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P-T-X$_{H_2O}$ Conditions of Sg. Ara Granite, Penang Island, P. Malaysia.

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Abstract: Sg. Ara granite occupies the major part of the southern half of the Penang Island and comprises several textural varieties. The rocks are peraluminous (S-type), and are characterised by the presence of primary muscovite and occasional andalusite. Plagioclase is identified to be the liquidus phase. The stability of andalusite and muscovite, and the implication of liquidus plagioclase are considered with reference to an appropriate granite phase diagram to evaluate the P-T-X$_{H_2O}$ conditions. Sg. Ara granite has probably crystallized under 3–4 Kb pressure (10–15 km) in the temperature range of 680°–780°C, with initial melt water content less than about 7 wt. %.

INTRODUCTION

The granitic complex of Penang Island is a composite body comprising at least three petrographically distinguishable units (cf. Amerizal, 1982). The individual units are not homogenous and comprise both compositional and textural variants. Sg. Ara granite constitutes one such unit that roughly covers the southern half of the Penang Island. Sg. Ara granite has many interesting petrographic features, such as the presence of andalusite and primary muscovite, that can be used to evaluate the P-T-X$_{H_2O}$ conditions of crystallization. The objective of this paper is to consider these petrographic features in conjunction with other petrologic aspects to bear upon the physical conditions of crystallization of the Sg. Ara granite.

GENERAL CHARACTERISTICS

Sg. Ara granite comprises textural variants ranging from coarse grained to fine grained and porphyritic to nonporphyritic. The rocks are prealuminous and have features characteristic of S-type granite of Chappell and White (1974). They are made up of quartz (30–40%), plagioclase (15–25%), microcline (30–45%). Biotite, muscovite, ilmenite and other accessories together usually constitute less than 15%. Andalusite occurs sporadically as small grains. Tourmaline, fluorite and zircon are common accessories. Inclusion of euhedral plagioclase in K-feldspar and other minerals, zoned plagioclase grains containing corroded cores of calcic andesine, some of which are possibly 'restite', provide evidence for an early crystallization of plagioclase and also indicate that it was the liquidus phase.

Muscovite is common in Sg. Ara granite. Secondary muscovites derived from feldspar and biotite are texturally obvious (Fig. 1), but textural features that have been regarded by other workers as indicative of primary muscovite are also frequently observed (Wright and Haxel, 1982; Miller, et al., 1981). Muscovite in Sg. Ara granite may occur as (i) euhedral to subhedral tablets, usually inclusion free, that are not spatially associated with feldspar or biotite, (ii) individual flakes having sharp contact with clear unaltered feldspar and biotite, (iii) intergrown leaves with biotite (Fig. 2)

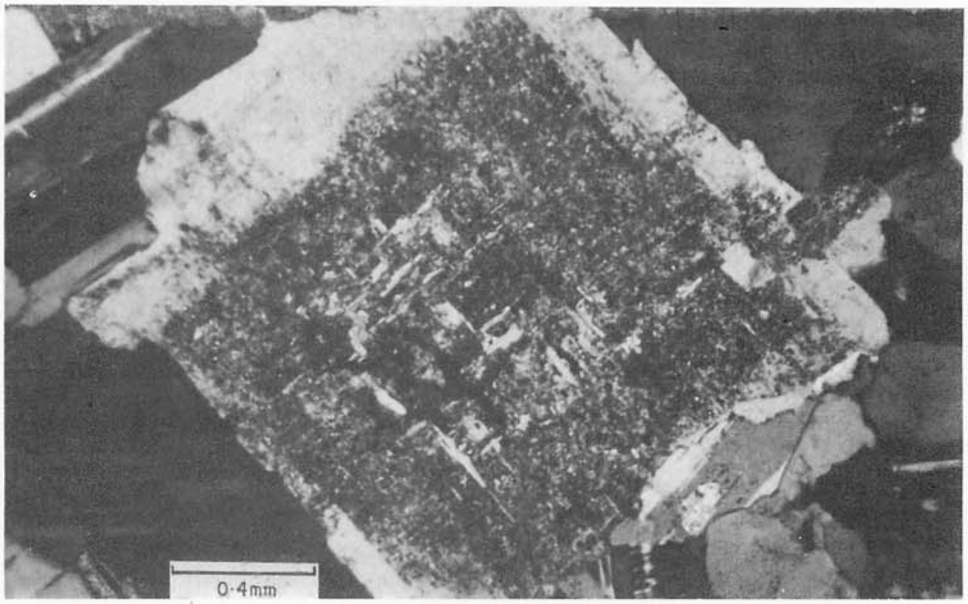

Fig. 1 Development of secondary muscovite along the cleavages and margins of the altered plagioclase. Note the clear albite rim around the altered plagioclase. (Crossed).

Fig. 2 Andalusite mantled by muscovite. Also note the fine biotite lamellae intergrown with muscovite. (Uncrossed).

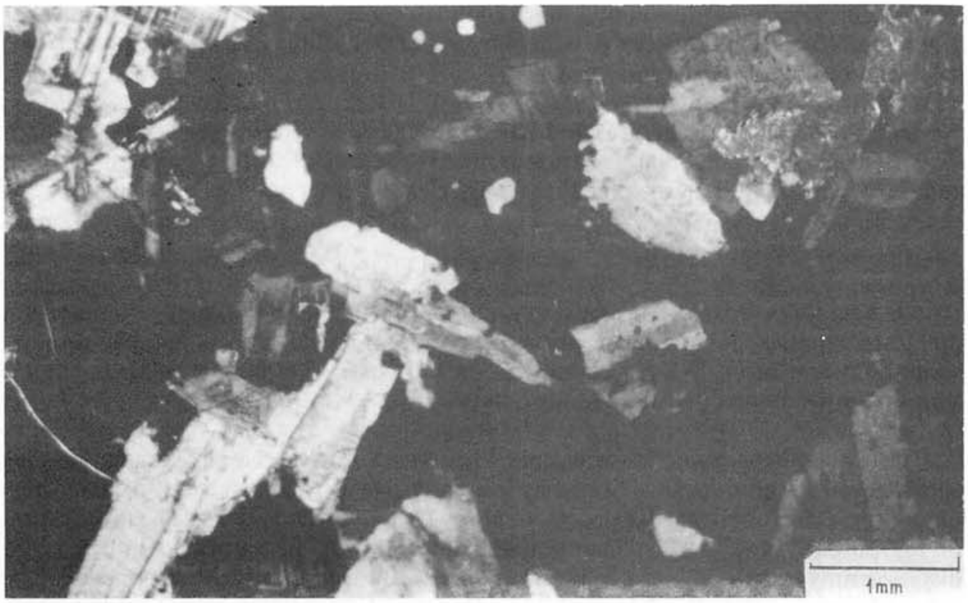

Fig. 3 Large poikilitic microcline grain (in extinction) with inclusions of muscovite, plagioclase and quartz.

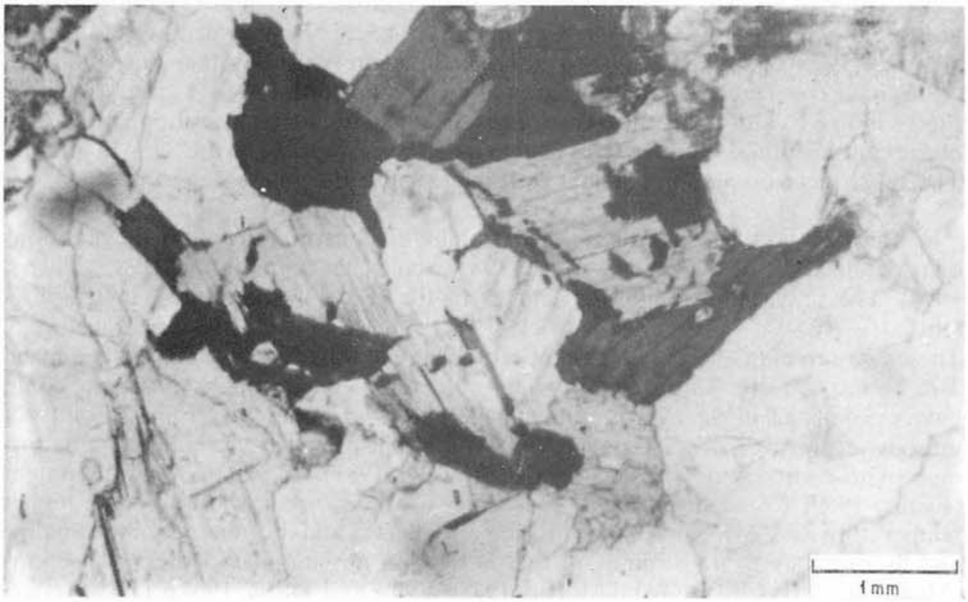

Fig. 4 Muscovite associated with biotite, feldspar and quartz. Biotite and feldspar are unaltered. Note the similar textural mode of occurrence of biotite and muscovite. (Uncrossed).

and (iv) euhedral inclusions in poikilitic K-feldspar (Fig. 3). In many cases the textural mode of occurrence of muscovite is similar to that of biotite (Fig. 4). The presence of primary muscovite thus seems certain.

Andalusite is not abundant and has been observed in a few specimens as small individual grains usually mantled by muscovite (Fig. 2) indicating a reaction between andalusite and melt. Petrographically it is not clear whether andalusite is magmatic or xenocrystic.

P-T-X_{H_2O} CONDITIONS

A reliable estimate of physical conditions is difficult to make as it requires an integrated approach combining various sets of data. However, it is possible to place some limits on the P-T-X_{H_2O} conditions on the basis of muscovite and andalusite stability with reference to the granite solidus.

Certain petrographic information when related to the approximate liquidus surface of the granite composition of interest may also provide some useful constraints on the crystallization history as pointed out by Day and Fenn (1982). The intersection of the plagioclase-alkali feldspar boundary curve with the saturated liquidus, for instance, may be used to limit the pressure or X_{H_2O} if the liquidus feldspar phase can be inferred petrographically. The method of Day and Fenn (1982) is applicable to low-calcium granites of compositions near the thermal minimum of "granite system". Sg. Ara granite satisfies these compositional requirements (see Amerizal, 1982 for chemical and normative compositions). It is not possible to construct the liquidus surface for Sg. Ara granite as necessary data are not available. The average normative composition of Sg. Ara granite (Amerizal, 1982) is close, though not identical, to that of the synthetic R1 granite (Q:Or:Ab:An = 26.5:34:32:7.5) experimentally studied by Whitney (1975) between 2 and 10 kb pressure. Based on Whitney's data, Day and Fenn (1982) have constructed a P-T projection of the liquidus surface of R1 granite which is shown in Fig. 5. This phase diagram applies strictly to the R1 composition, but in view of the compositional similarity it is assumed that it also applies to the Sg. Ara granite. The subsequent discussion is made with reference to this phase diagram.

Many authors have used muscovite stability to constrain the physical conditions of crystallization of acid melts (Price, 1983; Schleicher and Lippolt, 1981; Harris, 1974). The univariant equilibrium curves of the reaction muscovite + quartz = K-feldspar + Al_2SiO_5 + H_2O after Kerrick (1972) and Day (1973) are shown in Fig. 5. These two curves (a and b, Fig. 5) intersect the granite solidus approximately at 4.5 and 3.75 kb respectively. Thus, the minimum pressure at which primary muscovite could have crystallized in Sg. Ara granite can be placed at about 4 kb. The stability of muscovite, however, depends on its composition. The presence of celadonite and ferri-muscovite components (Anderson and Rowley, 1981) as well as high F-content (Evans, 1969) would displace the muscovite breakdown curve towards the higher temperature side. Also, high concentration of F, B, etc., and the presence of tourmaline and fluorite may be a testimony of that in Sg. Ara granite, may depress the solidus (Manning, 1981; Chorlton and Martin, 1978; Wyllie and Tuttle, 1961). The net effect of all these would be to lower the minimum pressure required for primary muscovite, but to what extent is uncertain though Schleicher and Lippolt (1981), and Anderson and Rowley (1981) believe that the stability field of muscovite may move down to 2-3 kb pressure.

It may be noted that the two-feldspar boundary curve intersects the saturated liquidus at about 4.5 kb which is the minimum pressure required for alkali feldspar to be the liquidus phase (Fig. 5). Since plagioclase is the liquidus phase, as pointed out earlier, it may be argued that Sg. Ara granite could not have crystallized at pressure much higher than 4kb, otherwise alkali feldspar would have been the early crystallizing phase. Thus 4kb seems to be the upper pressure limit.

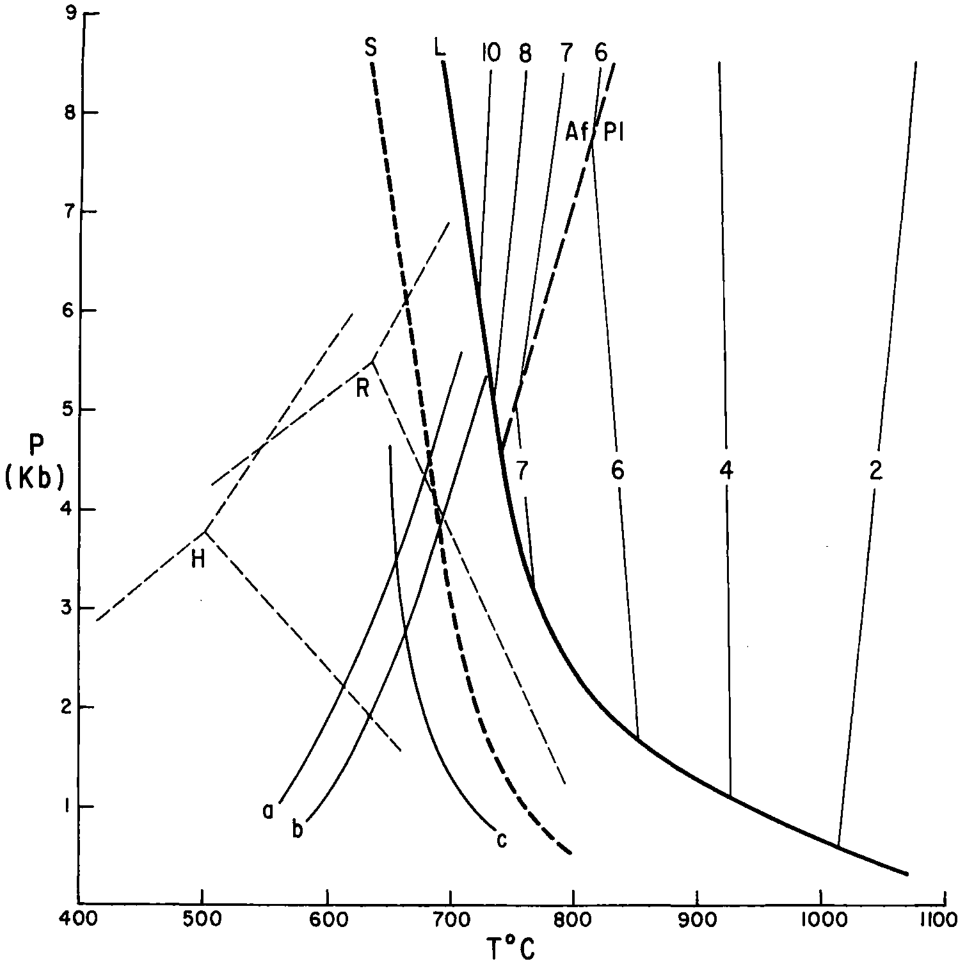

Fig. 5 P-T projection of the liquidus surface of granite composition R1 as constructed by Day & Fenn, 1982. S and L are the solidus and saturated liquidus respectively. Af/PL dashed line is the two-feldspar boundary curve. Fine solid lines with numerical values are the isopleths of water content. Curve 'C' is the minimum granite melting curve shown for comparison. Also shown are the muscovite + quartz stability curves after Kerrick, 1972 (curve 'a') and Day, 1973 (curve 'b'). H and R are the aluminosilicate phase diagrams of Holdaway, 1971 and Richardson et al., 1969, respectively.

The occurrence of andalusite puts further constraints on the pressure, though the use of andalusite as a pressure indicator poses some problem in view of the uncertainties regarding the stability limits of the aluminosilicates. The phase diagrams of aluminosilicates after Holdaway (1971) and Richardson, et al. (1969) are shown in Fig. 5 as H and R respectively, the former being currently favoured by many. The occurrence of andalusite/sillimanite in peraluminous granite is rather common, and in many cases they have been interpreted as magmatic (see Clarke, 1981). The mode of origin of the andalusite in Sg. Ara granite, whether magmatic or xenocrystic, could not be resolved petrographically. If a magmatic origin is assumed, which would be consistent with the phase diagram of Richardson et al. (1969), then the intersection of the andalusite-sillimanite boundary line with the solidus would limit the upper pressure to 4 kb. Holdaway's diagram precludes the possibility of getting magmatic andalusite unless, of course, some special conditions are stipulated such as impurity-induced expansion of andalusite stability field (Strens, 1968) coupled with drastic depression of the solidus due to B, F, etc. Under such conditions, however, the maximum pressure at which magmatic andalusite can form would be much less than 4 kb. If, on the other hand, xenocrystic origin of andalusite is assumed, then the triple points H (about 4 kb) or R (about 5 kb) would define the upper pressure limit irrespective of whether the andalusite xenocrysts are from the source region or from the intruded country rocks.

Based on the above discussion and integrating the estimates derived from primary muscovite, liquidus plagioclase and andalusite, it may be concluded that Sg. Ara granite has probably crystallized between 3 and 4kb pressure. The saturated liquidus temperature at 3 kb is about 780 °C and the solidus temperature at 4kb is about 680 °C (Fig. 5). These values may be taken as the probable range of crystallization temperature.

It is apparent from Fig. 5 that the initial melt water content cannot exceed 7.5 wt. % for a bulk composition similar to R1 if plagioclase is the liquidus phase. If the identification of plagioclase as the liquidus phase for Sg. Ara granite is valid, its initial water content must have been less than about 7.5 wt. %. According to Burnham (1967) water content in excess of 8–9 wt. % is necessary for primary muscovite to crystallize while experimental data of Huang and Wyllie (1981) suggest 6–10 wt. %. It is possible, and seems likely, that Sg. Ara granite with initial water content less than 7 wt. % became progressively more hydrous through crystallization of anhydrous phases like plagioclase until a_{H_2O} was sufficiently high for muscovite to crystallize.

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