Conditions of formation that could give rise to the appearance of these three important index minerals can be estimated by reference to an internally consistent body of experimental work due to Richardson and coworkers (Fig. 4). Within the stippled area of the diagram, sillimanite, staurolite and cordierite may all form. In other words, the stippled area represents limiting metamorphic conditions for the Glamorgan rocks. By inspection, the limits prove to be 4.5 to 7 kilobars total pressure, and (in round figures) 600 to 700 °C.

Discussion

In any exercise such as the foregoing, choice of experimental curves is obviously critical. In the case of staurolite and cordierite, no problem of choice arises, since Richardson's (1968) study is the only one to delimit clearly the field of mutual stability of the two minerals. However, with sillimanite almost an embarassment of choice exists. The work of Richardson et al. (1969) was used here because of its compatibility with Richardson's other work. Furthermore, it is consistent with Newton's reversals of the kyanite-sillimanite (1966b) and the kyanite-andalusite (1966a) reactions. The biggest problem arises with the sillimanite-andalusite boundary, which is an approximation at best. By comparison with other work (notably Weill 1966, Althaus 1967) it appears possible that the boundary may have been placed at too high a temperature. However, if we take the estimated uncertainty in the location of the triple point (Richardson et al. 1969), we can drawn an extreme, lower temperature sillimanite-andalusite curve consistent with Weill and Althaus. This curve would be approximately as shown by the lower dotted line in Fig. 4.

The temperature limits for the Glamorgan rocks now became 700 °C represented by the staurolite-quartz breakdown as before, and by the extreme triple point at about 580 °C. The upper pressure limit remains the same (7 kb.)—the intersection of the staurolite-quartz curve with the kyanite-sillimanite boundary. The lower pressure limit moves to 3.5 kb., the lowest pressure at which the Glamorgan assemblage staurolite-almandine-quartz is stable.

An important factor not yet explicitly considered is the equilibrium partial pressure of water ($P_{E_{H_2O}}$). The reactions of Fig. 4 were determined under conditions where $P_{E_{H_2O}}$ was equal to P_{load}. Lowering $P_{E_{H_2O}}$ relative to P_{load} would have no effect on the solid-solid boundaries, but the staurolite-quartz reaction under such conditions could be expected to occur at lower temperatures than shown on Fig. 4. Thus 700 °C remains as an upper temperature limit for the metamorphism. In similar fashion the staurolite-almandine-quartz reaction will move down temperature in systems where $P_{E_{H_2O}}$ is less than P_{load}. This cannot result in a broadening of the pressure and temperature limits.

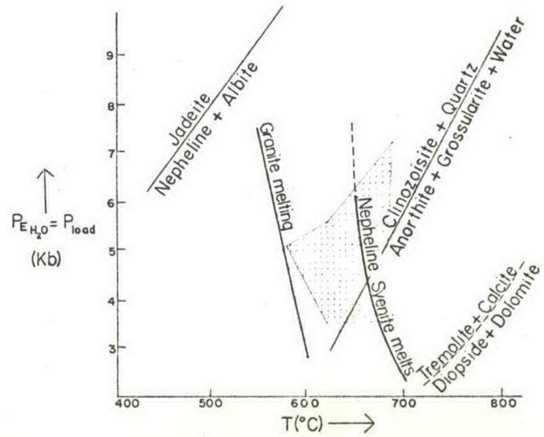

Fig. 5. Additional mineralogical equilibria pertinent to the Haliburton Highlands. The dotted area represents extremal conditions of formation for the Glamorgan rocks. Sources of reaction curves are as follows: Robertson et al. 1957 (Jadeite = Nepheline + Albite); Holdaway 1966 (Clinozoisite + Quartz = Anorthite + Grossularite + Water); Wyllie & Tuttle 1964 (minimum melting curve of granite in presence of Li_2O); Millhollen 1970 (minimum melting curve of nepheline syenite). The equilibrium Tremolite + Calcite = Diopside + Dolomite was calculated by the method of Turner 1967.

The effect of increasing the fugacity of oxygen to values greater than those appropriate to the QFM buffer used by Richardson will probably not increase the pressure-temperature limits of the field in which staurolite and cordierite may coexist (Richardson 1968, p. 485). The presence of MgO in staurolite will probably broaden this field (Richardson 1968, p. 484), but by an amount that is not as yet, predictable.

Some consequences of the proposed limits

The proposed limiting conditions of metamorphism for Glamorgan township have now been widened to 3.5 to 7 kilobars and 580 to 700 °C. If these are reasonable limits, certain predictions can be made by reference to other mineralogical equilibria (Fig. 5).

For example, clinozoisite may be used as a model for epidote, and Holdaway's (1966) breakdown curve for clinozoisite-quartz can be taken as an upper limit for this assemblage, since in the pressure range of interest here, it occurs at higher temperatures than either Newton's (1966c) version of the curve, or Merrin's (1962) curve for epidote- (33% iron component) quartz. From Fig. 5, it would appear likely, therefore, that epidote-quartz would be a stable assemblage in Glamorgan township. This is in fact, the case.

It would further be expected that anatectic granitic melts could have