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THE ELLISON LAKE PLUTON: A CORDIERITE-BEARING MONZOGRANITIC INTRUSIVE BODY IN SOUTHWESTERN NOVA SCOTIA

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ABSTRACT

The Ellison Lake pluton, located 3km NW of the South Mountain batholith in southwestern Nova Scotia, is a small intrusive body of porphyritic monzogranite containing the aluminous minerals cordierite, garnet and tourmaline. Cordierite and garnet are considered of magmatic and xenocrystic origin, respectively, whereas the tourmaline is probably metasomatic. The SiO_2 content and most other chemical characteristics of the monzogranite are similar to those of the biotite granodiorite of the South Mountain batholith, except that the monzogranite has higher Al_2O_3, K_2O and P_2O_5, consistent with its greater abundance of aluminous minerals, K-feldspar and apatite. The monzogranite may have formed from the same magma as the South Mountain granodiorite but with more extensive assimilation of pelitic material; a K–Ar age determination of 346 ± 12 Ma indicates that it is younger than the South Mountain granodiorite, but may reflect thermal events related to Cu–U mineralization in the Ellison Lake pluton.

Keywords: peraluminous granite, petrography, geochemistry, petrogenesis, cordierite, Ellison Lake pluton, South Mountain batholith, Nova Scotia.

SOMMAIRE

Le pluton du lac Ellison, situé à 3 km au nord-ouest du batholithe de South Mountain dans le Sud-ouest de la Nouvelle-Écosse, est un petit complexe intrusif de monzogranite porphyrique qui contient les minéraux alumineux cordiérite, grenat et tourmaline. La cordiérite est d'origine magmatique, le grenat est xénocristallin, tandis que la tourmaline est probablement métasomatique. La teneur en SiO_2 et la plupart des autres caractères chimiques du monzogranite sont semblables à ceux de la granodiorite à biotite du batholithe de South Mountain, sauf que le monzogranite a une teneur plus élevée en Al_2O_3, K_2O et P_2O_5, due à l'abondance de minéraux alumineux, feldspath potassique et apatite. Le monzogranite a pu se former à partir du même magma que la granodiorite de South Mountain, mais avec assimilation d'une plus grande quantité de matériau pelitique. Une datation (par la méthode K-Ar) de 346 ± 12 Ma donne un âge plus jeune au monzogranite qu'à la granodiorite de South Mountain, mais peut refléter les événements thermiques reliés à la minéralisation de Cu–U dans le pluton du lac Ellison.

Mots-clés: granite hyperalumineux, pétrographie, géochimie, pétrogenèse, cordiérite, pluton du lac Ellison, batholithe de South Mountain, Nouvelle-Écosse.

INTRODUCTION

The Ellison Lake pluton is a small granitoid intrusive body located 8 km SW of Bear River in Digby County, Nova Scotia (Fig. 1). In his map of the Digby area, Smitheringale (1973) showed the pluton as medium- to coarse-grained porphyritic quartz monzonite and granodiorite, finer grained and less strikingly porphyritic than the adjacent part of the South Mountain batholith, but inferred to be of the same age, Middle to Late Devonian. Geologists of Shell Canada Resources Limited (including the first author) assigned the name Ellison Lake to this pluton and compiled a revised map in 1981 with the aid of airborne radiometric data, boulder distribution, trenching and 41 drill holes. They found that the pluton consists of one major type of granitoid rock, which is described in this paper.

The Ellison Lake pluton is of economic interest because fracture-controlled uranium and copper mineralization occurs within the intrusive body. A published airborne radiometric map of the region shows a thorium anomaly centred on the pluton (Geological Survey of Canada 1977). In addition, tungsten anomalies exceeding 2000 ppm occur in heavy mineral separates from tills both east and southwest of the pluton (Stea & O'Reilly 1982).

The present study was undertaken to investigate the petrology and age of the Ellison Lake pluton and to compare it to other granitoid intrusive complexes in southern Nova Scotia. The pluton is very poorly exposed, and hence sampling sites were limited to the few accessible natural outcrops and the Shell exploration trenches and drillcore (Fig. 1). However, mapping of boulder lithologies over the pluton indicates that the samples are representative of the pluton as a whole.

GEOLOGICAL SETTING

The Ellison Lake pluton (and other granitoid intrusive bodies in southern Nova Scotia) intruded predominantly metasedimentary rocks ranging from Cambrian to early Devonian in age. These rocks had been folded and regionally metamorphosed (mostly to greenschist facies) during the middle Devonian Acadian orogeny (Keppie 1979). The plutonic rocks

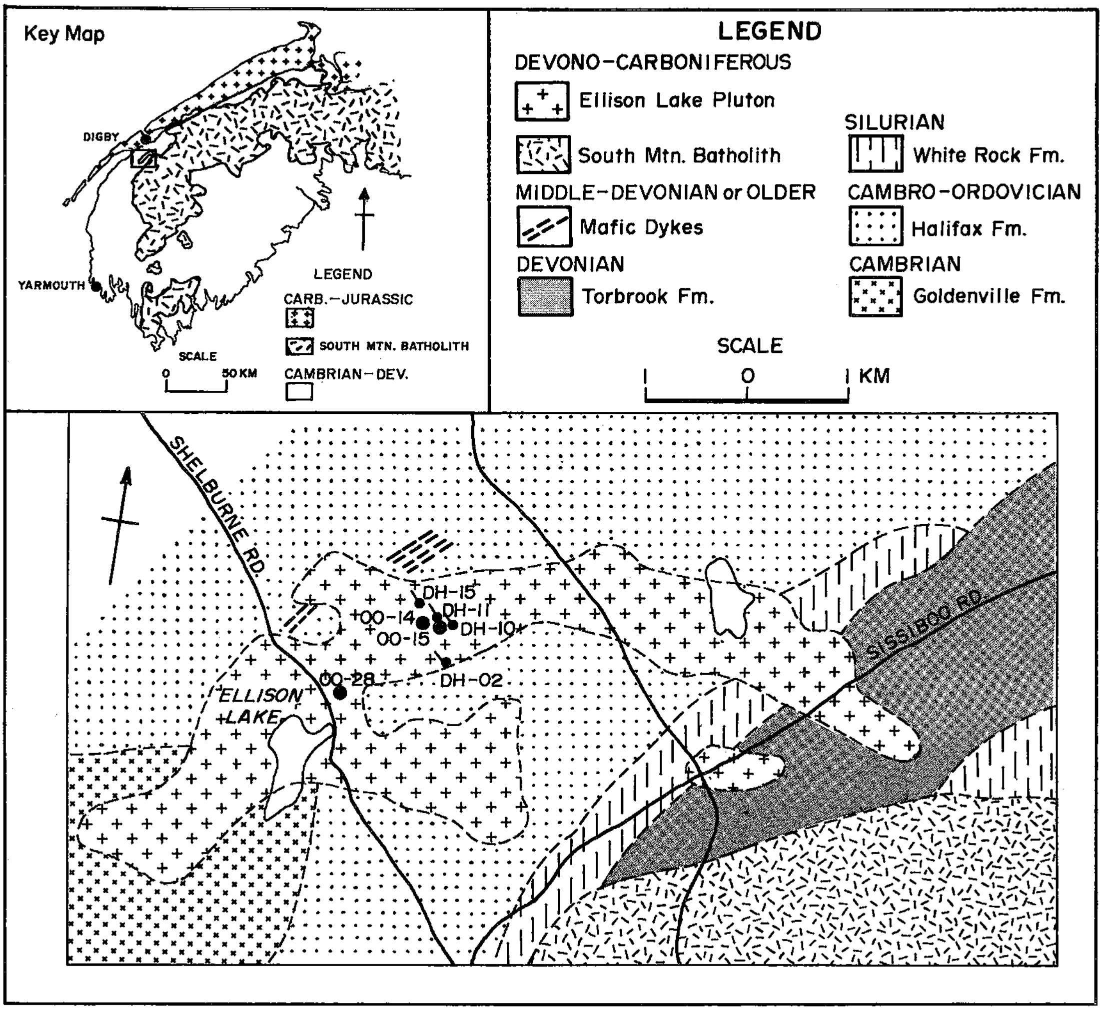

FIG. 1. Geological map of the Ellison Lake area, showing the distribution of rock units as mapped by Shell Canada Resources Limited (1981). Locations of analyzed samples 00–28 (from natural outcrop), 00–14 and 00–15 (from trenches) are shown, as well as drill holes from which eleven samples were taken for analysis.

were generally emplaced after this episode of deformation and regional metamorphism, which has been dated at 415–400 Ma (Reynolds & Muecke 1978). Rb–Sr isochron ages of 372–361 Ma (Clarke & Halliday 1980) and a mean K–Ar and $^{40}Ar/^{39}Ar$ age of 367 Ma (Reynolds *et al.* 1981) for the South Mountain batholith are in general agreement with this time frame. However, several southern satellite plutons of the South Mountain batholith have given younger ages in the range 320–300 Ma, which may reflect an intrusive or thermotectonic event in the Late Carboniferous (Reynolds *et al.* 1981). At least some episodes of mineralization in the granitoid rocks are apparently related to these younger event(s) (Reynolds *et al.* 1981, Robertson & Duncan 1982).

PETROGRAPHY

The Ellison Lake pluton is composed of essentially one rock type, a medium-grained biotite monzogranite grading to granodiorite (Fig. 2). The texture is seriate porphyritic hypidiomorphic inequigranular, with approximately 25% plagioclase and scattered K-feldspar phenocrysts. Metasedimentary xenoliths are abundant. The freshest samples are grey, but most are various shades of pink to red as a result of hematitic alteration. This is particularly intense in obvious shear zones, which were apparently the main focus of the exploration program.

The average modal abundance of major minerals in the 14 analyzed samples (Fig. 2) is quartz 26 ± 4%, plagioclase 35 ± 4%, microcline 24 ± 3% and biotite 15 ± 4%, with varying minor amounts (less than 5%) of cordierite and accessory muscovite, tourmaline, garnet, zircon, apatite and opaque phases. The rock is similar in content of mafic minerals to the typical biotite granodiorite of the South Mountain batholith (*e.g.*, McKenzie & Clarke 1975, Smith 1979) but generally contains more potassium feldspar and less quartz, and hence is classified as monzogranite (Fig. 2). However, it contains much more biotite and less muscovite than the monzogranites (adamellites of McKenzie & Clarke 1975) of the South Mountain batholith.

Quartz in the Ellison Lake pluton occurs as anhedral crystals of variable grain-size up to 3 mm. It typically displays undulatory extinction. The plagioclase forms euhedral to subhedral phenocrysts up to 3 cm in length as well as subhedral to anhedral grains averaging 2–3 mm in size in the groundmass. Compositions determined by the Michel-Lévy method and by microprobe range from oligoclase (An_{25}) to andesine (An_{38}). The crystals are generally zoned and variably affected by sericitic and hematitic alteration. Finely perthitic microcline with grid twinning forms anhedral grains generally 1–2 mm in size, as well as scattered phenocrysts. Late-stage or secondary albite rims some plagioclase and microcline crystals, and may occur interstitially as well.

Brown pleochroic biotite occurs in flakes up to 2 mm across. The smaller flakes tend to occur in clusters and may represent relict inclusions. Microprobe analyses (Table 1) gave compositions typical of those in peraluminous granitoid rocks in general (Fig. 3). Partial conversion to chlorite occurs in some samples. Zircon and apatite inclusions are exceptionally abundant.

Cordierite pseudomorphs are present in most samples, comprising as much as 5% of the rock. They occur typically as subhedral prismatic grains about 1–2 mm in size, in which the original cordierite has been completely replaced by muscovite or mixtures of muscovite, sericite and chlorite ("pinite"). Sector twinning was observed in rare, less altered grains that are free of inclusions. Microprobe analyses of the unaltered core of two such grains show overall compositions and Mg/(Mg + Fe) values (0.52 and 0.56) typical of cordierite in other granitoid rocks, although very low in water (Table 2).

Muscovite is relatively abundant but, on the basis of textural relationships, much is obviously of secondary origin. Secondary muscovite and sericite replace the feldspar, cordierite and tourmaline, and also occur interstitially. Muscovite that is possibly of primary origin occurs as subhedral to anhedral grains about 0.5 mm in length, and forms 1–2% of the rock at most.

Tourmaline is an important accessory constituent

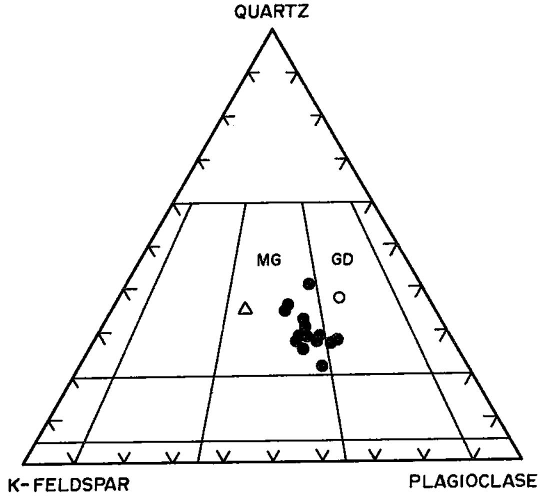

FIG. 2. Modal composition of analyzed samples from the Ellison Lake pluton (black circles) plotted on the quartz – potassium feldspar – plagioclase diagram of Streckeisen (1976). Data were obtained from counting at least 200 points on stained slabs. Open circle and triangle are average modal composition of granodiorite and monzogranite, respectively, of the South Mountain batholith, calculated from data in McKenzie & Clarke (1975).

in most samples. Its irregular, patchy distribution suggests a metasomatic origin. In thin section it is pale olive green, and extensively altered to chlorite, sericite and muscovite. Microprobe analyses suggest iron-rich compositions, typical of tourmaline in peraluminous granites (Clarke 1981), but reliable data could not be obtained because of the degree of alteration.

Garnet occurs as rare, relatively small anhedral grains. It is of almandine–pyrope composition, with relatively low spessartine and grossularite—andradite components (Table 3).

Apatite and zircon are abundant, mostly as small inclusions in biotite. Opaque minerals are typically skeletal in form, and spot checks by microprobe indicated that they are ilmenite. Sulfides, predominantly pyrite, occur on some fracture surfaces.

As previously noted, xenoliths are exceptionally abundant in the Ellison Lake pluton. They are generally small and rounded, with sharp contacts with the host monzogranite. However, vague concentrations of biotite in the monzogranite may also be of xenolithic origin. Most xenoliths have a pelitic composition and consist of biotite, feldspars, cordierite, garnet, quartz and opaque phases, with secondary muscovite, sericite and chlorite. A few are more quartzofeldspathic, with more abundant K-feldspar and quartz. These two types of xenoliths

TABLE 1. COMPOSITION OF BIOTITE* FROM THE ELLISON LAKE PLUTON

	10-24	10-24	15-17
SiO_2	35.65%	35.86%	35.26%
TiO_2	3.89	3.48	3.61
Al_2O_3	18.93	19.80	19.34
FeO**	22.61	22.92	24.07
MnO	0.33	0.35	0.21
MgO	6.30	6.41	6.19
K_2O	9.34	9.69	9.26
Anhydrous Total	97.05	98.51	97.94
Number of ions on the basis of 24 oxygen atoms			
Si	5.40	5.36	5.33
^{iv}Al	2.60	2.64	2.68
^{vi}Al	0.77	0.88	0.77
Ti	0.44	0.39	0.41
Fe	2.86	2.87	3.04
Mn	0.04	0.04	0.03
K	1.80	1.85	1.78
Phlogopite	32.9	32.9	31.2
Annite	66.2	66.1	68.2
Mn-biotite	1.0	1.0	0.6
Fe/(Fe+Mg)	0.67	0.67	0.69

* determined using the Cambridge Instruments Microscan 5 electron microprobe with Ortec energy-dispersive system at Dalhousie University. ** Fe as FeO.

TABLE 2. COMPOSITION OF CORDIERITE IN GRANITE

	Ellison Lake*		Musquodoboit**	New England***
	15-13-1	15-13-2	048	Average
SiO_2	48.80%	49.20%	48.18%	48.57%
TiO_2	0.00	0.00	0.03	-
Al_2O_3	33.33	33.67	32.30	33.36
FeO****	9.73	10.52	10.23	9.53
MnO	0.15	0.23	0.64	0.11
MgO	7.06	6.60	5.69	7.58
CaO	0.00	0.00	0.04	-
Na_2O	0.59	0.55	1.61	0.77
K_2O	0.00	0.00	0.06	0.08
Total	99.66	100.77	98.78	100.00
Mg/(Mg+Fe)	0.56	0.52	0.53	0.59

* Cordierite from the Ellison Lake pluton analyzed using the Cambridge Instruments Microscan 5 electron microprobe with Ortec energy dispersive system at Dalhousie University
** Cordierite from the Musquodoboit batholith, Nova Scotia, from MacDonald (1981)
*** Average cordierite analysis from the New England batholith, Australia, from Flood & Shaw (1975)
**** Total Fe as FeO

are undoubtedly derived from slates and metagreywackes of the Halifax and Goldenville Formations, respectively, into which the pluton was emplaced (Fig. 1).

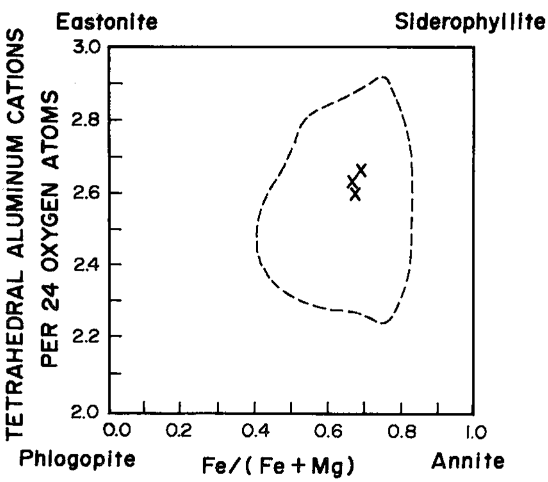

FIG. 3. Composition of biotite from the Ellison Lake monzogranite (crosses). Dashed line outlines field of biotite compositions in peraluminous granitoid rocks (Clarke 1981).

GEOCHEMISTRY

Major elements

A total of 14 samples were selected for chemical analysis, 3 from surface outcrop and trenches and the remainder from depths ranging from 12 to 57 m in four-drill holes (Fig. 1). The samples show a very limited range in major-element geochemistry (Table 4), consistent with their petrographic similarity. Silica contents are clustered at the low end of the spread reported by McKenzie & Clarke (1975) for the granodiorite of the South Mountain batholith (Fig. 4). Al_2O_3, K_2O and P_2O_5 are higher and CaO and Na_2O are lower in the Ellison Lake monzogranite than in South Mountain granodiorite of similar silica content. High P_2O_5 is reflected in the

TABLE 3. COMPOSITION OF GARNET FROM THE ELLISON LAKE PLUTON

	10-24	15-13	Number of cations on the basis of 24 oxygen atoms	10-24	15-13
SiO_2	36.83%	38.51%	Si	5.89	5.99
Al_2O_3	20.29	22.18	Al	3.89	4.07
FeO*	34.86	35.41	Fe	4.74	4.61
MnO	3.38	1.68	Mn	0.47	0.22
MgO	3.27	4.12	Mg	0.79	0.96
CaO	1.23	0.78	Ca	0.21	0.13
Total	100.48	102.68	Almandine	76.3%	77.9%
			Pyrope	12.7	16.2
			Spessartine	7.6	2.2
			Andradite/ Grossularite	3.4	3.7

* Total Fe as FeO

TABLE 4. MEANS AND STANDARD DEVIATIONS FOR CHEMICAL COMPOSITION AND CIPW NORMATIVE MINERALOGY OF 14 ANALYZED SAMPLES*, ELLISON LAKE PLUTON

SiO_2	67.31 ±	1.14	Q	29.57
TiO_2	0.61	0.01	C	2.64
Al_2O_3	14.94	0.04	Or	25.19
Fe_2O_3**	4.72	0.01	Ab	24.68
MnO	0.09	0.01	An	8.64
MgO	1.32	0.06	Hy	3.36
CaO	1.97	0.26	Ru	0.51
Na_2O	2.87	0.06	Il	0.19
K_2O	4.18	0.18	Hm	4.80
P_2O_5	0.19	0.01	Ap	0.45
LOI	1.3	0.6		
			D.I.***	79.4 ± 0.9
Total	99.5			
			A/CNK****	1.17 ± 0.05

* Analyses done by atomic absorption spectrometry at Acadia University. Analysts P. Allen and J. Cabilio
** Total Fe as Fe_2O_3
*** Differentiation Index (Thornton & Tuttle 1960)
**** Molecular Proportion $Al_2O_3/(CaO+Na_2O+K_2O)$

abundant apatite in the Ellison Lake monzogranite, and the other differences are consistent with the greater abundance of modal K-feldspar in the Ellison Lake samples.

The Ellison Lake monzogranite differs in composition from monzogranite (adamellite) in the South Mountain batholith, which ranges from about 71 to 75% SiO_2. The differentiation index (Thornton & Tuttle 1960) is approximately at the midpoint of the range for the South Mountain granodiorite, and much lower than that for the monzogranites (Fig. 5). However, the Ellison Lake monzogranite is more peraluminous than typical South Mountain granodiorite, with molar $Al_2O_3/(CaO+Na_2O+K_2O)$ values of 1.11 to 1.30, similar to those of the South Mountain monzogranite (Fig. 5).

Trace-element geochemistry

The trace-element contents of the Ellison Lake pluton are generally very similar to those of the granodiorite of South Mountain batholith, especially in the nearby West Dalhousie area (Table 5). The higher Th levels in the Ellison Lake pluton are consistent with the airborne radiometric anomalies in the area (Geological Survey of Canada 1977), but

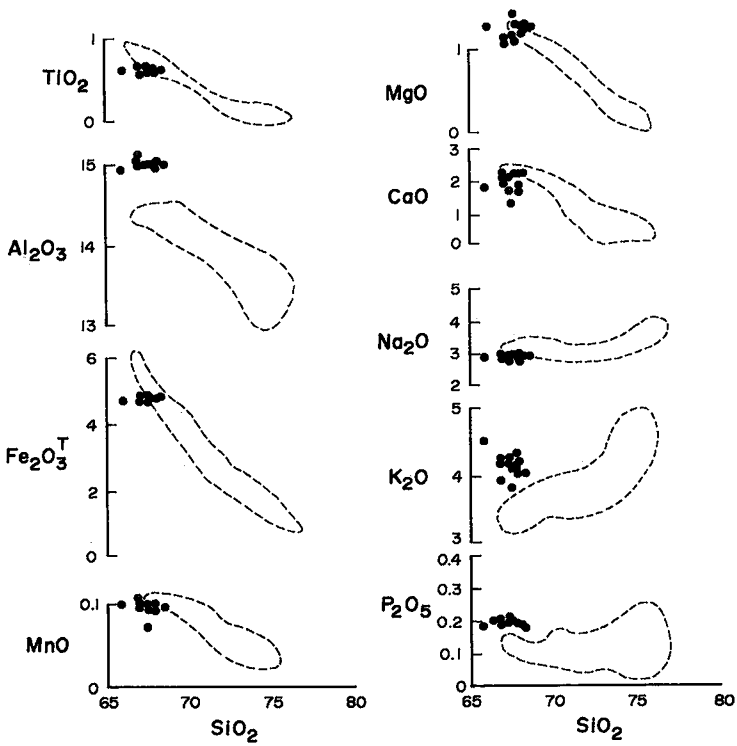

FIG. 4. Harker variation diagrams for major-element oxides in analyzed samples from the Ellison Lake pluton (black circles). Dashed lines outline fields for 90% or more of analyzed samples from the South Mountain batholith using data from McKenzie & Clarke (1975). The South Mountain granodiorite samples form the left-hand area of the dashed field, ranging from about 67 to 72% SiO_2, and the monzogranite (adamellite) samples form the centre-right area, ranging from about 71 to 75% SiO_2.

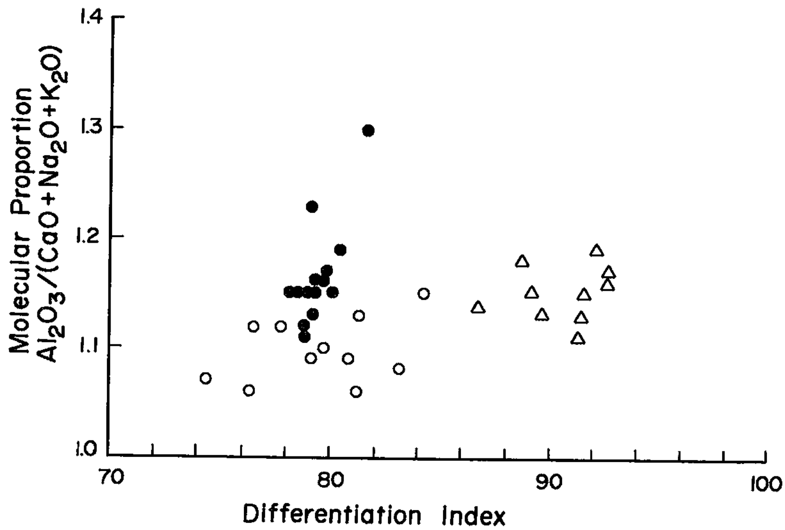

FIG. 5. Plot of A/CNK differentation index (ΣQ+Ab+Or in the norm) for Ellison Lake monzogranite (black circles), South Mountain granodiorite (open circles) and South Mountain monzogranite (triangles). Data for South Mountain batholith are from McKenzie & Clarke (1975).

their petrological significance is not clear. Mo, Sn and F abundances are lower in the Ellison Lake monzogranite. U and Cu values are similar to those in the granodiorite, with the exception of one high Cu value of 104 ppm (which was excluded from the calculation of the mean) in a sample from a depth of 42 m in drill-hole 15. This is compatible with the field observation that mineralization in the pluton is fracture-controlled.

Data on boron concentrations are not available for the South Mountain granodiorites, but the Ellison Lake samples contain high B compared to an average granite (Table 5). This is consistent with the abundance of tourmaline in the rocks. Tungsten values are below 4 ppm, thus providing no positive evidence that the pluton is the source of the W anomalies found in tills to the east and southwest (Stea & O'Reilly 1982).

TABLE 5. MEANS AND STANDARD DEVIATIONS OF TRACE ELEMENT DATA

	Ellison Lake Monzogranite*	South Mountain Batholith GD[1]	GD[2]	MG[2]	Average Granite[3]
Ba	775 ±95 ppm	667 ±109 ppm	766 ppm	502 ppm	840 ppm
Rb	163 ±14	147 ± 17	162	229	170
Sr	191 ±30	138 ± 25	142	74	100
Cu	13 ± 2**	-	10	8	10
Mo	1.9± 0.4	-	3.9	3.5	1.3
Pb	14 ± 6	-	11.0	9.5	19
Zn	66 ±14	64 ± 8	69	66	39
Sn	4.7± 0.4	11.7± 3.7	7	7	3.0
U	3.6± 1.0	3.9[4]	-	6.1[4]	3
Th	15.3± 1.6	11.5[4]	-	11.0[4]	17
W	<4	-	-	-	2.2
F	560 ±60	-	1100	1100	850
B	37 ±15	-	-	-	10
Li	81 ± 8	-	71	69	40

* 14 samples analyzed by CLIM Laboratories, Technical University of Nova Scotia, Halifax, by methods described in Barr et al. (1982).
** High value of 104 ppm excluded from mean calculation.
[1] Granodiorite from McKenzie & Clarke (1975); [2] granodiorite and monzogranite from West Dalhousie area from Smith & Turek (1976); [3] from Turekian & Wedepohl (1961); [4] from Chatterjee & Muecke (1982).

AGE OF THE PLUTON

A biotite concentrate (–60+100 mesh) from the Ellison Lake monzogranite yielded a K–Ar age of 346 ± 12 Ma (Table 6). This pluton is thus apparently somewhat younger than the South Mountain granodiorite, which has given K–Ar and $^{40}Ar/^{39}Ar$ ages of about 370 Ma (Reynolds *et al.* 1981). Furthermore, granodiorite samples from the batholith in the nearby Bear River area and from a locality about 20 km south of the Ellison Lake pluton have also yielded ages of 370 Ma (Fairbairn *et al.* 1960, Reynolds *et al.* 1981), so that it does not appear that younger ages are generally characteristic of the granodiorite in that area.

TABLE 6. K-Ar DATA** FROM THE ELLISON LAKE PLUTON

K%	^{40}K ppm	$^{40}Ar^*$ppm	$^{40}Ar^*/^{40}Ar$	$^{40}Ar^*/^{40}K$	Age (Ma)
7.150	8.733	0.1937	0.789	0.02221	346±12

* Radiogenic ^{40}Ar
** Biotite concentrate, -60/+100 mesh, from sample 10-24, analyzed by Krueger Enterprises, Inc., Geochron Laboratories Division, Cambridge, Massachusetts. Constants used: $\lambda\beta = 4.72 \times 10^{-10}$/year; $\lambda e = 0.585 \times 10^{-10}$/year; $^{40}K/K = 1.22 \times 10^{-4}$g /g.

Interpretations based on a single K-Ar age date must be made with caution, especially as a granodiorite age as young as 351 Ma was included in the average reported by Reynolds *et al.* (1981). However, mineralized areas within the South Mountain batholith are known commonly to give younger ages (Reynolds *et al.* 1981, D. McAuslan, pers. comm. 1981, Robertson & Duncan 1982). Hence the mineralizing event(s) in the Ellison Lake pluton may be the explanation for the apparently younger age.

Discussion

Most petrological features of the Ellison Lake pluton indicate an affinity with the biotite granodiorite rather than the monzogranite of the South Mountain batholith. The mafic mineral abundance, SiO_2 content, differentiation index and most other chemical characteristics are more typical of granodiorite than monzogranite (Fig. 4, Table 5). However, the Ellison Lake pluton is composed of monzogranite, not granodiorite, on the basis of modal K-feldspar content. Furthermore, this monzogranite is generally more peraluminous than the biotite granodiorite of South Mountain, with an excess of Al approximately the same as the South Mountain monzogranite in spite of a much lower silica content. This is reflected in the relative abundance of aluminum-rich minerals such as cordierite, muscovite and garnet.

An explanation for these features might be that the Ellison Lake monzogranite represents a magma separate from those of the South Mountain batholith that originated from a more Al- and K-rich source rock. An alternate explanation is that Ellison Lake monzogranite and South Mountain granodiorite magmas were originally similar but the Ellison Lake magma subsequently became contaminated by further inclusion of pelitic material than is typical of the main South Mountain granodiorite. This would lower the Si content and increase K and Al contents, thus making the magma more peraluminous and more "granitic" by increasing the modal concentration of K-feldspar. Alteration could also have increased the proportion of Al to Ca, Na and K (*e.g.*, Halliday *et al.* 1981) and may account for some of the variation in peraluminous character among the samples, but it is unlikely to be the cause of the greater absolute abundances of Al and K in the Ellison Lake monzogranite compared to the South Mountain granodiorite.

A related question is the origin of the cordierite and garnet in the Ellison Lake monzogranite. Magmatic crystallization of the cordierite is strongly suggested by its large size, subhedral form and lack of inclusions. Its chemical composition is reasonably consistent with a magmatic origin, although Na_2O may be somewhat lower than usual (*e.g.*, Speer 1981). In contrast to the cordierite, garnet in the Ellison Lake monzogranite occurs as relatively small anhedral grains, typical of garnet interpreted to be xenocrystic and of metamorphic origin (Allan & Clarke 1981). MnO contents in the range of 1.68 to 3.38% are also not characteristic of a magmatic origin (Miller & Stoddard 1978). Hence, these two aluminous minerals may have had contrasting origins in the Ellison Lake pluton.

Acknowledgements

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