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Magmatic epidote: probable absence and implication to the geobarometry of the granitic rocks from Peninsular Malaysia

ANUAR ISMAIL & AZMAN A. GHANI

Department of Geology
University of Malaya
50603 Kuala Lumpur

Abstract: Occurrence and implications of magmatic epidote in granitic rocks is reviewed. The presence of magmatic epidote in granodiorites, tonalites and trondhjemites is commonly used as evidence of magma crystallisation at pressure in the region of 6 to 8 kbar. The epidote is easily identified as they are usually euhedral, overgrowth on euhedral allanite, associated with magmatic flow, included in primary muscovite and have fine scale oscillatory zoning. The concept of magmatic epidote and its pressure is apply to granitic rocks from Peninsular Malaysia. Work on the barometry of Malaysian granitoid based on the aluminium content of amphiboles indicate that the highest crystallisation pressure of the granites is 4.98 kbar, which is below the crystallisation pressure of magmatic epidote. This may suggest that the Peninsular Malaysia granitic magmas may not have crystallised the epidote at low pressure.

INTRODUCTION

The presence of magmatic epidote in granodiorites, tonalites and trondhjemites is commonly used as evidence of magma crystallisation at pressures in the region of 6 to 8 kbar (Naney, 1983; Zen & Hammarstrom, 1984; Brandon *et al.*, 1996). Textural criteria that can be used to distinguish the magmatic epidote from secondary epidote (e.g. subsolidus reaction) are that magmatic epidote is (i) euhedral, weakly pleochroic within biotite (Tulloch, 1979), (ii) an overgrowth on euhedral allanite (Zen & Hammarstrom, 1984; Forizs *et al.*, 1995), (iii) wormy intergrowth with plagioclase, (iv) involvement of epidote in magmatic flow, (v) included in primary muscovite (Sial *et al.*, 1995) (vi) fine scale oscillatory zoning (Evans & Vance, 1987) and (vii) rounded to highly embayed hornblende enclosed in epidote (Zen & Hammarstrom, 1984). Chemical criteria for recognition of magmatic epidote in granitic rocks have also been proposed mainly based on Ps mole fraction (Ps%). A literature review shows different authors' suggestions on Ps% range for the magmatic epidote. They are: (1) 22.95 to 28.82% Ps (Farrow & Barr, 1992), (2) 25 to 29% Ps (Tulloch, 1979, 1986), (3) 23 to 27% Ps (Zen & Hammarstrom, 1984), (4) 19 to 24% Ps (Dawes & Evans, 1991), (5) 21% Ps (Evans & Vance, 1987), (6) 27–29% Ps (Brandon *et al.*, 1996), (7) 20–30% Ps (Roberts & Clemens, 1994), (8) 26–28% (Forizs *et al.*, 1995) and (9) 20–29% (Sial *et al.*, 1995). The aim of this paper is to examine the status of magmatic epidote in the Peninsular Malaysia granitoid and its implication to the geobarometry of the rock.

MAGMATIC EPIDOTE AROUND THE WORLD

Magmatic epidote have been described by many authors (e.g. Zen &Hammarstrom, 1984; Evans & Vance, 1987; Dawes & Evans, 1991; Farrow & Barr, 1992; Sial *et al.*, 1995; Azman, 1997). Zen & Hammarstrom (1984) described the magmatic epidote from the North American Cordillera as faintly to conspicuously pleochroic crystals about the same size as accompanying hornblende and biotite. Allanite forms cores of some epidote crystals. The epidote is always euhedral against biotite, but the same crystals in contact with plagioclase and quartz show highly embayed, wormy contacts that are almost mymerkitic.

In Boulder Country Colorado, epidote occurs as phenocrysts in dacitic dykes along with plagioclase, biotite, quartz, epidote, hornblende, muscovite and garnet (Evans & Vance, 1987). The epidote phenocrysts usually occur as thin prismatic up to 4 mm in length and occur in amounts of as much as 2% of the rock volume. The crystals face are mildly rounded probably due to the incipient resorption in the magma. The core of some crystals may be allanitic.

In the Donegal granites, the occurrence of epidote can be divided into two modes i.e. secondary and primary (magmatic epidote) (Azman, 1997). Secondary epidote occurs (i) associated with sericitisation and alteration of plagioclase and can be seen in all granites and (ii) as skeletal replacive grains in the cores of plagioclase crystals (e.g. in Thorr pluton). Inferred primary epidote is found in the granodioritic rocks of the outer and intermediate unit of the Ardara pluton. In these rocks, euhedral to subhedral epidote occurs as inclusions in biotite but is anhedral against feldspar and quartz (Fig. 1). The features of magmatic epidote described above is contrast to the secondary epidote as the latter usually small and occur as a product of alteration of plagioclase (Fig. 2).

PRESSURE INDICATED BY MAGMATIC EPIDOTE

Several authors showed that the magmatic epidote in granitic magma occurs at high pressure. Naney (1983) synthesized epidote in granodiorite melt at 600 to 700 MPa but not at 200 MPa which indicate a stability of epidote at magmatic condition. Recently, experimental work by Brandon *et al.* (1996) investigated the stability of magmatic epidote in granitic magma. They used gem epidote and reacted it with natural granodioritic glass at various pressures. They found that epidote is stable in granodioritic glass at high pressure (1,150 MPa). At lower pressure (450 MPa) they found that the epidote developed irregular crystal boundaries surrounded by a complex reaction rims similar to the reaction textures above. They suggested that to preserve the biotite/epidote textures described here transport of magma should be very rapid i.e. $<<10^3$ years to the emplacement level. Thus, the Ardara magma most likely would be transported by a dyke rather than a diapiric mechanism because the magma ascent rate of the latter is much slower. The above works indicate that the magmatic epidote can occur in the granitic magmas in the pressure of more than 6 kbar (~ 21 km).

Occurrence of magmatic epidote in granitic plutons Hammarstrom & Zen (1986) showed that the hornblende in the magmatic epidote-bearing plutons typically has Al^{tot} of about 2.0 to 2.6 p.f.u.

PENINSULAR MALAYSIA GRANITOID

The concept of magmatic epidote and its pressure is applied to granitic rocks from Peninsular Malaysia. The Peninsular Malaysia granites are distributed in three parallel belts which have been grouped into 2 granite provinces (Cobbing *et al.*, 1992); the Main Range province with a age range of 200 to 230 Ma and the Eastern province with a range of 200 to 264 Ma. The eastern granitoid province which consists of the Central Belt and the Eastern Belt (Cobbing *et al.*, 1992) comprises of an extended compositional spectrum from gabbro to monzogranite forming small batholiths and small plutons which are generally smaller than those of the Western Belt granitoid. The latter consists of granite (s.s) to granodiorite made up an elongated batholith from north to west central of the Peninsular Malaysia. The Western granite province occurs to the west of a belt containing ophiolite-mélange association which is known as the Bentong-Raub line by Hutchison (1975, 1977). Mitchell (1977) interpreted this ophiolite line to mark a Triassic collision suture separating an eastern Malay Peninsula crustal block and a western Malay Peninsula crustal block.

Western Granite province

In terms of rock types and mineral associations the whole Western Belt granite can be divided into three distinct groups. The first group covers about 90% of the total Western Belt granite volume. The main rock type is a coarse to very coarse grained megacrystic biotite muscovite granite. Two phase variants, however, developed almost everywhere and may be volumetrically important (Pitfield *et al.*, 1990; Cobbing *et al.*, 1992; Mursyidah & Azman, 1999). Aplo-pegmatite and mesogranites are commonly associated with the individual granitic body. Common features of the aplo-pegmatite and mesogranites complex is the development of mineral layering; good examples are found in the Kuala Lumpur Granites (Pitfield *et al.*, 1990); Tanjung Jaga area (Jerai pluton) and south of Tuba island (contact granite with Setul Formation) in the Langkawi Group and occurrence of aplo-pegmatite dykes e.g. Kuala Lumpur Granite (Ng, 1997). Distinct mineralogy of this group is high Al biotite, muscovite (may be primary, Miller

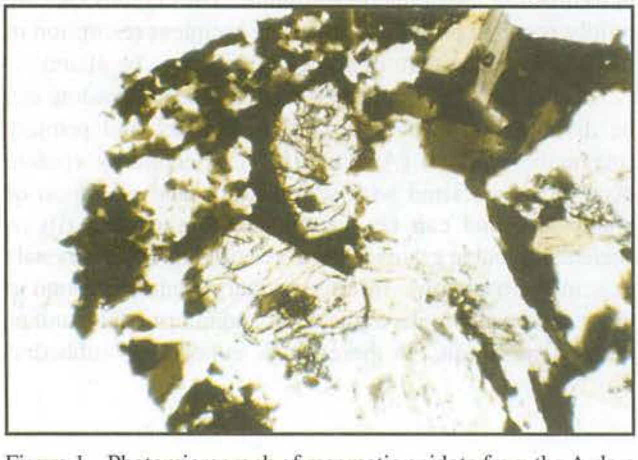

Figure 1. Photomicrograph of magmatic epidote from the Ardara pluton, Donegal. Note that the epidote has euhedral to subhedral margin against biotite but anhedral against feldspar and quartz

Figure 2. Secondary epidote occur as alteration product of plagioclase. Sample from the intermediate margin of Ardara pluton, Donegal.

et al., 1981) and Mn rich garnet (Liew, 1983).

The second group corresponds to the amphibole bearing granite found in several granitic bodies at the northern part of the Western Belt Granite. The Bintang Granite complex is the best example. Common mineralogical assemblages of this complex is low Al biotite + sphene ± actinolitic hornblende (Liew, 1983; Borhan Doya, 1995; Azman *et al.*, 2000). Khoo & Lee (1994) have reported a suite of plutonic rocks consisting of hornblende-biotite quartz monzonite, tonalite, granodiorite and adamellite from the northeasternmost Western Belt Granite. Amphibole bearing enclaves have also been reported in the Bujang Melaka Granite (Singh & Yong, 1982) and Baling Granite. The third group is the felsic volcanic rocks associated with the Western Belt Granite. The best-known volcanic complex is the Sempah Volcanic Complex that is related, both temporally and spatially, to the granite. The Sempah Volcanic Complex occupies the central part of the Western Belt Batholith to the east of Kuala Lumpur city. The complex intruded the Selut Schist (Pre Devonian), Gombak Chert (Late Devonian to Early Carboniferous) and Sempah Conglomerate (Permian) which were collectively known as the Bentong Group (Alexander, 1968). The complex comprises units of tuff lavas, lavas and a distinctive porphyry subvolcanic unit that contains orthopyroxene phenocrysts (Liew, 1983; Chakraborty, 1995). Two main rock types of the complex are rhyodacite and orthopyroxene bearing rhyodacite (Chakraborty, 1995; Singh & Azman, 2000).

Eastern granite Province

The eastern granitoid province which consists of the Central Belt and the Eastern Belt (Cobbing *et al.*, 1992) comprises an extended compositional spectrum from gabbro to monzogranite. The whole province consists of several batholiths such as Boundary Range, Kapal and Stong Complex to the north and Blumut Muntahak the south. As common with other terrains, narrow sedimentary screens often separate these mappable units. The batholiths are surrounded by narrow contact metamorphism aureoles superimposed on low grade metamorphic country rocks (Hutchison, 1977). A biotite ± hornblende monzogranite-granodiorite of variable texture is the most common rock type. Some of the granitic bodies such as Bukit Kemuning, Linden and Jerong batholiths (Cobbing *et al.*, 1992) are associated with gabbroic rocks. Mafic dykes of continental tholeiite, and similar to the magma formed in a within plate tectonic setting are common (Azman 2000a, 2001). The radiometric dating results summarized by Liew (1983) indicate ages of emplacement of the batholiths from Permain to Triassic.

GEOBAROMETRY OF THE PENINSULAR MALAYSIA GRANITOID

Works on the barometry of Malaysian granitoid based on the aluminium content of amphiboles by Hutchison (1989), Azman (2000b), Azman & Kamarul Hadi (2000), Azman & Khoo (unpublished data), indicate that the highest crystallisation pressure of the granites are 4.98 kbar. Hutchison (1989) found that a granitoid samples from Kampung Dong area, Central Belt contain Al^{tot} within the range of 1.31 to 1.77, representing pressures of crystallisation of nearly up to 5 kbar. The average pressure for the Main Range province and Eastern Belt granites are 0.49 to 0.68 kbar and 0.56 to 3.73 kbar respectively. Those from the Central Belt have an average pressure of 2.17 kbar. The geobarometry data also support by the metamorphic assemblage in the country rocks. The country rocks, especially in the Eastern Belt, are mainly of andalusite bearing semi-pelites which limit the pressure at which they were metamorphosed to a maximum of 3.75 ± 0.25 kbar. Recently Azman (2000b) found that the pressure of crystallisation of hornblende from the Noring granite of the Stong Complex give a mean value ranging from 1.89 to 3.08 kbar.

CONCLUDING REMARKS: MAGMATIC EPIDOTE AND PENINSULAR MALAYSIA GRANITOID

Application of hornblende geobarometer to the Peninsular Malaysia granitoid gives a pressure of crystallisation of the granites of 0.49 to 4.98 kbar. The pressure indicate that the Peninsular Malaysia granitic magmas crystallised at a depth of less than 15 km. The works on the magmatic epidote indicate that the mineral crystallised at a depth of more than 21 km. If the hyphothesis of magmatic epidote is correct, the Peninsular Malaysia granitic magmas may not have crystallised the mineral at low pressure.

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