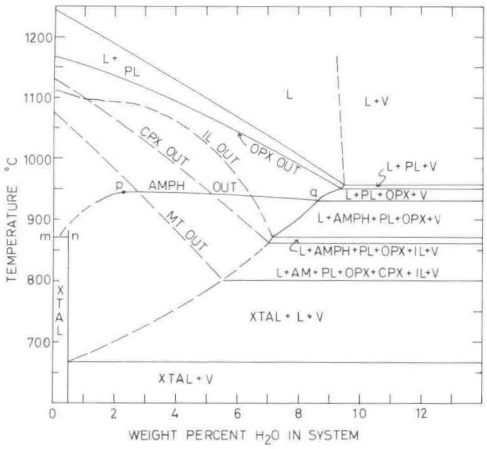

Figure 8. Melting relations in the system Mount Hood andesite–H_2O at 5 kb. Constructed curves are long dashed where run data are approximate.

the system only if the relative amounts of crystals and liquid are known. In Figure 8, on the other hand, the abscissa of the section is bulk composition of the system and gives no information on water content of the melt, except, of course, at the liquidus. Another difference is the extent of fluid-absent regions; in the system andesite–H_2O–CO_2, fluid exists even when the melt is H_2O undersaturated, whereas in the system andesite–H_2O, the melt can be H_2O undersaturated only in a fluid-absent region.

Solidus

In andesite–H_2O–CO_2, the solidus melting reaction is divariant, and its temperature, at any pressure, depends on the composition of the fluid (Fig. 4). Although Figure 4 shows the isobaric solidus as a smooth curve, in reality a break must occur at point b, where it intersects the divariant amphibole dehydration curve ab. The segment bf is a melting reaction not involving amphibole.

Point b is one point on a univariant curve which is formed by the loci of intersection of X_{H_2O} contours of the solidus and amphibole dehydration reactions. In the system andesite–H_2O, the same univariant reaction is the fluid-absent solidus, shown in *P–T* projection in Figure 1 and in *T–X* section in Figure 8 as line mn. Its temperature of 880° at 5 kb is the temperature of b in Figure 4. In andesite–H_2O (Fig. 8), beginning of melting occurs only by this reaction (at 880° at 5 kb) or by the fluid-present reaction (785° at 5 kb).

Liquidus Phases

As Yoder (1969) has noted, experimental melting relations of many andesite suites correspond to their petrography only if the magma is assumed to contain a small amount of H_2O. In Mount Hood andesite, 2 percent or more H_2O substantially reduces the melting interval between plagioclase and orthopyroxene (Fig. 8). In Paricutin andesite, 2 percent H_2O changes the liquidus phase to orthopyroxene, and 6 percent nearly places clinopyroxene on the liquidus (Fig. 4).

Amphibole Stability

Subsolidus stability of amphibole is governed by its dehydration reaction (curve ab in Fig. 4). In the system andesite–H_2O–CO_2, amphibole may not be a subsolidus phase when CO_2–rich fluids are present. In andesite–H_2O, on the other hand, amphibole is always a subsolidus phase (at 5 kb). It is often erroneously stated that the intersection of the H_2O–saturated solidus and amphibole-out curve (500 b for Mount Hood andesite; Fig. 1) is a limiting f_{H_2O} for crystallization of amphibole-bearing assemblages. Inasmuch as f_{H_2O} at b is 1,690 b, at any lower f_{H_2O} (at 5 kb) an amphibole-free rock will crystallize.

In the melting range, amphibole no longer breaks down by dehydration, but by one of several *melting* reactions. At H_2O–saturated conditions at 5 kb, amphibole in Mount Hood andesite melts at 930° (g, Fig. 4) to one or more (unknown) solid phases and to a liquid which must contain 9.5 percent H_2O. An incongruent reaction is postulated by analogy with basaltic melting relations (Holloway and Burnham, 1972). The melting temperature is considerably less than the temperature (c) of the metastable dehydration curve. At H_2O–undersaturated conditions, $f^m{}_{H_2O} < f^\circ{}_{H_2O}$, and the assemblage of amphibole, liquid, fluid, and other crystalline phases must melt at a higher temperature. The temperature increase in andesite (Fig. 4) at 5 kb is not large, but is more pronounced at higher pressure in basalt (Hill and Boettcher, 1970) and in pargasite–H_2O–CO_2 (Holloway, 1973). An equivalent effect is seen in andesite–H_2O (Fig. 8), as along *pq* $f^m{}_{H_2O} < f^\circ{}_{H_2O}$.

An isobaric temperature maximum of

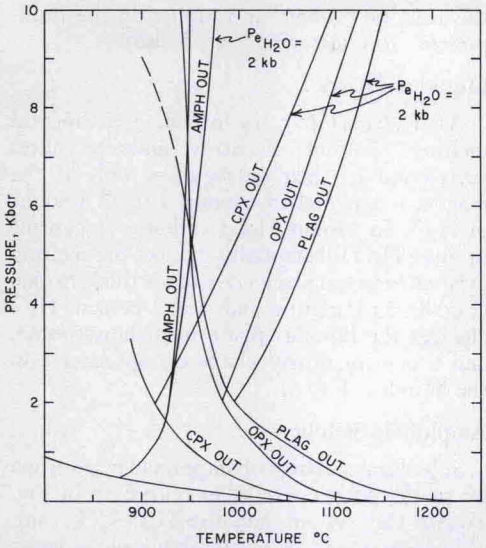

Figure 9. P_{eH_2O} isobaric melting curves for Mount Hood andesite.

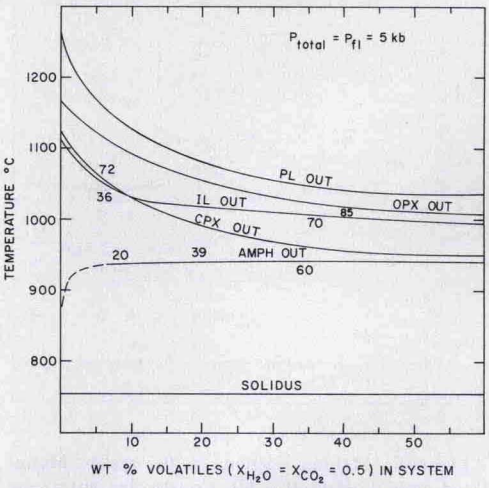

Figure 10. Relation of melting curves to percent volatiles ($H_2O + CO_2$) in the andesite–H_2O–CO_2 system at 5 kb.

stability is reached at d in Figure 4 and at p in Figure 8, points at which the melting curve breaks to intersect the solidus. Theoretical analysis of model systems (Eggler, in prep.) indicates that these maxima occur along *restricted univariant reactions*, at which a hydrous phase melts directly to solid phases and liquid; H_2O, other than that in the hydrous phase, is neither consumed nor released in the reaction. Along dg (Fig. 4), H_2O, in addition to that in the amphibole, must be supplied to saturate the melt, as in a "normal" melting reaction of an anhydrous silicate phase; along bd (Fig. 4) and np (Fig. 8), amphibole melts to a H_2O–poor liquid. Sufficient H_2O is evolved from the amphibole to saturate that liquid and to melt additional silicates in the process. The shape of curve bdg, only suggested by experimental runs, can be derived theoretically and has been dramatically confirmed by equivalent curves for pargasite–H_2O–CO_2 (Holloway, 1973).

P_{eH_2O} Isobars

P_{eH_2O} isobars have been constructed for Mount Hood andesite melt in Figure 9. They are constructed from T–X sections, such as in Figure 4. Because $X^{fl}{}_{H_2O}$ is assumed equal to $f_{H_2O}/f^{\circ}{}_{H_2O}$, P_{eH_2O} corresponding to any $X^{fl}{}_{H_2O}$ and, accordingly, f_{H_2O}, may be read from H_2O thermodynamic tables.

These isobars emphasize that the relative positions of melting curves determined at H_2O–saturated conditions ($P_{eH_2O} = P_{total}$) are not the positions for the same P_{eH_2O} at other total pressures. Their positions are a function of temperature, total pressure, P_{eH_2O} (or, equivalently, $X^{fl}{}_{H_2O}$ or $f^{m}{}_{H_2O}$), and, in some cases, f_{O_2}. If the assumptions stated in this paper are correct, their position will not change whether H_2O is the only volatile species or whether $H_2O + CO_2$ are present.

Effect of Fluid-Phase Abundance

We have so far mentioned the composition of the fluid phase but not the amount of the phase present. In terms of phase relations, the amount of fluid present has no effect. Yet in assessing a crystallization history of a natural magma, the amount present at any time must be considered. Figure 10 illustrates the principle. A T–X section is constructed, in which X is the weight percent volatiles present, of composition 50 mole percent CO_2 – 50 mole percent H_2O, in a rock–H_2O–CO_2 system. The subsolidus fluid-phase composition is 50 percent H_2O, no matter how much (X) fluid is present. Above the solidus, H_2O must be partitioned between melt and fluid, so that, if very little fluid is present, that fluid may be very CO_2–rich.

The diagram shows that with an excess of fluid, the amount of fluid has no effect on the