High-resolution $^{40}\text{Ar}/^{39}\text{Ar}$ chronology of multiple intrusion igneous complexes

Application to the Cretaceous Mount Brome complex, Quebec, Canada

K.A. Foland, J.-F. Chen, J.S. Linder, C.M.B. Henderson, and I.M. Whillans

Abstract. The Mount Brome complex of the Monteregean province of southern Quebec, Canada, consists of several major intrusions ranging compositionally from gabbro to syenite. The relative ages of these intrusions have been investigated with high-resolution $^{40}\text{Ar}/^{39}\text{Ar}$ analyses, including a specially designed irradiation configuration to cancel the effects of fluence gradients. Small yet distinct apparent age differences are observed. While a number of analytical and geological factors could be proposed to explain the small variations, evaluation of these suggests the age differences reflect those in emplacement times. The gabbro and nepheline diorite were emplaced within a short span 123.1 Ma ago. Generally more evolved lithologies (biotite monzodiorite, pulaskite, nordmarkite) appear to have been emplaced within a restricted interval 1.4±0.3 Ma later. Whole-rock Rb-Sr systematics do not give acceptable isochrons because of significant scatter interpreted to reflect initial $^{87}\text{Sr}/^{86}\text{Sr}$ heterogeneities resulting from crustal contamination. Considering the variations in initial ratio, the Rb-Sr data are consistent with the $^{40}\text{Ar}/^{39}\text{Ar}$ age.

Geology of Mount Brome

The Mount Brome complex is located in southern Quebec, about 75 km east of Montreal. With an exposed area of approximately 60 km$^2$, it is one of the largest of the Monteregean Hills alkaline intrusions which form an east-west belt more than 200 km long. The basic field and petrographic relations of the complex were described by Valiquette and Pouliot (1977); more recently, Eby (1985) presented chemical and Sr-isotopic data. The Mount Brome complex is composed of a series of intrusions of widely varying composition which were emplaced at a shallow level (see Fig. 1).

According to Valiquette and Pouliot (1977), the gabbro, located in the southern part of the complex, is the oldest unit which was cut by later intrusives thus taking on a crescent shape. Subsequent intrusions are divided into two groups: those inside the gabbroic crescent and those to the outside. The outer group consists of silica oversaturated units emplaced in the order: biotite monzodiorite; microsyenite; and, nordmarkite. The inner group is silica undersaturated with mapped units emplaced in the order: nepheline diorite, pulaskite and nepheline syenite (foyaite). From field observations, the age relation between the two groups is unclear. In addition to these main rock types, minor dike intrusions, including a late stage tinguaitie of mappable proportion, occur but are not discussed here.

Early isotopic work indicated a Cretaceous age for the Mount Brome complex based upon: a 125±8 Ma K-Ar date on biotite from nordmarkite (Lowdon, 1960); and, a $128±3$ Ma date from combined Rb-Sr whole-rock data for Brome and the nearby Shefford complex (Fairbairn et al. 1963). Subsequently, Eby (1984a) reported: a whole-rock Rb-Sr date of 136.2±1.7 Ma for the pulaskite; $118.4±2.2$ Ma based on Rb-Sr whole-rock analyses of three rock types (nepheline dioniite, foyaite, and tinguaitue); and, apatite fission-track ages of 139±13 and 117±9 Ma for the gabbro and nepheline dioniite, respectively. Foland et al. (1986) reported four $^{40}\text{Ar}/^{39}\text{Ar}$ plateau ages (two for amphibole from the nepheline dioniite and two for gabbro biotites) which gave an age of $123.1±1.2$ Ma, similar to those for other Monteregean plutons. They suggested that the later more evolved felsic units were emplaced within a short interval not exceeding 1–2 Ma.
The compositional variations found at Mount Brome reflect crystal-sorting processes and fractionation at depth and also at the present exposure level (Valiquette and Pouliot 1977; Eby 1985). Field relations such as locally abundant xenoliths (Valiquette and Pouliot 1977), Sr isotopic variations (Eby 1985), and generally correlated Sr and Nd isotope heterogeneities (Chen et al. 1988) point to the importance of crustal assimilation. Eby (1985) proposed that the complex formed from two different types of parental magma: the gabbros, diorites, pulaskites, and nordmarkites from alkali picrites; and, the nepheline-bearing diorites and syenites from basanites about 15 Ma later. More recently, Chen et al. (1988) suggested that the major units of the complex might have formed from a common basaltic parent by fractionation and assimilation. Thus, the timing of intrusive events is important to evaluation of the petrogenesis of the complex including possibly coeval-quartz and nepheline syenites.

Methods, samples, and results

The general principles of using the $^{40}$Ar/$^{39}$Ar method to examine small age differences, sometimes termed "high resolution" in this context, have been described previously (see references cited in the Introduction and standard treatises) and need only brief discussion here. $^{40}$Ar/$^{39}$Ar ages are relative to the "known" age of a monitor mineral via the relationship:

$$t = (1/\lambda) \ln \left(1 + \frac{F}{J} \right)$$

where: $t$ is the apparent age of the unknown; $\lambda$ is the total decay constant of $^{40}$K; $F$ is the ratio of radiogenic $^{40}$Ar to K-derived $^{39}$Ar and is corrected for interferences for Ar produced by reactions other than $^{39}$K (n, p) $^{39}$Ar and for atmospheric Ar contamination; and, $J$ is the irradiation parameter determined from monitors irradiated along with the unknowns. The analytical accuracy of the measured age is typically limited mainly by that for $J$ which is a function of the accuracies of the absolute age of the monitor. Fig. 1. Sketch map of the Mount Brome complex, Quebec (after Valiquette and Pouliot 1977). Solid circles show sample locations identified by the last number in the specimen notation. $M$ in the index map is for Montreal.

Fig. 2. Schematic neutron irradiation configuration showing the positions of samples for the described special measurement for five biotite specimens. Height is the vertical distance, measured from the bottom of each of five (G through K) consecutive radially-positioned vials. The $F$ value is shown for each sample aliquot; these show variations reflecting both vertical and horizontal fluence gradients and different sample ratios of radiogenic $^{40}$Ar to $^{39}$K. A vertical gradient produces a general decrease in $F$ from the bottom of each vial; radial fluence differences, due to uneven rotation of the sample holder, produce a small offset for each vial. Within each vial, relatively higher and lower $F$ values for Q83-59 and Q83-68, respectively, reflect differences in $^{40}$Ar/$^{39}$K or apparent age.