

$^{40}\text{Ar}/^{39}\text{Ar}$ Dating of Hydrothermal Biotite Associated with High-grade Gold Mineralization in the Whin Vein, Tangier Gold Deposit (NTS 11D/15), Southern Nova Scotia

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Introduction

The origin of vein gold deposits in the Meguma Group of southern Nova Scotia has been a contentious issue for decades, with variations on a metamorphic model being the most common (see review in Sangster, 1990). In these metamorphic models, the age of veining spans the pre-folding, early folding and syn-folding stages of the Meguma Group (e.g. Graves and Zentilli, 1982; Henderson and Henderson, 1986; Henderson *et al.*, 1990; Sangster, 1990) to late in the folding history (Mawer, 1985, 1987; Kontak *et al.*, 1990a, b; Horne and Culshaw, in press). The difference among these various models relates to the timing of vein emplacement with respect to strain history of the host rocks (early versus late). Timing of vein formation can be determined by radiometrically dating vein-forming minerals, thereby determining the absolute age of vein formation. Although a variety of methods may be applied if the appropriate minerals are present (Rb/Sr, Re-Os, Pb-Pb, U/Pb), the most widely applicable is the $^{40}\text{Ar}/^{39}\text{Ar}$ technique given the abundance of hydrothermal vein micas in many gold districts. Using this method, Kontak *et al.* (1990a, 1993, 1996) dated hydrothermal vein minerals from six gold districts (Fig. 1) and obtained ages of ca. 375 Ma. Of particular relevance is that at one of these deposits (Beaver Dam) concordant ages were obtained for amphibole, muscovite and biotite, which indicates rapid cooling of the area after vein formation given the ca. 200°C range in blocking temperatures for these minerals (McDougall and Harrison, 1988). Thus, the absolute ages so far obtained for the dated gold districts favour the late-stage metamorphic model of auriferous vein formation.

In this paper we report the results of a single $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of hydrothermal biotite collected from the underground workings of the Tangier gold district. The sample used in this study consists of hydrothermal biotite in the footwall of a high-grade gold vein (Whin

Vein; Smith, 2000). Thus, the opportunity to directly date an auriferous vein was presented. What is most significant about this locality is that biotite formation is obviously related to vein emplacement and this vein carries high gold grades. Thus, direct dating of the alteration will provide an age for vein formation which provides at least a maximum age for gold formation, if not the absolute age.

Regional Geology and Nature of Meguma Gold Veins

The Tangier gold district is located 45 km east of Halifax, along the Eastern Shore of southern Nova Scotia (Fig. 1). The area is located within the Meguma Terrane, the most easterly of the terranes comprising the Appalachian orogenic belt, which trends northeastward along the eastern margin of North America. The Meguma Terrane is underlain by two dominant rock units, the lower Paleozoic, metaturbiditic Meguma Group and the ca. 370 Ma peraluminous granitoids that intrude the former. The Meguma Group was deformed and metamorphosed (greenschist facies) into northeast-trending, generally upright, tight to open folds during the Acadian Orogeny, which resulted from accretion of the Meguma Terrane with the Avalon Terrane. The suture zone is now represented by the east-west Cobequid-Chedabucto Fault Zone (Fig. 1). Although the main phase of the Acadian Orogeny has been dated using the whole-rock $^{40}\text{Ar}/^{39}\text{Ar}$ method at ca. 395 Ma (Keppie and Dallmeyer, 1987; Kontak *et al.*, 1998; Hicks *et al.*, 1999), deformation continued into the Late Devonian, as recorded by syntectonic emplacement of the 370 Ma granites (e.g. Benn *et al.*, 1997, 1998) and offset of contact metamorphic cordierite along folding-related movement horizons in slates adjacent to 370 Ma granites (Horne, 1998; Horne and Culshaw, in press).

Gold districts occur throughout the Meguma Group and consist of bedding-concordant and -discordant veins

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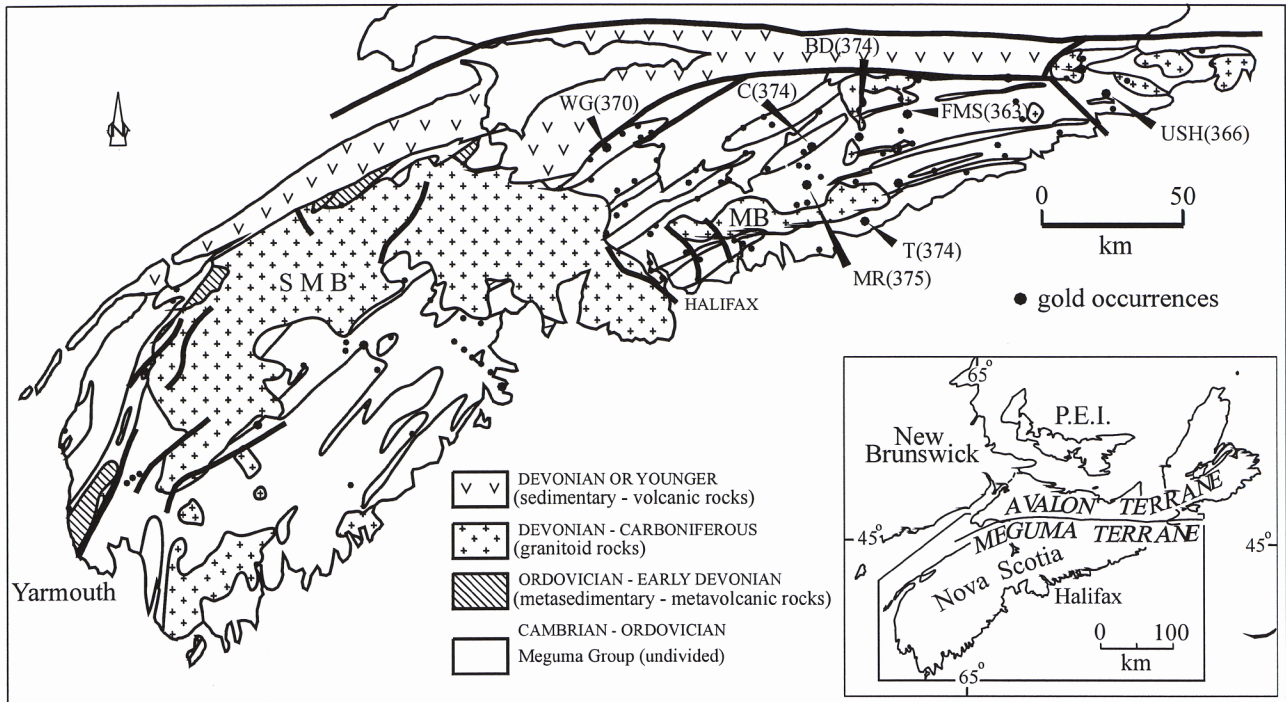


Figure 1. Simplified geology of the Meguma Terrane of southern Nova Scotia with location of Meguma gold deposits for which $^{40}\text{Ar}/^{39}\text{Ar}$ data are available (Kontak *et al.*, 1990a, 1993, 1996 and this study). Inset box shows the outline of the Meguma and Avalon zones. Abbreviations follow: WG-West Gore, C-Caribou, BD-Beaver Dam, FMS-Fifteen Mile Stream, MR-Moose River, T-Tangier, USH-Upper Seal Harbour, MB-Musquodoboit Batholith, SMB-South Mountain Batholith.

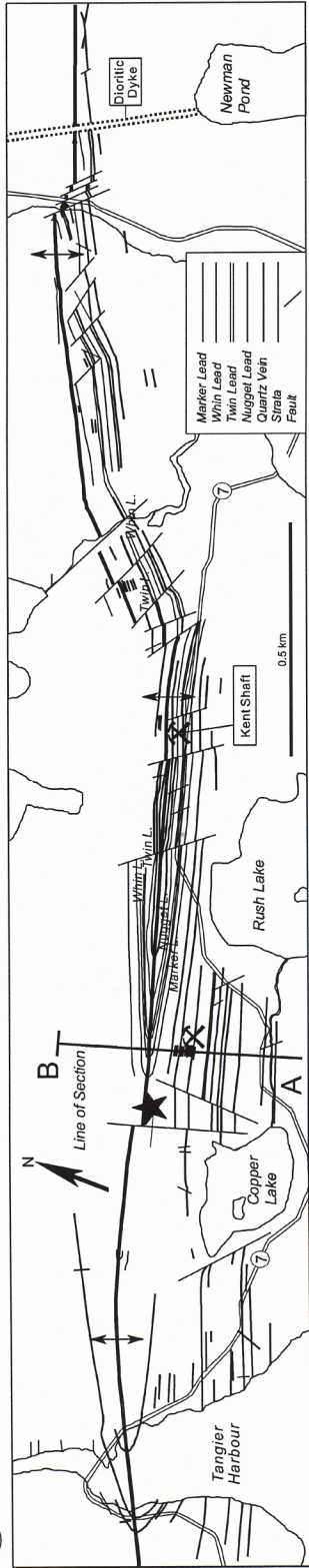
within or near the hinges of regional-scale anticlines. The veins are dominated by quartz, Ca-Mg-Fe-carbonates, and Fe sulphides, may contain laminae of wall-rock material, and are variably folded. The similar setting, paragenesis of vein minerals, fluid chemistry, and wall-rock alteration in gold districts suggest (Smith and Kontak, 1986; Kontak *et al.*, 1990b) a similar origin for many of the gold districts. Although a variety of models exist, we favour a late-stage model for vein emplacement, based on a recent structural analysis of vein emplacement at the Ovens (Horne, 1998). Based on the mutually cross-cutting relationships of concordant and discordant veins, and the formation of concordant veins along movement horizons within slate beds, Horne (1998) concluded that all veins were emplaced during flexural-slip folding late in the folding history of the area. A 376 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ muscovite age (Hicks *et al.*, 1999) for mica extracted from pressure shadows around arsenopyrite in the veined area supports this suggested timing of vein formation. Veins at other gold districts are very similar to those at the Ovens (Malcolm, 1929); thus, a similar model for vein emplacement is suggested (Horne and Culshaw, in press). This late vein formation is supported by both relative age relationships and absolute age dating of many gold districts (Kontak *et al.*, 1990a, 1993, 1996).

Tangier Deposit Geology and Sample Description

The Tangier gold district is located ca. 3 km south of the 370 Ma Musquodoboit Batholith (Reynolds *et al.*, 1981; MacDonald and Clarke, 1985) and lies within a package of metasilstone and slate of the Meguma Group (Fig. 1). The deposit occurs mainly on the southern limb of an upright, northeast-trending (074°) regional fold known as the Tangier-Harrigan Cove anticline (Fig. 2). The fold has a chevron shape, an interlimb angle of $40\text{--}50^\circ$, and is doubly plunging at 12° away from the district. Local stratigraphy consists of interbedded sandstone, siltstone and shale. Both bedding-concordant and -discordant quartz veins occur with concordant veins preferentially in shale beds. Veins have been traced along strike for ca. 3 km and some 15 major bedding-concordant vein systems occur on the southern limb of the fold (Fig. 2). The most recent studies of the deposit are those of Corey and Mills (1992), who examined the mine stratigraphy, vein mineralogy, alteration and litho-geo-chemistry, and Smith (2000), who examined the grade and distribution of gold within part of the workings (i.e. Whin Vein). These studies indicate that the Tangier deposit has many features common to other Meguma vein gold systems.

Plan Map - Tangier Gold District

(a)



Cross-Section A - B (near portal looking west)

(b)

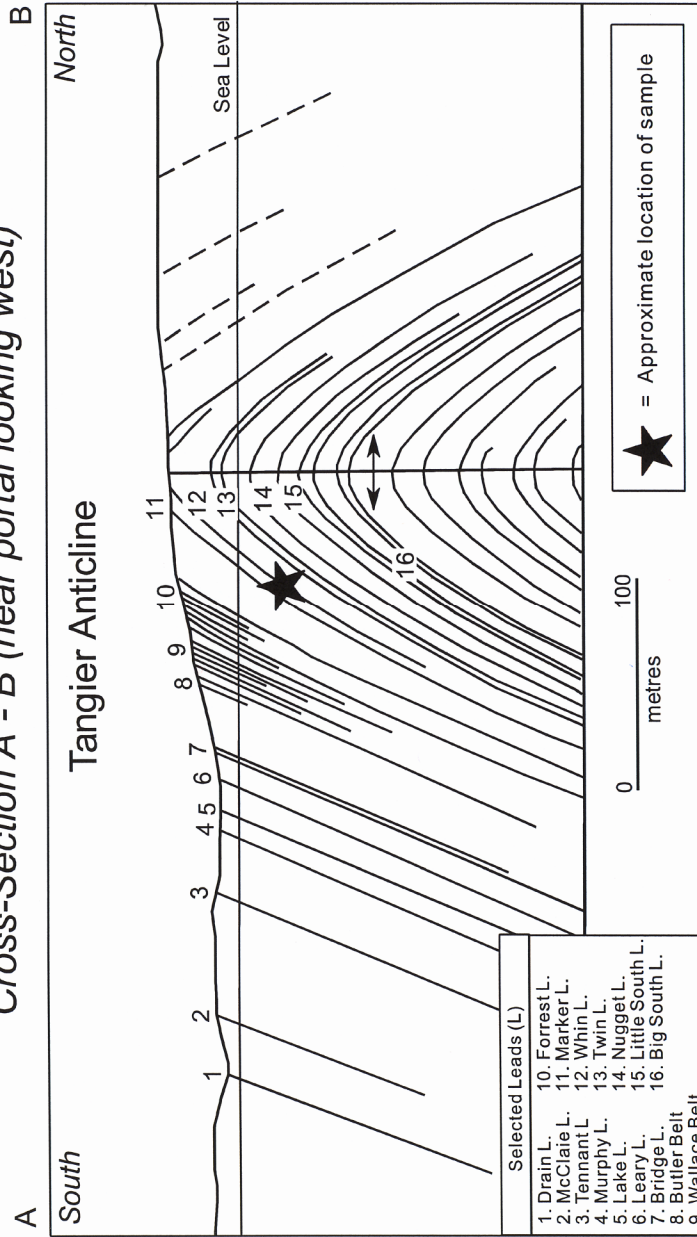


Figure 2. Geological map and cross-section of the Tangier deposit area (after Smith, 2000). The area sampled for this study is indicated by the star.

The sample selected for dating came from underground workings of the 12-55 south-drift-west (SDW) heading (Figs. 2, 3), more specifically the Whin Vein or lead. At this locality, the Whin Vein is in the hinge zone of the fold closure in the western part of the shallowly plunging dome. Where sampled, the Whin Vein actually consists of two distinct veins, with the upper vein being thicker (ca. 10-15 cm) and the lower vein thinner (1-2 cm; Fig. 3). The two veins are variably folded, with the various amount of minor folding and differences in wave lengths of the folds reflecting variation in vein thickness (Fig. 3a, b). The veins are cloudy or milky white and have ribbons of wall-rock inclusions and locally well developed crack-seal textures. Arsenopyrite, pyrrhotite and pyrite are locally disseminated within the veins ($\leq 10\%$) and minor carbonate and chlorite also occur. Along the western side of the drift, the slate beds adjacent to the lower contact of the Whin Vein contain multi-centimetre thick clots or beds of massive, fine-grained, dark brown biotite with associated coarse clots and platy grains of white to pale pink carbonate and minor pyrite (Fig. 3c). The textural relationship of carbonate to biotite suggests a late paragenesis. Slabs of the biotite-rich rock reveal that the biotite layers are folded, whereas the presence of very small clots of carbonate in the surrounding shale reflects carbonate alteration of the wall rock (Corey and Mills, 1992). The biotite in this sample is interpreted to be of hydrothermal origin, resulting from reaction of the vein-forming fluids with the pelitic wall rock.

Analytical Techniques

A sample of biotite-rich rock was crushed and fragments of biotite were hand picked under the magnification of a binocular microscope. This biotite was further crushed and sieved and a high-quality biotite concentrate produced using standard methods of magnetic separation and heavy liquids. The sample was irradiated along with an intralaboratory standard at the McMaster University nuclear reactor (Hamilton, Ontario). The sample was then analyzed for $^{40}\text{Ar}/^{39}\text{Ar}$ dating at the Geochron Laboratory, Queen's University (Kingston, Ontario) using a defocused, 8W Lexel 3500 continuous argon laser. Complete analytical procedures are outlined in Clark *et al.* (1998). Errors for individual steps and the age spectrum plot represent the analytical precision at a 2σ level, assuming the errors in the ages of the flux monitors (i.e. standards) are 0. This is suitable for comparing within-spectrum variation and for determining which steps constitute a plateau. A conservative estimate for the error in the J value is 0.5%.

Biotite gain mounts were used for chemical analysis using a JEOL 722 Superprobe at Dalhousie University

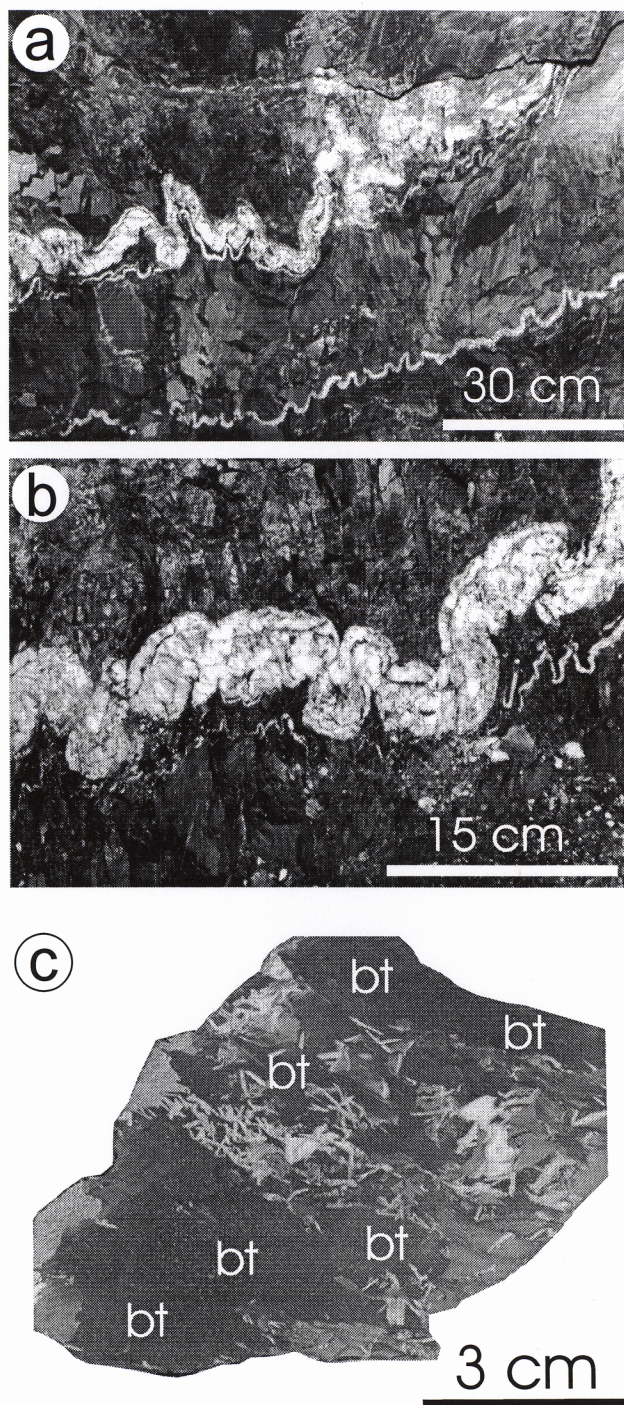


Figure 3. Underground photos (a, b) of the Whin Vein where the sample was collected and slab of the dated sample (c). (a, b) Photographs of the Whin Vein at the face of the 12-55 south-drift west heading (April, 2000) where the gold grade is ore quality (i.e. multi-ounce per tonne, Smith, 2000). Note the vein is in the hinge zone and that in photo b the Upper Whin Vein cuts off the Lower Whin Vein. (c) Slabbed sample of the biotite-rich alteration that was sampled for dating. The white mineral as clots and plates is carbonate. The darkest material is all biotite (bt) and makes up ca. 50% of the rock sample.

using procedures similar to Kontak and Smith (1993). Several grains were analyzed both in their core and rim in order to see if the biotite was chemically uniform.

Analytical Results

Electron microprobe analysis of several biotite grains indicates compositions typical of hydrothermal biotite in Meguma vein gold deposits (Kontak and Smith, 1993). The Fe/(Fe+Mg) ratios of 0.6 are similar to those in wall-rock biotite at Tangier (Corey and Mills, 1992) and indicate the biotite composition was wall-rock buffered. Low totals and wt.% K₂O levels below those typical of fresh biotite in some of the analyses indicate that some chlorite alteration of biotite occurred in the concentrate.

Results of step-heating experiments on the biotite separate are shown in a conventional argon age spectrum plot in Figure 4a and summarized in Table 1. The data show that the low temperature gas fractions, excluding the first two steps and comprising about 30% of the total gas, define ages of ca. 353 to 363 Ma. In contrast, the higher temperature gas extractions, which include 65% of the total gas, define a plateau age of 373.8 ± 1.7 Ma, which is slightly older than the integrated age of 367.3 ± 3.5 Ma for the sample.

Discussion

The ⁴⁰Ar/³⁹Ar age spectrum for the hydrothermal biotite indicates that this mineral cooled through its ca. 300°C blocking temperature (McDougall and Harrison, 1988) ca. 374 Ma. However, this age contrasts markedly with ⁴⁰Ar/³⁹Ar whole-rock ages of ca. 385 Ma and 392 Ma for ribbon bands of slate in quartz veins from Tangier (Kontak *et al.*, 1998), which are contrasted with the biotite age in Figure 4b. The whole-rock ages have been interpreted to reflect the timing of regional metamorphism in the Meguma Group (Kontak *et al.*, 1998). Thus, the contrast between the whole-rock and biotite ⁴⁰Ar/³⁹Ar ages is interpreted to indicate the following important temporal relationships: (1) there was a gap of about 10-15 million years between cessation of regional metamorphism and biotite formation, hence, also vein emplacement; and (2) the Tangier area must have cooled below ca. 300°C, the blocking temperature of biotite, prior to vein emplacement since biotite is an important constituent of the whole-rock samples dated. Locally temperatures exceeded ca. 400°C (e.g. fluid inclusion data; unpublished data of Kontak) during vein formation when the hydrothermal biotite formed. In addition, the similarity in age between formation of vein biotite and emplacement of the Musquodoboit Batholith is not

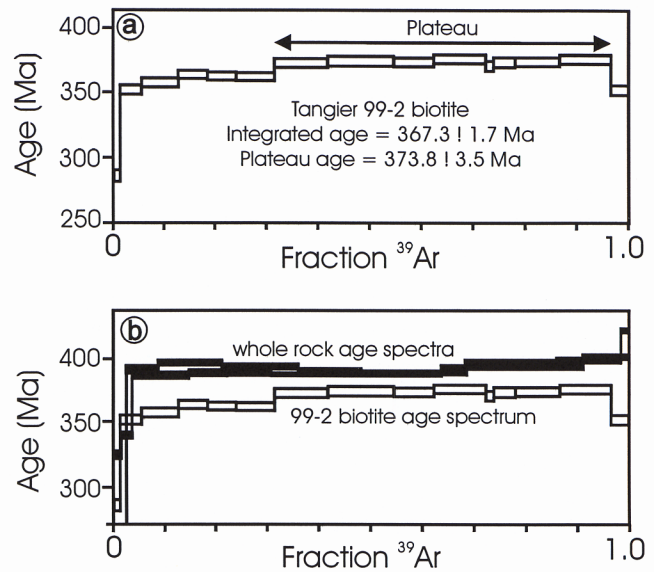


Figure 4. ⁴⁰Ar/³⁹Ar age spectrum plots for samples from the Tangier deposit. (a) Plot for biotite sample dated in this study. (b) Whole-rock slate samples dated by Kontak *et al.* (1998), compared to the biotite sample dated in this study. Note that samples are all plotted at the same scale and this highlights the difference in age between the whole-rock samples and hydrothermal biotite.

related to resetting of the vein biotite due to thermal influence of the batholith since the whole-rock samples should also have been affected. This conclusion is also supported by the lack of any textural features in the rocks that would indicate contact metamorphism had affected the area. We conclude, therefore, that the 374 Ma plateau age reflects the primary cooling of the hydrothermal biotite through 300°C and dates the formation of auriferous quartz veins.

The 374 Ma age for the Tangier deposit is similar to ⁴⁰Ar/³⁹Ar ages obtained for six other Meguma gold districts (Fig. 1) and collectively the geochronological data indicate vein emplacement was essentially coincident over the eastern Meguma Terrane. Some authors have noted that this age is similar to the age of granites in the Meguma Zone and that thermal resetting must be considered (e.g. Sangster, 1990, 1991; Henderson *et al.*, 1991). However, two points mitigate against this argument, namely: (1) the ca. 375 Ma ages are for deposits both proximal to (i.e. Beaver Dam, Fifteen Mile Stream, Tangier) and distal from (West Gore, Upper Seal Harbour, Moose River, Caribou) the granites; and (2) the ⁴⁰Ar/³⁹Ar ages for samples of slate extracted from gold veins retain older ages that reflect regional metamorphism rather than a thermal influence related to granite emplacement (Kontak *et al.*, 1998). Thus, the apparent ages of the gold deposits are most compatible with the recent inference of Horne and

Table 1. Results of step-heating experiments on the biotite separate.

Step	Isotope Ratios										Age
	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{38}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{36}\text{Ar}/^{39}\text{Ar}$	Ca/K	^{40}Ar atmos. (%)	^{39}Ar rad. (%)	$^{40}\text{Ar}/^{39}\text{Ar}_K$			
1	22.393±0.015	0.042±0.205	0.011±0.436	0.025±0.199	0.045	20.11	0.25	18.502±1.560	236.21±18.67		
2	23.125±0.006	0.020±0.112	0.002±0.590	0.005±0.240	0.009	3.51	1.28	22.582±0.377	284.39±4.39		
3	28.595±0.006	0.017±0.103	0.001±0.724	0.002±0.490	0.015	1.21	4.19	28.482±0.321	351.86±3.60		
4	28.949±0.006	0.016±0.106	0.001±0.823	0.001±0.760	0.012	0.67	7.1	28.970±0.306	357.33±3.43		
5	29.444±0.006	0.015±0.147	0.001±0.712	0.001±0.691	0.014	0.54	5.76	29.512±0.284	363.38±3.16		
6	29.331±0.006	0.016±0.117	0.001±0.711	0.001±0.689	0.012	0.5	5.67	29.412±0.270	262.27±3.01		
7	29.308±0.006	0.016±0.109	0.001±0.870	0.001±0.716	0.013	0.54	7.35	29.369±0.268	361.79±2.99		
8	30.142±0.006	0.015±0.123	0.001±1.056	0.000±1.873	0.012	0.15	10.33	30.311±0.306	372.27±3.39		
9	30.305±0.006	0.014±0.136	0.001±1.050	0.000±2.283	0.011	0.19	12.75	30.459±0.345	373.92±3.83		
10	30.280±0.006	0.014±0.141	0.001±0.710	0.001±0.965	0.018	0.43	7.83	30.373±0.294	372.96±3.26		
11	30.397±0.006	0.014±0.108	0.001±0.856	0.000±2.135	0.011	0.08	10.01	30.593±0.292	375.40±3.23		
12	29.843±0.006	0.016±0.153	0.002±0.466	0.002±0.455	0.009	0.23	1.47	30.126±0.337	370.21±3.74		
13	30.226±0.006	0.015±0.160	0.001±0.619	0.001±0.937	0.016	0.3	4.12	30.390±0.330	373.15±3.65		
14	30.247±0.006	0.015±0.154	0.001±1.070	0.001±1.575	0.014	0.15	8.61	30.423±0.305	373.51±3.38		
15	30.386±0.006	0.015±0.104	0.001±0.925	0.000±2.008	0.015	0.07	9.9	30.584±0.296	375.30±3.27		
16	28.327±0.006	0.019±0.107	0.001±0.639	0.001±0.731	0.013	0.4	3.39	28.464±0.336	351.66±66.37		

Culshaw (in press) that veins were emplaced during late-stage, brittle-ductile re-activation of the regional fold belt.

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