithfully than do mole units. Thus oxygen units will prove more useful in the comparison of compositions and modes. Fig. 1a also demonstrates that mole units may combine in a non-linear fashion, i.e. a mixture of equal moles of orthopyroxene and anorthite does not plot midway between these two components. This effect arises from the "non-conservative" nature of mole units (6) in contrast to conservative units based upon weight, numbers of cations, or numbers of oxygen. Consequently, mole-based diagrams can easily give misleading impressions about composition. Therefore, we recommend that oxygen units replace mole units in projections.

Fig. 2 (oxygen units) illustrates the inherent compositional dependence of liquidus boundaries in the pseudo-ternary system due to variations in Wollastonite component, i.e. "excess" CaO , when Mg and An are constant. In other words, even in the simple CMAS system projected phase boundaries are not simple lines. The most significant effects of variable Wo component occur in the vicinity of the spinel field, where it can be seen that the positions of the ol + sp and an + sp boundaries are strong functions of Wo content of the liquids.

Heavy dashed lines in Fig. 3 illustrate the positions of liquidus boundaries in the pseudo-ternary diagram as a function of Mg with An fixed approximately at lunar levels (~ 0.9). This family of diagrams is appropriate to melts of proposed whole Moon compositions, the parental magmas of ferroan anorthosites, low-Ti mare basalts, and eucrites. There are two major effects of decreasing Mg : one is the expansion of the plagioclase phase volume toward the Ol- SiO_2 join; the other is the pinching out of the low-Ca pyroxene phase volume as the lpyx/sil boundary overtakes the lpyx/ol boundary and generates a boundary between the ol and sil fields in liquids with Mg 0.15. The effect of decreasing An (or increasing alkalis) is opposite to that of Mg on the plagioclase liquidus field: at high Mg the two effects are nearly balanced; at low Mg the An effect dominates. Because liquids saturated with the assemblage ol + pl + lpyx plot on the high-Si side of the Opx-Pl join, olivine will always be in reaction with such liquids and thus will be lost during fractional crystallization. In plagioclase-undersaturated liquids the ol/lpyx boundary changes from a reaction curve to a cotectic as Mg decreases, but the change occurs at a lower Mg than is apparent. At Mg 0.6 the ol/lpyx appears nearly straight and intersects the Ol- SiO_2 join between the Ol and Opx projection points, thus suggesting a cotectic or "even" curve. However, a tangent drawn to this curve of constant Mg does not intersect the "instantaneous" solid composition along the Ol- SiO_2 join. The combined effects of decreasing Mg during crystallization of olivine and pyroxene and the movement of the ol/lpyx boundary away from SiO_2 with decreasing Mg require that the true instantaneous solid composition lies at a higher SiO_2 position along the Ol- SiO_2 join. The magnitude of this effect can be appreciated by noting that olivine reactions have been observed in plagioclase-undersaturated liquids with Mg low as 0.4 (7,8).

The most direct application of these phase diagrams concerns the evolution of liquids residual to the formation of lunar ferroan anorthosites (LFA). Given an approximate Mg of 0.4 for the liquids that formed the LFA (eg. 9), residual liquids would have had Mg values that were lower still. Figs. 3d and e require that continued fractional crystallization of such liquids saturated with pigeonite, augite, and calcic plagioclase would have quickly produced saturation with a silica phase (probably tridymite) followed soon thereafter by the disappearance of pigeonite and the reappearance of Fe-rich olivine. Predictably then, a succession of melanocratic olivine-tridymite gabbros or granitoids should accompany the LFA, if the LFA formed in near-surface layered intrusions as suggested by serial magmatism models (eg. 10). Although estimates of proportions of rock types are strongly model dependent, 10 volume % is a conservative estimate of the amount of residual liquid at the onset of tridymite crystallization from a liquid parental to the LFA that was initially saturated with olivine and plagioclase. Since even under the most favorable conditions the LFA would themselves only be a fraction of the original volume, the volumetric ratio of tridymite gabbros to LFA should be non-negligible in simple petrogenetic models. The absence of such tridymite gabbros argues against the genesis of LFA during simple serial magmatism.

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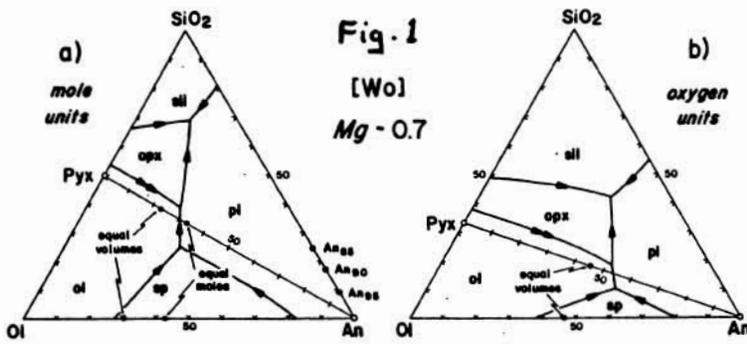


Fig. 1. The Ol-An-Qtz pseudoternary diagram in mole units (a) after (1) and in oxygen units (b) after (5). Plagioclase compositions do not plot at the An corner in la because Na_2O and K_2O are ignored in this projection. Volume proportions were calculated with Mg in ol and $opx = 0.7$; plagioclase is pure anorthite.

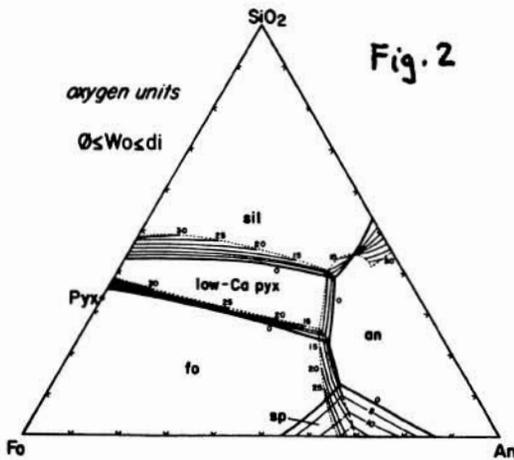


Fig. 2. The shift in position of liquidus boundaries in a portion of the CMAS system as a function of Wo ($CaSiO_3$) after (4). Contours are in % Wo (oxygen units) above the Fo - An - SiO_2 ternary join (heavy solid curves). Dotted curves are the terminations of the various surfaces where they intersect the diopside liquidus surface. For example, the $fo + an$ liquidus surface terminates against the di surface thereby generating a $fo + an + di$ liquidus curve.

Fig. 3. Shifts in position of liquidus curves involving ol, pl, lpyx (low-Ca pyroxene), and silica as a function of Mg in lunar-like compositions (heavy dashed lines) and terrestrial compositions (dash-dot lines) after (4). Asteriks are compositions of fine-grained Apollo 12 and 15 quartz-normative basalts. Solid star is average composition of eucritic liquids saturated with ol + pl + lpyx (3).

