

divariant and may be represented as a surface in a TX prism. For silicate systems containing a volatile component such as  $\text{H}_2\text{O}$ , a liquidus surface may be terminated by an isobaric field boundary giving the locus of liquids that are saturated with respect to two phases, one crystalline, and one a vapor phase; this is a vapor-saturated field boundary. The  $\text{H}_2\text{O}$ -saturated field boundaries in each of the ternary systems  $\text{CaO-MgO-H}_2\text{O}$ ,  $\text{CaO-SiO}_2\text{-H}_2\text{O}$ , and  $\text{MgO-SiO}_2\text{-H}_2\text{O}$  are AB, AC, and BC, respectively (Fig. 2). The liquidus field boundaries of ternary systems extend into quaternary tetrahedra as isobaric divariant surfaces; the ternary field boundaries

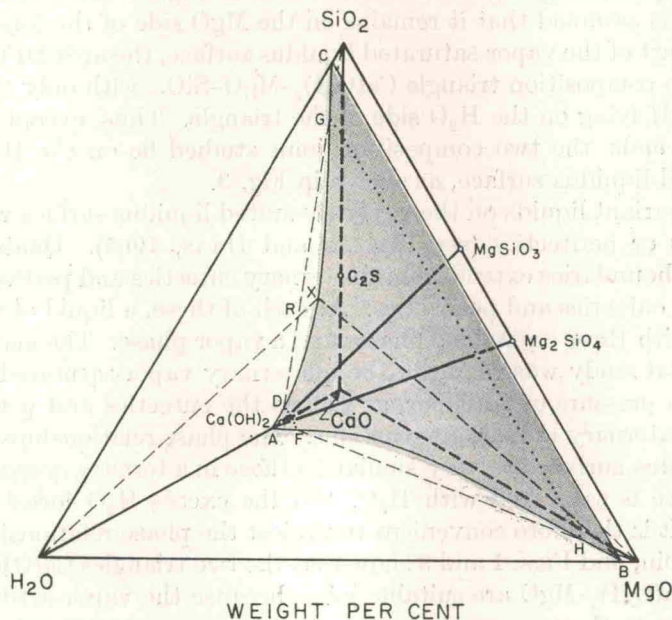


Fig. 3. The vapor-saturated liquidus surface ABC (shaded) connecting the ternary vapor-saturated liquidus field boundaries AB, BC, and AC shown in Fig. 2. The composition triangle  $\text{Ca(OH)}_2\text{-MgO-SiO}_2$  intersects the shaded surface along the dotted lines DF and GH. The upper face of the compatibility tetrahedron  $\text{C}_2\text{S-Ca(OH)}_2\text{-MgO-H}_2\text{O}$  intersects the shaded surface along the dashed line XB, which is therefore a thermal maximum on the surface.

AB, AC, and BC in Fig. 2 form the edges of the quaternary vapor-saturated liquidus surface shown schematically in Fig. 3. The approximate position of the shaded surface ABC can be ascertained from Figs. 1 and 2. The vapor-saturated liquidus surface is *not* a normal liquidus surface; the characteristics of such a surface have been discussed by WYLLIE and HAAS (1965).

The dashed lines in Fig. 1 delineate the composition triangle  $\text{Ca(OH)}_2\text{-MgO-SiO}_2$ , which includes the two composition joins studied, and the tetrahedron  $\text{Ca}_9\text{SiO}_4\text{-Ca(OH)}_2\text{-MgO-H}_2\text{O}$ . The dashed lines can also be located in Fig. 2. The composition triangle intersects the upper face of this tetrahedron in the line RSTP (Fig. 1), with S and T lying on the enstatite and forsterite joins, respectively. The composition triangle also intersects the ternary field boundaries in the points

D, F, G and H, as shown in Fig. 3, and it intersects the quaternary surface ABC along the dotted lines DF and GH. The positions of the lines are only estimated, but there is little possibility of variation from the plotted positions. The upper surface of the  $\text{Ca}_2\text{SiO}_4\text{-Ca(OH)}_2\text{-MgO-H}_2\text{O}$  tetrahedron,  $\text{Ca}_2\text{SiO}_4\text{-MgO-H}_2\text{O}$ , intersects the vapor-saturated liquidus surface in the dashed line XB in Fig. 3. The line XB is a thermal divide on the vapor-saturated liquidus surface, corresponding to the thermal divide  $\text{Ca}_2\text{SiO}_2\text{-MgO}$  of the anhydrous system (Fig. 2) in the presence of excess  $\text{H}_2\text{O}$  vapor. The line of intersection of the vapor-saturated liquidus surface with the triangle  $\text{Ca}_2\text{SiO}_4\text{-Ca(OH)}_2\text{-MgO}$  is not illustrated in Fig. 3. It would extend from F to H, and it is assumed that it remains on the MgO side of the forsterite join.

The main part of the vapor-saturated liquidus surface, the area DFGH, lies on the CaO side of the composition triangle  $\text{Ca(OH)}_2\text{-MgO-SiO}_2$ , with only the small areas ADF and BCGH lying on the  $\text{H}_2\text{O}$  side of the triangle. Thus, except for small portions at either ends, the two composition joins studied lie on the  $\text{H}_2\text{O}$  side of the vapor-saturated liquidus surface, as shown in Fig. 3.

Isobaric invariant liquids on the vapor-saturated liquidus surface will be referred to as eutectics or peritectics (see WYLLIE and HAAS, 1965). Quaternary vapor-saturated field boundaries extend from the ternary eutectics and peritectics and meet at quaternary eutectics and peritectics. At each of these, a liquid of fixed composition coexists with three crystalline phases and a vapor phase. The main objective of the experimental study was to locate the quaternary vapor-saturated liquidus field boundaries at a pressure of 1 kilobar, as well as the eutectics and peritectics corresponding to quaternary univariant reactions. The phase relationships on the vapor-saturated liquidus surface are very similar to those in a ternary system, except that the liquid phase is saturated with  $\text{H}_2\text{O}$ , and the excess  $\text{H}_2\text{O}$  forms an additional vapor phase. It is therefore convenient to project the phase relationships from  $\text{H}_2\text{O}$  onto a planar join, and Figs. 1 and 3 show that the two triangles  $\text{Ca(OH)}_2\text{-MgO-SiO}_2$  and  $\text{Ca}_2\text{SiO}_4\text{-Ca(OH)}_2\text{-MgO}$  are suitable joins, because the vapor-saturated liquidus surface lies close to them.

## EXPERIMENTAL RESULTS

### *Phase fields intersected*

Figure 4 illustrates the phase fields intersected at 1 kilobar pressure in the temperature range 700–900°C by parts of the enstatite join and the forsterite join. The positions of critical runs are plotted, and appropriate details are listed in Table 1. The criteria for the recognition of a trace of vapor in the small samples that we employed are not unambiguous, but there is evidence for the presence of vapor in all runs completed. This is consistent with the estimated position of the vapor-saturated liquidus surface in Fig. 3.

On the  $\text{Ca(OH)}_2$  side of the compositions S and T (Figs. 1 and 4), five four-phase elements are intersected by the enstatite and forsterite joins, with a sixth being required by the phase relationships in the enstatite join. In each join, these are arranged around two isothermal lines representing isobaric invariant reactions:

