Granitoid plutons of the Brookville terrane, southern New Brunswick: petrology, age, and tectonic setting

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ABSTRACT

Latest Neoproterozoic and Cambrian plutons in the Brookville terrane of southern New Brunswick are termed the Golden Grove Plutonic Suite. Four groups are recognized on the basis of composition: gabbro (2 plutons), diorite - granodiorite (17 plutons), granodiorite - monzogranite (8 plutons), and syenogranite - monzogranite (7 plutons). The dioritic to granodioritic and most of the granodioritic to monzogranitic plutons form linear trends on chemical variation diagrams, suggesting that magma evolution was dominated by plagioclase and amphibole fractionation. These plutons appear to constitute a typical I-type, calc-alkaline suite characteristic of continental margin subduction zones. This interpretation is supported by U-Pb zircon ages, which show that these plutons have ages between 540 Ma and 526 Ma. A new U-Pb age of 539.6 ± 1.2 Ma from one of the gabbroic plutons shows that the gabbroic plutons are co-genetic with the dioritic to granitic plutons, although they show varied ultramafic to anorthositic and dioritic compositions as a result of crystal accumulation. The syenogranitic to monzogranitic plutons and two of the granodioritic and monzogranitic plutons, as well as felsic volcanic rocks of the Dipper Harbour volcanic unit, show chemical trends that differ from the other plutons in having A-type characteristics. A U-Pb age of 548 ± 2 Ma for the Fairville Granite, as well as similar ages for a syenogranitic pluton and the Dipper Harbour volcanic unit, suggests that these units represent early stages of magmatism in the Golden Grove Plutonic Suite.

RESUMÉ

Les plutons du Cambrien et des périodes les plus anciennes du Néoprotérozoïque à l'intérieur du terrane de Brookville dans le Sud du Nouveau-Brunswick sont désignés sous le nom de « cortège plutonique de Golden Grove ». On y distingue quatre groupes en fonction de leur composition : ceux à base de gabbro (deux plutons), de diorite - granodiorite (17 plutons), de granodiorite - monzogranite (huit plutons) et de syénogranite - monzogranite (sept plutons). Les plutons dioritiques à granodioritiques et la majorité des plutons granodioritiques à monzogranitiques forment des tracés linéaires sur les schémas de diversité de la composition chimique, ce qui laisse supposer que l'évolution magmatique a été dominée par une cristallisation fractionnée des plagioclases et des amphiboles. Ces plutons semblent constituer un cortège calco-alcalin intrusif typique, caractéristique des zones de subduction de la marge continentale. Cette interprétation est corroborée par la datation au U-Pb, obtenue à partir de zircon, qui révèle que ces plutons ont des âges entre 540 Ma et 526 Ma. Une nouvelle datation au U-Pb obtenue à partir de zircon situant à 539,6 ± 1,2 Ma l'âge de l'un des plutons gabbroïques, signale que les plutons gabbroïques sont cogénétiques avec les plutons dioritiques à granitiques, même s'ils présentent des compositions ultramafiques à anorthositiques et dioritiques diversifiées par suite d'une accumulation de cristaux. Les plutons syénogranitiques à monzogranitiques et deux des plutons granodioritiques et monzogranitiques, de même que les roches volcanofelsiques de l'unité volcanique de Dipper Harbour, livrent des tracés chimiques différents des autres plutons du fait qu'ils possèdent les caractéristiques des plutons de type anorogénique. L'âge au U-Pb de 548 ± 2 Ma du granite de Fairville ainsi que les âges similaires d'un pluton syénogranitique et de l'unité volcanique de Dipper Harbour permettent de supposer que ces unités représentent les stades précoces du magmatisme à l'intérieur du cortège plutonique de Golden Grove.

INTRODUCTION

The Brookville terrane of southern New Brunswick (Fig. 1) consists of abundant gabbroic to granitic plutons intruded into Proterozoic gneissic, metasedimentary, and minor volcanic rocks (White 1996; White and Barr 1996; Eby and Currie 1996). White (1996) and White and Barr (1996) defined and described the petrological characteristics of 28 separate plutonic units in the terrane, most of which they interpreted to belong to a compositionally expanded comagmatic I-type suite formed in a late Neoproterozoic to Cambrian continental margin subduction zone. The age interpretation was based on U-Pb and $^{40}Ar/^{39}Ar$ dates that demonstrated latest Neoproterozoic and Cambrian ages for several plutons in the Saint John area. Eby and Currie (1996) presented petrological data for some of these plutons, and suggested links with plutons of similar ages in the Caledonia and New River terranes to the southeast and northwest, respectively (Fig. 1).

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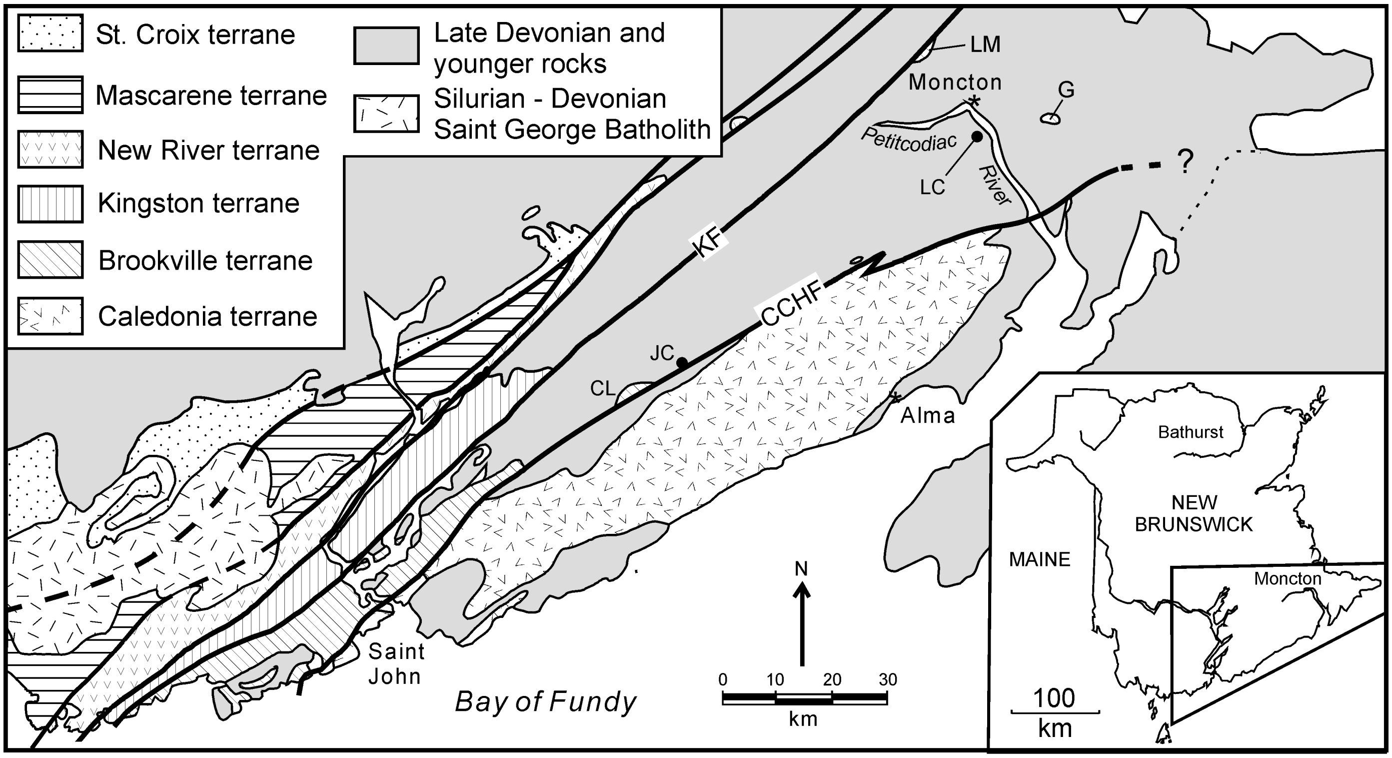

FIG. 1 *Location of the Brookville and adjacent terranes in southern New Brunswick. Abbreviations: CCHF, Caledonia-Clover Hill Fault; CL, Cassidy Lake inlier; G, Gaytons Granite; JC, Jeffrey Corner inlier; KF, Kennebecasis Fault; LC, Lower Coverdale Gabbroic Complex (in subsurface); LM, Lutes Mountain.*

The purpose of this paper is to present new and previously unpublished petrological and U-Pb geochronological data for plutons in the Brookville terrane. These new data show that the Neoproterozoic - Cambrian plutonic suite in the Brookville terrane also includes plutons in the Pocologan and Moncton areas, and that gabbroic plutons in the Saint John area, previously assumed to be younger (White and Barr 1996), are also part of this Neoproterozoic-Cambrian suite. In contrast, some plutons assumed to be part of the Neoproterozoic-Cambrian suite by White and Barr (1996) are now known to be younger (Barr *et al.* 2002a). Our new data, in combination with other recently published U-Pb ages (Currie and McNicoll 1999), provide additional constraints on the duration of plutonic activity in the Brookville terrane. We present a revised compilation of petrological features of Neoproterozoic and Cambrian plutons throughout the Brookville terrane, re-establish the name Golden Grove Plutonic Suite for these plutons, and further discuss their tectonic implications in the light of the new data.

GEOLOGICAL SETTING

The Brookville terrane is located between the Kennebecasis fault on the northwest and the Caledonia - Clover Hill fault on the southeast (Fig. 1). Rocks characteristic of the terrane outcrop mainly in the Saint John area, but have been traced to the northeast as far as the Moncton area on the basis of scattered outcrops and drill-hole intersections (White 1996). Metasedimentary rocks in the terrane are mainly assigned to the Green Head Group, which is divided into the two formations: Ashburn (dominantly marble with minor metaclastic rocks) and Martinon (dominantly metasiltstone with minor calc-silicate rocks, quartzite, conglomerate, and marble) (Fig. 2). These two formations have been interpreted to be lateral facies equivalents (White and Barr 1996). Based on locally preserved stromatolites, Hofmann (1974) suggested that the Green Head Group is Neohelikian (Mesoproterozoic) in age; more recent assessment suggested a minimum age of ca. 750 Ma (H. Hofmann, written communication, 1991). The Green Head Group is in tectonic contact with the Brookville Gneiss, a locally migmatitic paragneiss with sheets of granodioritic to tonalitic orthogneiss, minor calc-silicate and marble layers, and rare quartzite and amphibolite layers. The paragneiss, which comprises about 75% of the Brookville Gneiss, contains detrital zircon indicating a maximum depositional age of ca. 640 Ma (Bevier *et al.* 1990). The orthogneiss has an igneous crystallization age of 605 ± 3 Ma, and was metamorphosed to amphibolite facies at 564 ± 6 Ma (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). These dates indicate that the Brookville Gneiss is younger than the Green Head Group, but the original relationship between the two units remains problematic.

The Dipper Harbour volcanic unit is exposed in thrust sheets in the southern part of the terrane (Fig. 3). It includes felsic crystal and lithic tuff, flow-banded rhyolite, andesitic lithic tuff, laminated siltstone, and banded marble. A two-point U-Pb age of ca. 555 Ma reported previously (Zain Eldeen 1991) for rhyolite in the Dipper Harbour unit has been confirmed by a new, more precise U-Pb (zircon) age of 552 ± 3 Ma (Barr *et al.* 2002a). The volcanic unit is associated spatially with syenogranitic plutons (Jarvies Lake, Cranberry Head, and Fishing Cove; Figs. 2, 3), and the U-Pb age is consistent with the imprecise U-Pb (zircon) age of 550 ± 15 Ma reported for syenogranite in the nearby Musquash Harbour Pluton (Currie and Hunt 1991).

The units of the Brookville terrane contrast with those of the adjacent terranes in rock types and/or age (Barr and White 1996). The Caledonia terrane to the southeast (Fig. 1) consists of ca. 620 Ma and 560–550 Ma volcanic and sedimentary rocks intruded by plutons of similar ages, overlain by Cambrian sedimentary rocks (Barr and White 1999). The Kingston terrane to the northwest (Fig. 1) consists mainly of Silurian volcanic and epiclastic rocks and related granitic plutons (Barr *et al.* 2002c). A fault-bounded belt of partly mylonitic metasedimentary rocks termed the Pocologan metamorphic suite occurs between the Brookville and Kingston terranes in the southwest (Fig. 3), and has been linked to the Kingston terrane (Barr *et al.* 2002c).

GOLDEN GROVE PLUTONIC SUITE

Introduction

Plutons in the vicinity of the city of Saint John, as well as the Brookville Gneiss, were originally termed the "Golden Grove Intrusives" by Hayes and Howell (1937). The name was subsequently used to include plutons over a wider area in southern New Brunswick (e.g., Ruitenberg *et al.* 1979; Currie 1988). White *et*

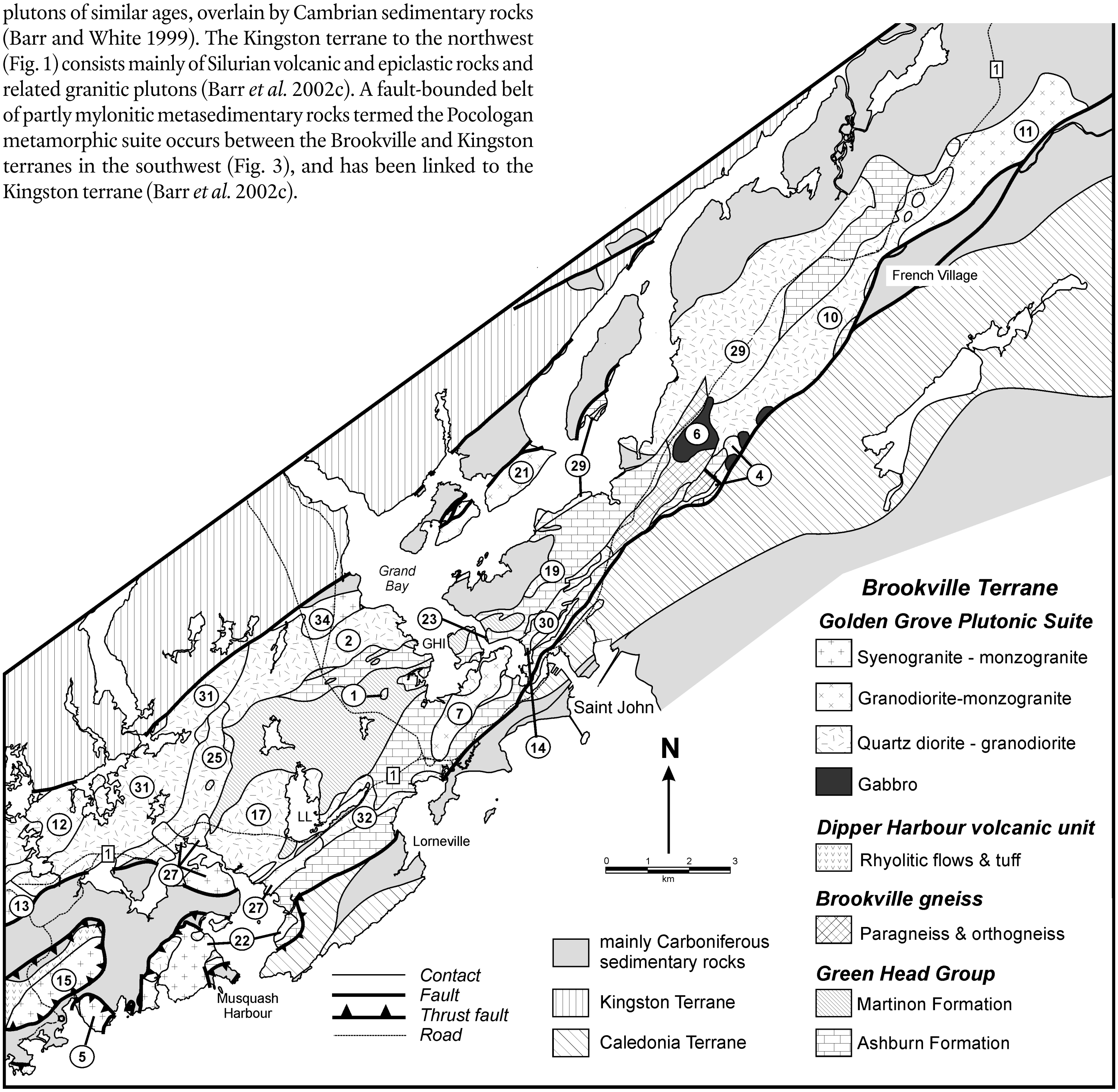

FIG. 2 *Simplified geological map showing the distribution of major units in the central part of the Brookville terrane (Saint John area). Plutons are numbered - see Table 1 for names and brief descriptions. Abbreviations: GHI, Green Head Island; LL, Ludgate Lake.*

Table 1. Plutons of the redefined Golden Grove Plutonic Suite.

	Pluton and U-Pb age [Ref #]	General lithology	Texture	Contacts	Other field observations
1	Acamac Tonalite	dark grey to red, quartz diorite to tonalite	m.g. hypidiomorphic equigranular	intrusive into Martinon Fm	similar to Mayflower Lake Tonalite.
2	Belmont Tonalite	light to dark grey tonalite gradational to quartz diorite and granodiorite	m.g., allotriomorphic to hypidiomorphic equigranular; locally inequigranular	intrusive into Martinon Fm.; intruded by Vairs Beach Granite	xenoliths of marble, metasiltstone, quartzite; locally foliated; f.g. granite/aplite dykes.
3	Carrying Cove Granite	red biotite monzogranite	m.g. hypidiomorphic equigranular	Occurs in a fault(?)-bounded sliver in Carrying Cove area, adjacent to Carboniferous sedimentary rocks.	lacks the large quartz crystals and abundant dioritic xenoliths of the Hanson Stream Granodiorite. Has more biotite (ca. 5%) than the Red Head Granite.
4	Chalet Lake Granite	orange monzogranite to granodiorite	c.g. hypidiomorphic inequigranular	poorly exposed; intrusive into Ashburn Fm.	megacrysts of K-feldspar; tectonic foliation.
5	Cranberry Head Syenogranite	pink to maroon to orange syenogranite to monzogranite	m.g. to c.g. hypidiomorphic to allotrimorphic equigranular to inequigranular	thrust-faulted	locally highly fractured and albitized; leucocratic; granophyric; aplite veins common.
6	Duck Lake Pluton 539.6 ± 1.2 Ma [1]	black to white, gabbroic, ultramafic, and anorthositic rocks	varied textured layered intrusion	poorly exposed; intrusive into French Village pluton and Brookville Gneiss	local pegmatoid lenses.
7	Fairville Granite 548 ± 2 Ma [1]	pink to orange monzogranite to granodiorite	c.g. hypidiomorphic inequigranular	strongly deformed southeast contacts; intrusive into Brookville Gneiss and Ashburn	xenoliths of gneiss and marble; rare dioritic enclaves; megacrysts of K-feldspar.
8	Fishing Point Syenogranite	similar to Cranberry Head Syenogranite	similar to Cranberry Head Syenogranite	faulted against Dipper Harbour volcanic unit and Triassic rocks	probably related to Cranberry Head Syenogranite.
9	Foleys Cove Granodiorite	grey to red altered granodiorite	originally c.g. but now sheared and deformed, with mylonitic bands common; relict granophyric texture observed in one sample.	faulted against Kingston terrane to the north and McCarthy Point Granodiorite to the south	May also be present in the Pocologan Harbour granitoid belt. Not well exposed.
10	French Village Quartz Diorite 537 ± 2 Ma [5]	dark grey to black, light grey to white diorite to tonalite	m.g. to c.g., hypidiomorphic equigranular to inequigranular	faulted contacts; intrusive into Brookville Gneiss and Ashburn Fm.	xenoliths of marble, quartzite and gneiss; dioritic enclaves; locally foliated and porphyritic.
11	Hammond River Granite	pink to orange monzogranite to granodiorite	f.g. to c.g. hypidiomorphic equigranular to inequigranular	intrusive into Ashburn Fm. and French Village pluton; unconformably overlain by Devonian to Carboniferous sedimentary rocks	xenoliths of marble, amphibolite, and gneiss; rare elongate dioritic enclaves; locally foliated; also exposed in Cassidy Lake inlier (see Fig. 1)
12	Hanson Stream Granodiorite 528 +1/-3 Ma [4]	grey to light grey granodiorite to monzogranite	c.g. hypidiomorphic ineqigranular	intrusive into Harvey Hill Syenogranite	small rounded dioritic to tonalitic enclaves; phenocrysts of quartz; interstitial K-feldspar; f.g. aplitic dykes.
13	Harvey Hill Syenogranite 544 ± 4 Ma [4]	pink to maroon syenogranite	f.g. allotrimorphic to hypidiomorphic inequigranular	surrounded by younger plutons	leucocratic and granophyric; locally subporphyritic; minor muscovite and rare fluorite.
14	Indiantown Pluton	black to white orthopyroxene gabbro, anorthosite	varied textured; layered intrusion	poorly exposed	locally pegmatoid.
15	Jarvies Lake Syenogranite	pink to maroon to orange syenogranite to monzogranite	m.g. to c.g. hypidiomorphic to allotrimorphic equigranular to equigranular	thrust faulted; intrusive into Dipper Harbour volcanic unit(?)	leucocratic; granophyric; aplite veins common. Probably related to Cranberry Head Syenogranite.
16	Joshua Lake Granodiorite	red granodiorite	m.g. to c.g. hypidiomorphic equigranular	thin sliver in the Joshua Lake area.	Contains ca. 20% amphibole; becomes coarser and more granitic to the SW
17	Ludgate Lake Granodiorite 546 ± 2 Ma [1]	grey to grey-green granodiorite to tonalite	f.g. to m.g., hypidiomorphic equigranular	intrusive into Martinon Fm. and faulted against Spruce Lake Pluton; locally intruded by Prince of Wales Granite	xenoliths of metasiltstone; enclaves of f.g. diorite to tonalite; locally foliated; aplite dykes
18	Lutes Mountain Diorite 542 ± 1.5 Ma [1]	dark grey diorite	m.g. hypidiomorphic equigranular	faulted sliver surrounded by Carboniferous rocks	very altered and sheared.
19	Mayflower Lake Tonalite	dark grey to red, quartz diorite to tonalite	f.g. to m.g., hypidiomorphic equigranular	intrusive into Ashburn Fm.; unconformably overlain by Carboniferous sedimentary	minor dioritic to tonalitic enclaves; similar to the smaller Narrows and Acamac plutons

Table 1. (contd.)

	Pluton and U-Pb age [Ref #]	General lithology	Texture	Contacts	Other field observations
20	McCarthy Point Granodiorite 528 +4/-3 Ma [3]	grey to grey-green granodiorite	m.g. hypidiomorphic granular, with subhedral plagioclase grains	well exposed, less altered to the east; intruded by Penn Island Granite.	very deformed locally; also a major component of the Pocologan Harbour granitoid belt.
21	Milkish Head Pluton	pink to red monzogranite to granodiorite	c.g. hypidiomorphic inequigranular monzogranite; granodiorite tends to be more m.g. and equigranular.	faulted and locally mylonitic along northern contact	rare dioritic to tonalitic enclaves; large phenocrysts of quartz common; f.g. granite & aplite dykes
22	Musquash Harbour Pluton 550 ± 15 Ma [2]	pink monzogranite to syenogranite; grey-green granodiorite to quartz diorite	m.g. to c.g., hypidiomorphic inequigranular to equigranular	faulted contacts; intrusive into Ashburn Fm.; unconformably overlain by Carboniferous limestone	composite pluton; syenogranite granophyric; f.g. granite/aplite dykes in granodiorite to quartz diorite parts.
23	Narrows Tonalite	dark grey to red, quartz diorite to tonalite	f.g. to m.g., hypidiomorphic equigranular	not exposed; intrusive into Ashburn Fm.?	similar to Mayflower Lake Tonalite.
24	Penn Island Granite	grey to pink monzogranite	m.g. to c.g. hypidiomorphic equigranular	intrusive into McCarthy Point Granodiorite.	also a component of the Pocologan Harbour graniotid belt.
25	Perch Lake Granodiorite	light to dark grey granodiorite	m.g., hypidiomorphic equigranular to inequigranular	intrusive into Martinon Fm.; intruded by Prince of Wales Granite	dioritic to tonalitic enclaves; foliated near contacts with Martinon Fm.
26	Pocologan Harbour granitoid belt	protolylonitic to mylonitic granodiorite, granite, diorite	little original granitoid mineralogy or texture preserved. Contains muscovite, epidote, minor biotite, no amphibole; quartz ribbons, highly saussuritized plagioclase; minor K-feldspar.	faulted against the Pocologan metamorphic suite to the north and mainly McCarthy Point Granodiorite to the south.	a mixture of McCarthy Point Granodiorite, Penn Island Granite, Foleys Cove Granodiorite, and more dioritic rocks.
27	Prince of Wales Granite	pink monzogranite to syenogranite	m.g., allotrimorphic to hypidiomorphic equigranular to inequigranular	locally faulted; intrusive into Perch Lake, Ludgate Lake, and Spruce Lake plutons	locally tectonic foliation; leucocratic and granophyric.
28	Red Head Granite	red granite	c.g. allotriomorphic equigranular	faulted contact with McCarthy Point Granodiorite	no chemical data. Could be related to the syenogranitic plutons.
29	Renforth Pluton	dark grey to red, quartz diorite to tonalite, locally granodioritic	f.g. to m.g., hypidiomorphic equigranular; locally allotrimorphic inequigranular	intrusive into Ashburn Fm. and French Village pluton; unconformably overlain by Carboniferous sedimentary rocks	minor dioritic to tonalitic enclaves; locally porphyritic; locally mineralized along shear zones.
30	Rockwood Park Granodiorite 538 ± 1 Ma[2]	grey tonalite to granodiorite	m.g. foliated, hypidiomorphic equigranular	poorly exposed; intrusive into Ashburn Fm.	forms two bodies; elongate dioritic to tonalitic enclaves.
31	Shadow Lake Granodiorite	grey granodiorite to tonalite	m.g. to c.g., hypidiomorphic to allotrimorphic inequigranular	poorly exposed or faulted; sharp contact with Hanson Stream pluton and intruded by Harvey Hill pluton	elongate dioritic to tonalitic enclaves; magma mixing/mingling textures; locally foliated.
32	Spruce Lake Pluton	light grey to black quartz diorite to tonalite; minor granodiorite	m.g. to c.g., hypidiomorphic equigranular to inequigranular	generally faulted; intrusive into Ashburn Fm. and intruded by Prince of Wales Granite	xenoliths of metasiltstone and marble; dioritic enclaves; locally foliated
33	Talbot Road Granodiorite	grey to pink granodiorite to tonalite	f.g. to m.g. hypidiomorphic equigranular to locally inequigranular	poorly exposed; locally faulted	forms two bodies; dioritic to tonalitic enclaves; locally foliated; f.g. granite/aplite dykes
34	Vairs Beach Granite	red to orange monzogranite to granodiorite	m.g. to c.g. hypidiomorphic to allotrimorphic equigranular	northern contact faulted; intrusive into Belmont pluton; unconformably overlain by Carboniferous sedimentary rocks	leucocratic and granophyric; xenoliths of marble and metasiltstone

References:
1 This paper
2 White et al. (1990)
3 Currie and Hunt (1991)
4 Currie and McNicoll (1999)
5 Bevier et al. (1991)

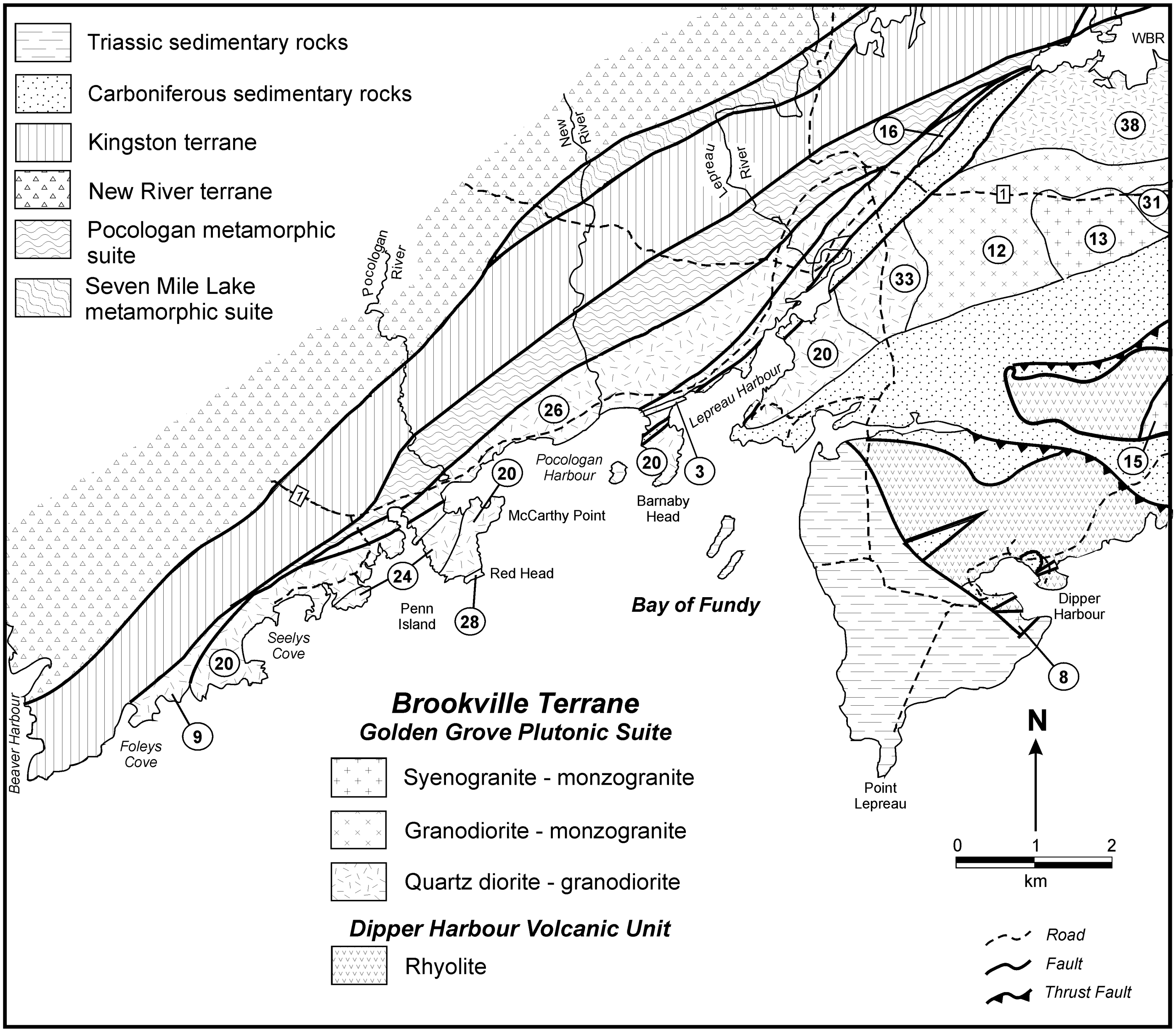

FIG. 3 *Simplified geological map showing the distribution of major units in the southwestern (Pocologan) part of the Brookville terrane. Plutons are numbered - see Table 1 for names and brief descriptions.*

al. (1990) suggested that the term Golden Grove Intrusive Suite should be abandoned because the rocks assigned to it are not all plutonic, are not all the same age, and do not belong to a single intrusive suite. However, in recognition that a collective name is needed for plutons in the Brookville terrane, Barr *et al.* (2001) suggested that the name Golden Grove Plutonic Suite be redefined to refer only to the latest Neoproterozoic to Cambrian gabbroic to granitic plutons of the Brookville terrane, a recommendation followed here.

The 34 plutons that comprise the redefined Golden Grove Plutonic Suite are listed in Table 1. They include most plutons known in the Brookville terrane; exceptions are orthogneissic components of the Brookville Gneiss, the Gaytons Granite, and subsurface gabbroic, anorthositic, and granitic rocks of the Lower Coverdale Gabbroic Complex. These units are excluded because U-Pb data indicate an older, ca. 605 Ma, age for the Brookville orthogneiss, as noted above, and a Devonian age for the Gaytons Granite and the Lower Coverdale complex (Barr *et al.* 2002a). Although not all plutons of the re-defined Golden Grove Plutonic Suite have been dated, a latest Neoproterozoic to Cambrian age is assumed on the basis of petrological similarities to dated plutons. Some pluton names have been changed from those used by White (1996) and White and Barr (1996) because of conflicts with pre-existing unit names (L.R. Fyffe, personal communication, 2000), or because additional work clarified their inclusion in other units (Barr *et al.* 2001). Some plutons have been added as a result of additional work in the Pocologan and Lutes Mountain area, as described below. Because a variety of different names have been used in the past for some of these plutons, White (1996) provided, for clarification, a compilation of the previous terminology relative to current usage. Detailed maps that include the plutons in the Saint John and Pocologan areas have been published (Barr and White 2001); simplified maps are shown in Figures 2 and 3.

Composition

The plutons of the Golden Grove suite can be broadly grouped into four compositional types depending on the dominant rock type, abundance of mafic minerals, and texture: (1) gabbro, (2) diorite to granodiorite, (3) granodiorite to monzogranite, and (4) syenogranite to monzogranite. As summarized in Table 1, relative ages among some plutons of the suite can be established based on cross-cutting relationships and/or the presence of xenoliths. These observations do not suggest a clear sequence of intrusive relationships from mafic to felsic. The lack of a compositional pattern is supported also by the U-Pb ages (see below) in those cases where the ages are precise enough to indicate an order of intrusion. However, the close spatial association of the plutons suggests that they were generated in the same place at more or less the same time by more or less the same processes, but that magma evolution was parallel, as well as sequential. Such complex “compositionally expanded series” are typical of Andean-type subduction zones (e.g., Pitcher 1994).

1. Gabbroic plutons

Two small gabbroic plutons, Duck Lake and Indiantown (Fig. 2), are part of the Golden Grove Plutonic Suite. The Duck Lake Pluton has an area of about 1.5 km^2, and mainly intruded the Brookville Gneiss. However, its eastern margin is an inferred intrusive contact with the Renforth and French Village plutons (Fig. 2), consistent with its slightly younger U-Pb age (see below and Table 1). Rock types sampled in the Duck Lake Pluton include gabbro, orthopyroxene gabbro, gabbronorite, olivine gabbronorite, anorthosite, dunite, and wehrlite (Grammatikopoulos 1992; White 1996). The smaller Indiantown body, less than 0.5 km^2 in area, consists of orthopyroxene gabbro and anorthosite, surrounded by rocks of the French Village Quartz Diorite (Fig. 2). Smaller, probably related, gabbroic bodies also occur in the area of the Duck Lake Pluton (Fig. 2), and it is probable that some of the mafic dykes that occur widely in units of the Brookville terrane are also related to these gabbroic bodies.

White (1996) interpreted the Duck Lake and Indiantown plutons, as well as the Lower Coverdale Gabbroic Complex southwest of Moncton (Fig. 1), to be younger than other plutons in the Brookville terrane. He suggested a Silurian age, because Silurian gabbroic bodies occur elsewhere in southern New Brunswick and Maine (West *et al.* 1992), and in central Cape Breton Island (Keppie *et al.* 2000). However, the U-Pb age presented here demonstrates that the Duck Lake Pluton is the same age as the intermediate and felsic plutons described below, and hence it is here included in the Golden Grove Plutonic Suite. The Indiantown Pluton is similar in petrology to the Duck Lake pluton, and is likely of similar age. In contrast, the Lower Coverdale Gabbroic Complex is not included in the Golden Grove suite because of its probable Devonian age (Barr *et al.* 2002b).

2. Dioritic to granodioritic plutons

Dioritic to granodioritic plutons are the largest and most abundant in the Brookville terrane at the present level of exposure (Figs. 2, 3). They are generally elongate northeast-southwest, parallel to the terrane margins. These plutons are named according to their most abundant rock type, but most show a wide range in composition. Most also contain abundant dioritic to tonalitic enclaves, which may represent cognate material formed at earlier stages of crystallization from the same magma as the host. Locally, they display evidence of magma mingling and mixing between enclaves and host, and in these cases the enclaves may represent blebs of immiscible, more mafic melt in the host magma (e.g., Barbarin and Didier 1992). Locally, enclaves are elongate parallel to the long axis of the intrusion, suggestive of a flow fabric.

In addition to the plutons described in detail by White (1996), the dioritic to granodioritic group also includes the Lutes Mountain Diorite (Fig. 1) and most plutons in the Pocologan Harbour area (Fig. 3), as described by Barr *et al.* (2001). The former Lepreau Harbour and Lepreau plutons of White (1996) and White and Barr (1996) are now considered part of the McCarthy Point Granodiorite and Pocologan Harbour granitoid belt, respectively. The Pocologan Harbour granitoid belt is an informal name for a mixture of highly deformed rocks in which recognition of protoliths and subdivision is difficult due to the extent of deformation. This belt coincides approximately with the Pocologan mylonite zone of earlier workers (e.g. Park *et al.* 1994).

The dioritic to granodioritic plutons are typically medium grained, with more than 20% combined hornblende and biotite. Zoned plagioclase with average composition of andesine is the most abundant mineral, with less abundant interstitial K-feldspar and quartz. Amphibole is typically second in abundance to plagioclase, and is mainly calcic amphibole of magnesio-hornblende composition (White 1996). Remnant clinopyroxene cores were observed rarely in amphibole in the most mafic plutons and their enclaves. Biotite is generally less abundant than amphibole, has Fe/Mg ratio intermediate between phlogopite and annite end members, and overall composition typical of biotite in calc-alkalic plutons (Abdel-Rahman 1994). The most abundant accessory minerals are magnetite and titanite.

3. Granodioritic to monzogranitic plutons

Plutons of granodioritic and monzogranitic composition are less abundant and typically smaller than those of the dioritic to granodioritic group. They also show less range in composition, and are generally composed of granodiorite and/or monzogranite and minor syenogranite. These plutons are typically coarse grained, and contain less than 10% amphibole and biotite. Mafic xenoliths are not generally abundant, except in the Hanson Stream Granodiorite (#12, Table 1), which is characterized by abundant small dioritic xenoliths and prominent large quartz grains. Similar large quartz grains occur locally in the Penn Island and Milkish Head plutons. The Hammond River Granite forms the northeastern part of the terrane and appears to grade from granodiorite to monzogranite and locally syenogranite

Table 2. New chemical data from plutons of the Golden Grove Plutonic Suite.

Pluton #	3	9	9	16	18	20	20	20	20	20	20	20	20	24
Sample	NB00-105	K99-516	K99-517	K99-472	NB00-11	K99-482A	K99-487A	K99-518A	K99-522A	NB00-104	NB00-112	NB00-43A	NB99-5	K99-519
Easting	701400	682800	683350	703200	355450	687750	700450	683600	689200	700900	689750	695050	690750	686650
Northing	5000750	4993400	4993600	5009150	5113950	4997300	4906700	4993400	4996600	5007150	4998150	4998800	4998450	4995800
Major elements (wt. %)														
SiO_2	75.64	68.66	66.33	62.85	56.73	65.18	57.01	66.28	60.33	55.13	64.01	65.29	59.43	68.98
TiO_2	0.24	0.31	0.36	0.71	0.71	0.37	1.19	0.38	0.46	1.20	0.40	0.66	0.48	0.30
Al_2O_3	12.66	14.22	15.65	16.49	16.19	16.09	17.12	15.53	17.25	17.23	16.02	15.47	17.94	15.19
$Fe_2O_3^t$	1.15	3.20	3.75	4.74	6.21	4.27	7.18	3.93	5.39	7.61	4.59	4.68	6.12	3.14
MnO	0.06	0.07	0.06	0.10	0.12	0.08	0.13	0.07	0.09	0.14	0.08	0.09	0.11	0.07
MgO	0.27	1.31	1.87	2.06	4.08	1.99	2.98	2.07	2.89	3.28	2.48	2.07	3.15	1.67
CaO	0.89	1.88	2.79	2.57	4.98	4.58	5.49	3.29	5.77	6.29	3.94	3.12	6.42	2.33
Na_2O	4.24	2.73	4.02	4.07	4.57	2.74	3.53	2.85	2.95	3.43	2.89	5.40	3.04	3.47
K_2O	3.34	4.64	2.29	4.43	3.41	2.67	3.28	3.18	2.39	2.45	3.13	0.96	1.81	3.71
P_2O_5	0.05	0.07	0.10	0.23	0.13	0.09	0.44	0.09	0.11	0.45	0.08	0.20	0.12	0.08
LOI	1.44	2.41	2.06	1.66	3.32	1.65	1.21	2.07	1.10	2.16	2.08	1.88	2.09	1.50
Total	99.97	99.50	99.28	99.90	100.45	99.71	99.56	99.74	98.73	99.37	99.70	99.82	100.71	100.43
Trace elements (ppm)														
Ba	461	491	417	708	552	410	597	404	306	821	414	189	295	364
Rb	97	144	81	151	88	99	89	106	79	68	111	34	61	123
Sr	37	76	302	329	204	241	555	223	261	595	218	145	324	163
Y	29	13	7	21	23	10	29	10	12	26	18	34	11	11
Zr	101	118	115	368	147	122	284	112	113	263	98	125	90	113
Nb	8	5	4	15	9	6	12	4	2	13	5	8	3	5
Th	13	14	15	22	3	14	15	14	6	15	7	5	9	22
Pb	55	8	11	32	6	7	19	5	11	9	13	11	1	16
Ga	14	12	15	18	13	14	22	13	16	20	15	14	18	16
Zn	36	60	38	60	61	50	66	32	61	70	46	63	51	38
Cu	201	0	10	124	14	8	35	28	33	76	30	15	28	7
Ni	10	4	4	22	42	5	9	90	0	16	6	<3	13	0
V	33	46	72	84	122	73	159	82	107	178	90	95	129	51
Cr	13	9	17	17	36	6	19	22	13	24	<4	<4	16	0

Pluton #	24	24	24	24	26	26	26	26	26	26	26	26	26
Sample	K99-520	NB00-110	NB00-111	NB00-44	K99-434	K99-440	K99-446A	K99-467	NB00-109	NB00-68	NB00-75	NB00-76	NB00-91
Easting	689950	689400	689550	694550	693050	690600	697900	702150	691700	693250	691050	691100	690500
Northing	4997050	4998150	4998150	4999200	5001750	4999700	5004850	5008450	5000600	5000550	4999900	4999900	4999450
Major elements (wt. %)													
SiO_2	68.50	66.22	65.86	74.30	68.01	75.56	58.79	67.64	70.10	64.70	67.17	75.99	63.52
TiO_2	0.30	0.34	0.34	0.21	0.44	0.26	0.57	0.37	0.28	0.35	0.45	0.11	0.44
Al_2O_3	15.11	15.43	15.80	13.53	14.93	13.35	17.72	15.70	13.99	15.73	14.70	12.53	16.44
$Fe_2O_3^t$	3.26	3.27	3.58	1.53	4.08	1.38	6.83	3.52	2.51	4.24	4.18	0.97	5.12
MnO	0.06	0.07	0.07	0.03	0.08	0.02	0.14	0.08	0.04	0.08	0.09	0.01	0.08
MgO	1.20	1.45	1.69	0.63	1.81	0.63	3.11	1.57	1.24	1.90	1.87	0.36	2.33
CaO	3.88	3.27	3.75	1.01	3.77	0.80	6.66	3.89	2.32	3.97	4.30	0.09	4.23
Na_2O	3.45	3.68	3.26	4.06	2.85	3.39	2.75	3.42	3.13	3.31	2.86	3.01	3.67
K_2O	2.67	3.36	3.19	2.92	2.64	3.21	2.20	2.29	2.85	2.94	2.72	5.28	2.14
P_2O_5	0.07	0.08	0.07	0.06	0.09	0.07	0.13	0.11	0.06	0.10	0.08	0.03	0.11
LOI	1.09	1.93	1.59	0.68	1.31	1.61	1.18	1.52	2.23	1.99	2.10	0.75	1.89
Total	99.58	99.10	99.20	98.95	100.01	100.28	100.08	100.11	98.75	99.31	100.52	99.12	99.97
Trace elements (ppm)													
Ba	212	487	402	584	793	235	178	500	560	389	441	728	446
Rb	96	106	109	86	85	191	59	68	94	103	80	129	62
Sr	233	195	192	96	217	118	295	256	205	214	226	65	233
Y	7	15	16	19	10	9	20	6	13	17	24	13	18
Zr	113	119	105	109	123	166	126	138	102	109	190	69	114
Nb	6	5	5	6	4	14	6	4	3	4	6	5	5
Th	16	11	11	7	15	56	7	8	9	9	15	27	9
Pb	7	16	21	8	21	25	26	10	13	15	18	23	9
Ga	18	13	16	12	15	17	18	16	12	15	14	9	15
Zn	40	63	37	18	44	27	99	38	26	45	57	16	40
Cu	0	11	28	<4	39	0	38	3	112	30	28	9	24
Ni	34	3	4	78	1	0	5	0	<3	3	7	<3	4
V	55	66	70	32	82	11	142	75	52	72	91	22	97
Cr	8	<4	<4	<4	3	0	14	0	<4	<4	5	<4	<4

Pluton #: 3 = Carrying Cove Granite, 9 = Foleys Cove Granodiorite, 16 = Joshua Lake Granodiorite, 18 = Lutes Mountain Diorite, A3620 = McCarthy Point Granodiorite, 24 = Penn Island Granite, 26 = Pocologan Harbour granitoid belt.

Table 3. Hf, Ta, and rare-earth element data obtained by ICP-MS[1]

Pluton[2]	1	6	6	6	10	11	12	14	17	20	22	29	31	31	DH
Samp. #	NB91-8522	DL91-02	DL91-09	CW88-256	CW88-153	CW88-200	NB92-9050	CW90-835B	NB91-8590	NB99-5	NB92-9202A	CW88-191	NB91-8599B	NB92-9033	NB92-9073
Hf	3.960	0.429	0.089	0.338	0.960	2.130	2.646	0.276	3.882	1.570	2.439	1.910	6.612	5.069	6.176
Ta	0.422	0.295	0.119	0.443	1.640	1.270	1.171	0.342	0.444	0.618	0.437	0.602	0.575	0.636	2.158
La	16.732	1.480	0.820	1.660	11.360	19.390	16.174	1.000	19.563	11.666	12.707	32.650	15.651	10.738	43.401
Ce	32.798	3.780	1.550	3.270	27.360	39.490	32.795	2.390	40.256	28.591	28.398	64.890	37.124	22.072	83.861
Pr	3.465	0.550	0.180	0.400	3.430	4.340	3.367	0.340	4.400	3.330	3.383	-	4.625	2.612	10.218
Nd	11.899	2.860	0.643	1.390	13.080	14.310	11.952	1.690	16.802	13.285	14.646	22.230	18.707	10.335	38.461
Sm	2.151	0.875	0.120	0.280	3.200	2.720	2.288	0.484	3.078	3.019	3.264	3.790	4.405	2.234	8.439
Eu	0.731	0.346	0.092	0.206	0.914	0.465	0.666	0.255	0.752	0.769	0.961	0.699	1.056	0.813	1.218
Gd	2.037	1.060	0.124	0.261	2.890	1.870	1.769	0.587	3.048	2.588	3.709	2.730	4.792	2.582	7.716
Tb	0.297	0.156	0.017	0.046	0.531	0.251	0.250	0.084	0.448	0.379	0.515	0.456	0.648	0.370	1.235
Dy	1.916	1.100	0.099	0.276	3.410	1.250	1.756	0.509	3.097	2.393	3.553	-	4.439	2.319	7.692
Ho	0.364	0.219	0.021	0.062	0.692	0.213	0.329	0.109	0.593	0.481	0.669	-	0.841	0.463	1.449
Er	1.126	0.701	0.058	0.221	2.090	0.576	1.052	0.266	1.710	1.456	2.136	-	2.549	1.330	4.43
Tm	0.169	0.098	0.011	0.037	0.312	0.083	0.155	0.042	0.283	0.243	0.282	0.262	0.397	0.202	0.700
Yb	1.235	0.578	0.067	0.233	2.130	0.639	1.091	0.269	1.844	1.384	1.951	1.720	2.658	1.328	4.847
Lu	0.183	0.090	0.013	0.044	0.327	0.109	0.202	0.035	0.316	0.185	0.317	0.263	0.373	0.222	0.779

[1] Analyses at Memorial University by the Na_2O_2 sinter method (Longerich *et al.* 1990)

[2] Pluton numbers are from Table 1, except DH = Dipper Harbour volcanic unit. Sample locations are shown in White (1996) or listed in Table 2.

toward the northeast (White 1996). Granitic rocks exposed in the Cassidy Lake and Jeffrey Corner areas (Fig. 1) may be part of the Hammond River Granite. The Fairville and Chalet Lake plutons are characterized by large megacrysts of K-feldspar. The Fairville Granite is locally intruded by quartz diorite apparently related to the French Village Quartz Diorite, a relationship consistent with the U-Pb ages of these plutons (see below).

4. Syenogranitic to monzogranitic plutons

Most of the syenogranitic to monzogranitic plutons occur in the coastal part of the Brookville terrane, southwest of Saint John (Figs. 2, 3). They are typically small, relatively homogeneous bodies, although the Musquash Harbour Pluton is larger and shows more compositional variation, including granodioritic and dioritic components. These plutons appear to lack mafic enclaves, and contain less than 5% mafic minerals. Granophyric textures are common, suggesting that these plutons may be the high-level intrusive equivalents of the Dipper Harbour volcanic rocks, with which they show close spatial association (Figs. 2, 3). However, widespread Carboniferous thrusting (Nance 1987; White 1996) has obscured many of the original contact relationships in this area.

GEOCHEMISTRY

Introduction

A total of 163 chemical analyses for major and selected trace elements are available from the plutons of the Golden Grove Plutonic Suite. They include data from White (1996) and Eby and Currie (1996), as well as new data obtained in the present study (Table 2). Rare-earth element data are available for 48 samples, 14 from the present study (Table 3) and 32 from Eby and Currie (1996) and Currie (1996; written communication). The size of the data set precludes detailed discussion of chemical variations within individual plutons, and instead an overview of the chemical variations among plutons is emphasized. Because of the range in loss-on-ignition values in the samples, the major element oxide data have been recalculated to total 100% volatile-free before being plotted on the various diagrams.

Gabbroic plutons

The varied compositions of the Duck Lake and Indiantown gabbroic plutons are reflected in the chemical data. SiO_2 content ranges from less than 40% in ultramafic samples to 48% in gabbroic and anorthositic samples (Fig. 4). Ranges in Al_2O_3, CaO, and Na_2O correlate with the varying abundance of plagioclase; anorthositic samples have more than 20% Al_2O_3, 14–18% CaO, and 1–2% Na_2O (Figs. 4b, e, f). Ultramafic (lowest SiO_2) samples have higher Fe_2O_3 and MgO (Figs. 4c, d) and low Al_2O_3, CaO, and Na_2O (Figs. 4b, e, f). Most samples are low in TiO_2, K_2O, and P_2O_5 (Figs. 4a, g, h). The low TiO_2 and P_2O_5 are in marked contrast to the Lower Coverdale gabbroic complex sampled in drill holes near Moncton (Fig. 1), in which TiO_2 and P_2O_5 contents exceed 20% and 8%, respectively, in some gabbroic samples (Barr *et al.* 2002d).

The gabbroic samples with highest SiO_2 contents overlap with the most mafic (lowest SiO_2) samples from the dioritic plutons. These overlapping samples have generally similar abundances of most major element oxides and in the cases of Al_2O_3, MgO, CaO, Na_2O, and K_2O the gabbroic samples lie on reasonably linear trends with the dioritic samples (Figs. 4b, d, e, f, g), suggesting a genetic relationship. Trends are less continuous in the cases of TiO_2, $Fe_2O_3^t$, and P_2O_5 (Figs. 4a, c, and h), but those more erratic

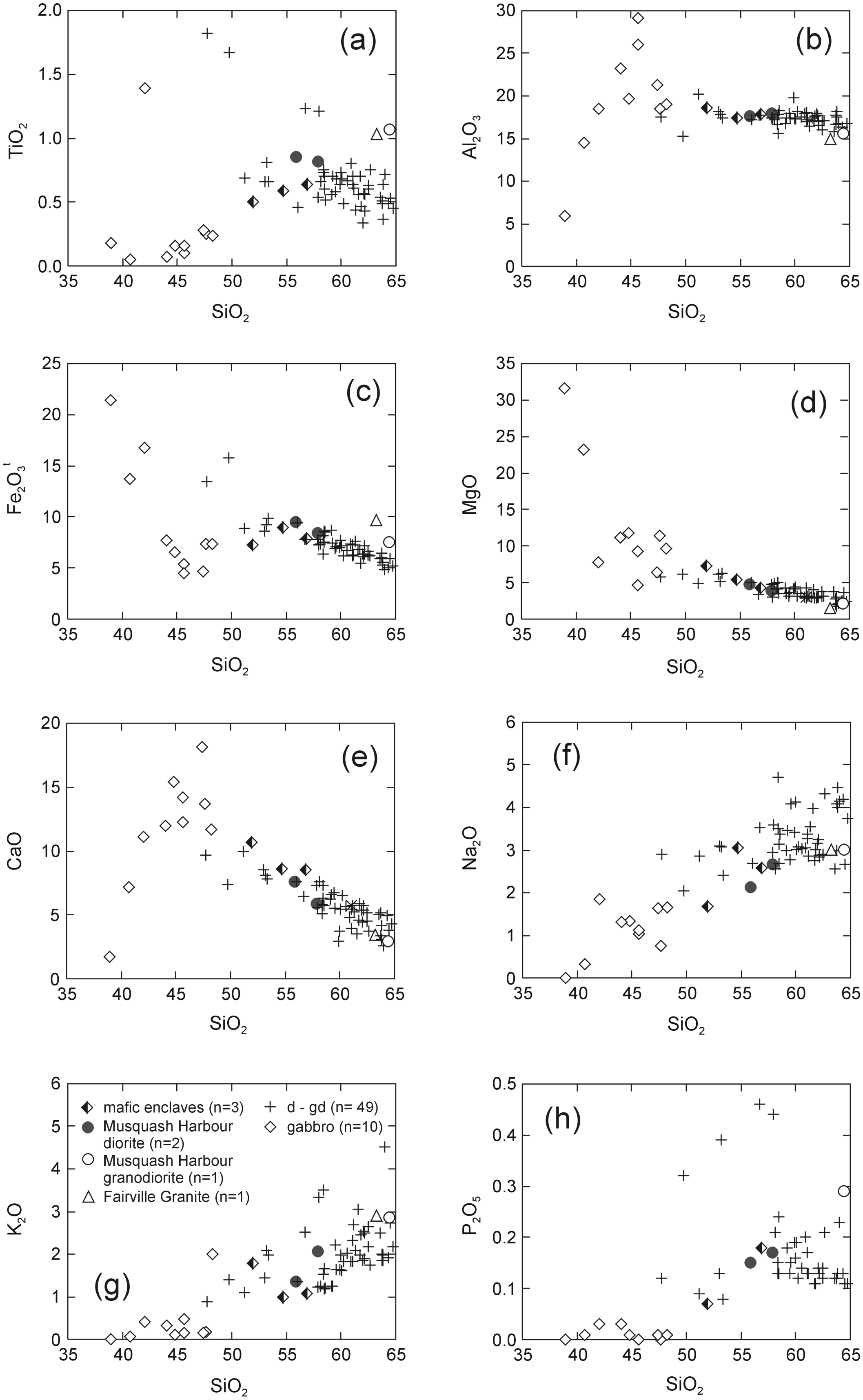

FIG. 4 *Diagrams to illustrate chemical variations in gabbroic, dioritic, and granodioritic samples (35–65% SiO_2). All data are in weight %. $Fe_2O_3^t$ is total iron expressed as Fe_2O_3. Data are from Table 2 and sources described in text. The data shown for the Fairville Granite include 3 samples from the similar Chalet Lake Granite. Abbreviations: d, diorite; gd, granodiorite.*

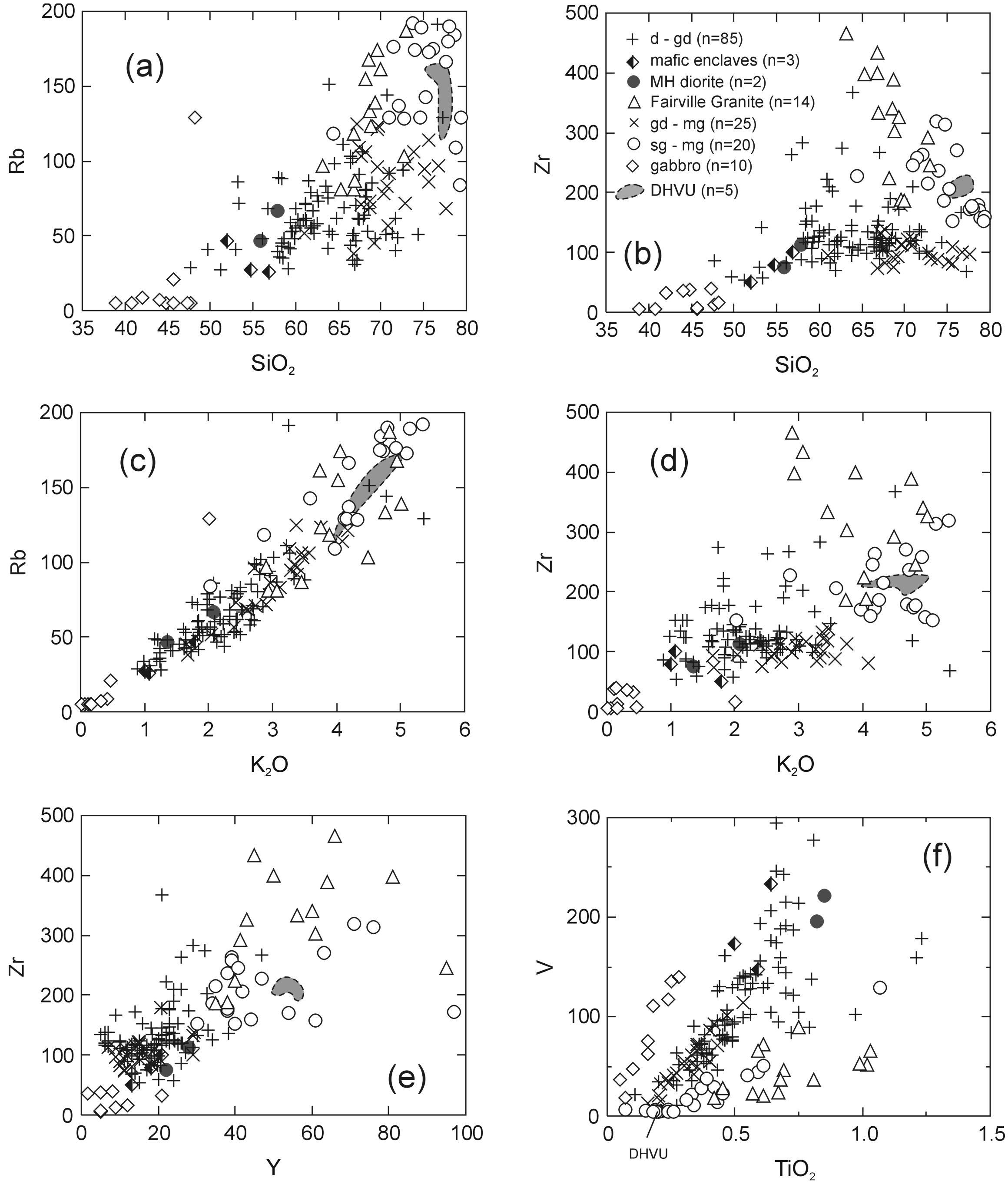

fig. 5 Diagrams to illustrate trace element variations in all samples. Oxide data are in weight %; elemental data are in ppm. Data are from Table 2 and sources described in text. Abbreviations: d, diorite; gd, granodiorite; mg, monzogranite; sg, syenogranite; MH, Musquash Harbour; DHVU, Dipper Harbour volcanic unit.

variations could result from fractionation of titaniferous magnetite, ilmenite, and apatite.

Trace elements such as Rb and Zr that are incompatible in mafic minerals and plagioclase are generally low in the gabbroic samples (Figs. 5a, b). Conversely, compatible elements show wide variation (e.g., V, 18 to 437 ppm; Cr, 36 to 2926 ppm, and Ni, 45 to 838 ppm) and positive correlation with TiO_2 (Fig. 5f; one sample with 437 ppm V and 1.36% TiO_2 is off the scale of the figure) and $Fe_2O_3^t$ and MgO (not shown).

REE concentrations are low and, relative to chondritic values, show slight light REE enrichment (Fig. 6a). All four samples show slight to moderate enrichment in Eu, suggesting accumulation of plagioclase in the analyzed samples.

Diorite to granodiorite

The large range in chemical compositions in the dioritic to granodioritic plutons corresponds well with the range in modal mineralogy. SiO_2 contents vary from less than 50% in dioritic samples to over 75% in the most granitic parts of some plutons, but

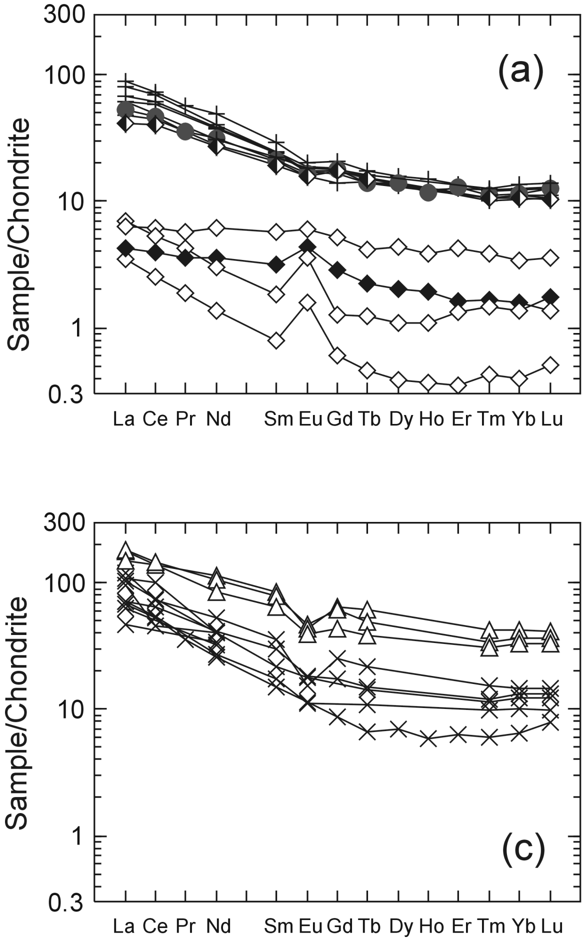

FIG. 6 *Chondrite-normalized rare-earth element diagrams. (a) Samples from the Duck Lake pluton (open diamonds), Indiantown gabbro (filled diamonds), and 5 samples with less than 60% SiO_2 from other units (symbols as in Fig. 4). (b) Samples with more than 60% SiO_2 from the dioritic to granodioritic plutons. Shaded field includes the 5 samples with less than 60% SiO^2 from (a) for comparison. (c) Samples from the granodioritic and monzogranitic plutons; triangles are samples from the Fairville Granite. (d) Samples from the syenogranitic and monzogranitic plutons; the grey circle is a sample from the quartz dioritic part of the Musquash Harbour Pluton, and is also shown in (a). The half-shaded circle is sample NB92-9073 from the Dipper Harbour volcanic unit (Table 3). Chondrite-normalizing values are from Sun and McDonough (1989).*

the majority of the samples are intermediate in composition, with between 60% and 70% SiO_2 (Fig. 7). Most major element oxides show a strong negative correlation with SiO_2 (Figs. 7a, b, c, d, e, h), with the exceptions of Na_2O, which is relatively constant at 3–4% (Fig. 7f), and K_2O, which shows a positive correlation with SiO_2 (Fig. 7g). Trace elements such as Ba, Rb, and Sr that are compatible in feldspars, generally the most abundant minerals in these samples, show trends similar to the major oxides, as illustrated by Rb which shows strong correlation with SiO_2 and K_2O (Figs. 5a, c). The major and trace element trends are consistent with fractional crystallization of mafic minerals and feldspars as the major cause of chemical variation within this suite of plutons. In contrast, incompatible elements such as Zr show little co-variation with SiO_2 or K_2O (Figs. 5b, d), but positive correlation with some other elements such as Y (Fig. 5e). Positive correlation between V and TiO_2 follows a different trend than that in the Duck Lake and Indiantown gabbroic samples (Fig. 5f). This difference suggests that fractionation in the dioritic to granodioritic suite involved minerals with lower V relative to Ti than the gabbroic suite, or that the parental magmas for the gabbroic suite contained higher V relative to Ti.

Three samples from mafic enclaves in these plutons generally show chemical similarities to the dioritic samples with lowest SiO_2 contents (Figs. 5, 7). This similarity supports the possibility that the enclaves are cognate, and represent concentrations of minerals crystallized from the same magmas as their host rocks. This interpretation is further supported by REE data from one of the enclaves, which displays a chondrite-normalized pattern very similar to that of the dioritic rocks, but slightly less evolved (Fig. 6a). The REE patterns for the dioritic and granodioritic suite as a whole show light REE enrichment (La between 45 and 150 times chondritic values) and nearly flat heavy REE at 6.5 to 25 times chondritic values). The patterns are nearly parallel to one another and show slight to moderate negative Eu anomalies (Fig. 6b). These patterns are consistent with fractionation of plagioclase, amphibole, and biotite, as suggested by major and trace element variations.

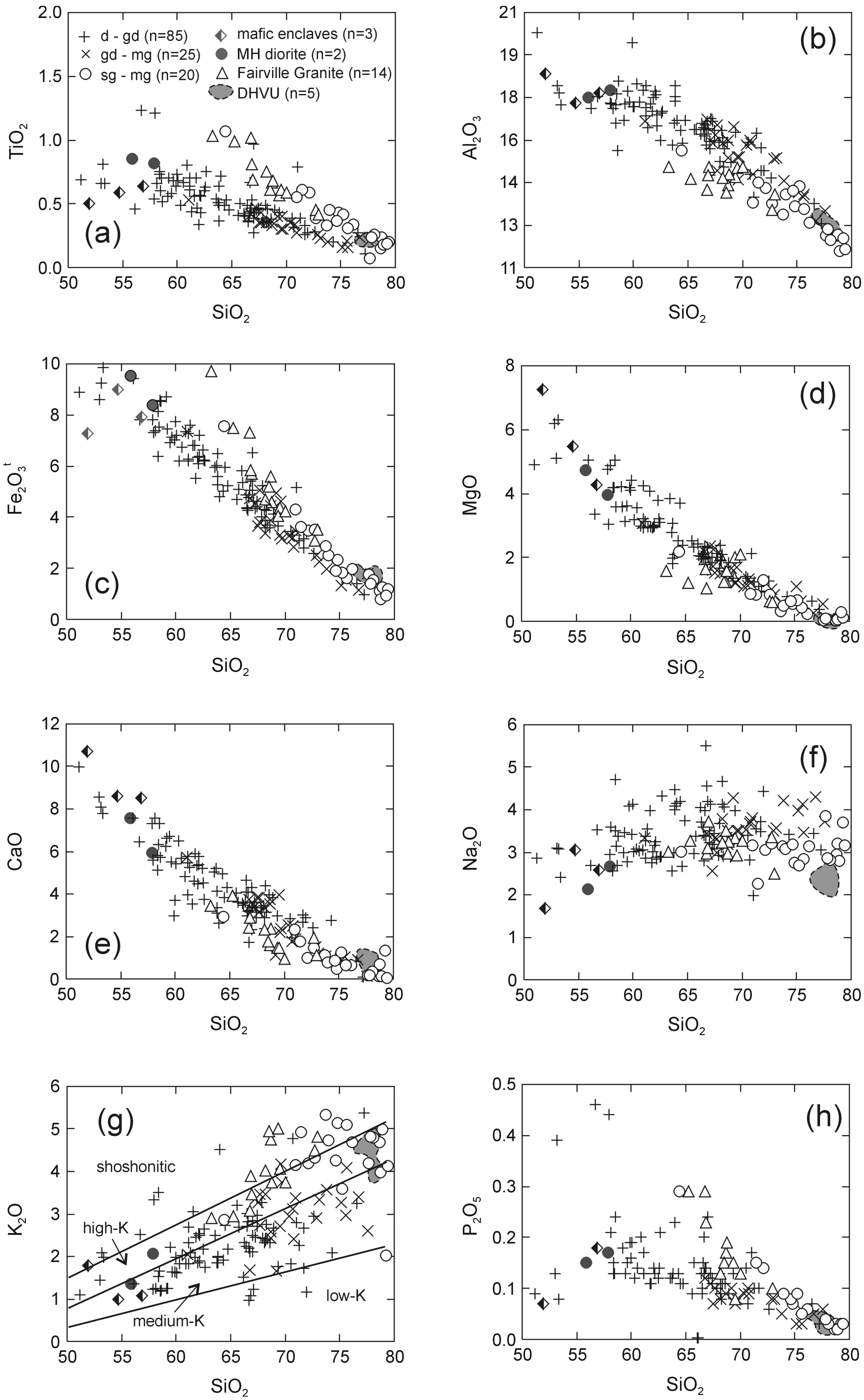

FIG. 7 *Diagrams to illustrate chemical variations in dioritic to granitic samples (50–80% SiO_2). Note that the scale for SiO_2 overlaps with and is the same as that in Fig. 4; samples with 50– 65% SiO_2 appear on both figures, but the vertical scales are different for Al_2O_3, $Fe_2O_3^t$, MgO, and CaO. All data are in weight % (after recalculation to total 100% volatile free). Fields in (g) are after Middlemost (1975). Symbols are as in Fig. 4.*

Granodiorite and monzogranite

Plutons in this group are dominated by granodiorite and monzogranite, consistent with their SiO_2 contents which are mainly between 67% and 71%, with rare more syenogranitic samples ranging up to 76% SiO_2 (Fig. 7). One sample from the Hanson Stream Granodiorite analyzed by Eby and Currie (1996) contains about 60% SiO_2 and may be from a mafic enclave. The samples show compositional overlap with data from the more abundant dioritic to granodioritic plutons and together the two groups of plutons form strong trends, with the exception of the samples from the Fairville and Chalet Lake plutons. The latter samples show trends of higher TiO_2, $Fe_2O_3{}^t$, and K_2O and lower Al_2O_3, MgO, and CaO compared to the other plutons (Fig. 7). Trace elements show similar differences; for example, many of the analyzed samples from the Fairville and Chalet Lake plutons have higher Rb, Zr, and Y (Figs. 5a, b, d, e) and lower V (Fig. 5f). Total REE concentrations are higher, especially the heavy REE (Fig. 6c). In contrast, the other granodioritic and monzogranitic plutons have REE patterns similar to those of the dioritic to granodioritic samples.

Syenogranite and monzogranite

Analyzed samples from the syenogranitic to monzogranitic plutons have more than 70% SiO_2, with the exception of 2 samples from the more mafic parts of the composite Musquash Harbour Pluton (Fig. 7). They generally have higher SiO_2 contents than samples from the granodioritic and monzogranitic plutons, although there is considerable overlap. However, on many of the major element variation diagrams, the syenogranitic samples form linear trends with samples from the Fairville and Chalet Lake plutons, trends that involve higher TiO_2, $Fe_2O_3{}^t$, and K_2O and lower Al_2O_3, MgO, and CaO compared to the trends of the other plutons. Trace elements show similar variations; the syenogranitic and monzogranitic suite of samples has higher Rb, Zr, and Y (Figs. 5a, b, e) and lower V (Fig. 5f). They tend to form scattered trends with the samples from the Fairville and Chalet Lake plutons that differ from those in the remaining samples, such as a negative correlation between Zr and SiO_2 (Fig. 5b). The REE values are higher and like those in the Fairville Granite, although they display wider variation in heavy REE and more pronounced negative Eu anomalies than the Fairville Granite samples (Fig. 6d). Such differences suggest that these plutons may be related by fractionation of K-feldspar and zircon.

In contrast to the differences displayed by the syenogranitic to granodioritic samples from the Musquash Harbour Pluton, two quartz diorite samples and a granodiorite sample from that pluton are chemically like dioritic samples from the dioritic to granodioritic suite, and generally plot within the trends defined by those samples (Figs. 5, 7). The similarity is also shown by the REE data from one of these samples, which is identical to the REE pattern of the other dioritic samples (Fig. 6a). These data suggest that the dioritic parts of the Musquash Harbour Pluton may not be cogenetic with its more voluminous granitic parts, and may instead be related to the dioritic – granodioritic plutons of the Brookville terrane.

A field for 5 analyzed samples from the Dipper Harbour volcanic unit is shown on the various chemical plots for comparison with the granitoid rocks. The samples show limited chemical variation, and are similar to samples from the syenogranitic plutons, with about 77–78% SiO_2 (Fig. 7). Like those plutons they show elevated contents of Rb, Zr, and Y, and low V and TiO_2 (Fig. 5), and similarly have within-plate and A-type characteristics (Fig. 8). The REE pattern of one sample (NB92-9073; Table 3) is similar to those of the syenogranitic samples (Fig. 6d). These chemical similarities support a comagmatic relationship between the syenogranitic plutons and the volcanic rocks, also suggested by their spatial association and U-Pb ages, as noted above.

Chemical affinity and tectonic setting

Most of the analyzed samples plot on a clear calc-alkaline trend on an AFM diagram (Fig. 8a), although some samples from the Fairville, Chalet Lake, and syenogranitic plutons plot away from the trend because of their higher Fe contents, and most gabbroic samples plot toward the MgO corner. Most of the dioritic to granodioritic samples, as well as the granodioritic and monzogranite samples, plot in the volcanic arc field on Zr-TiO_2 and Rb-Y+Nb tectonic setting discrimination diagrams (Figs. 8b, c). However, on both of these diagrams, the syenogranitic and monzogranitic samples, and those from the Dipper Harbour volcanic unit and the Fairville and Chalet Lake plutons, are offset toward the within-plate fields. Samples for which Th, Yb, and Ta data are available plot mainly in the active continental margin field (Fig. 8d). Most samples have "I-type" affinities, although the syenogranitic and monzogranitic samples, as well as those from the Dipper Harbour volcanic unit and Fairville and Chalet Lake plutons, mainly plot in the A-type fields (Figs. 8e, f), consistent with their "within-plate" tendencies.

GEOCHRONOLOGY

Introduction

The five U-Pb dates reported here were done by three of the authors in different laboratories, although the methodology was similar. The Fairville Granite and Ludgate Lake Granodiorite samples were dated by C. White in the laboratory of G. Dunning at Memorial University of Newfoundland, by methods described in White (1996). The Lutes Mountain Diorite and McCarthy Point Granodiorite were dated by B. Miller at the University of North Carolina, Chapel Hill, using methods similar to those described by Ratajeski *et al.* (2001). The sample from the Duck Lake Pluton was dated by M. Hamilton at the Geological Survey of Canada, Ottawa, using methods described by Barr *et al.* (2000). The analytical data for all five samples are presented in Table 4, together with UTM co-ordinates of sample locations.

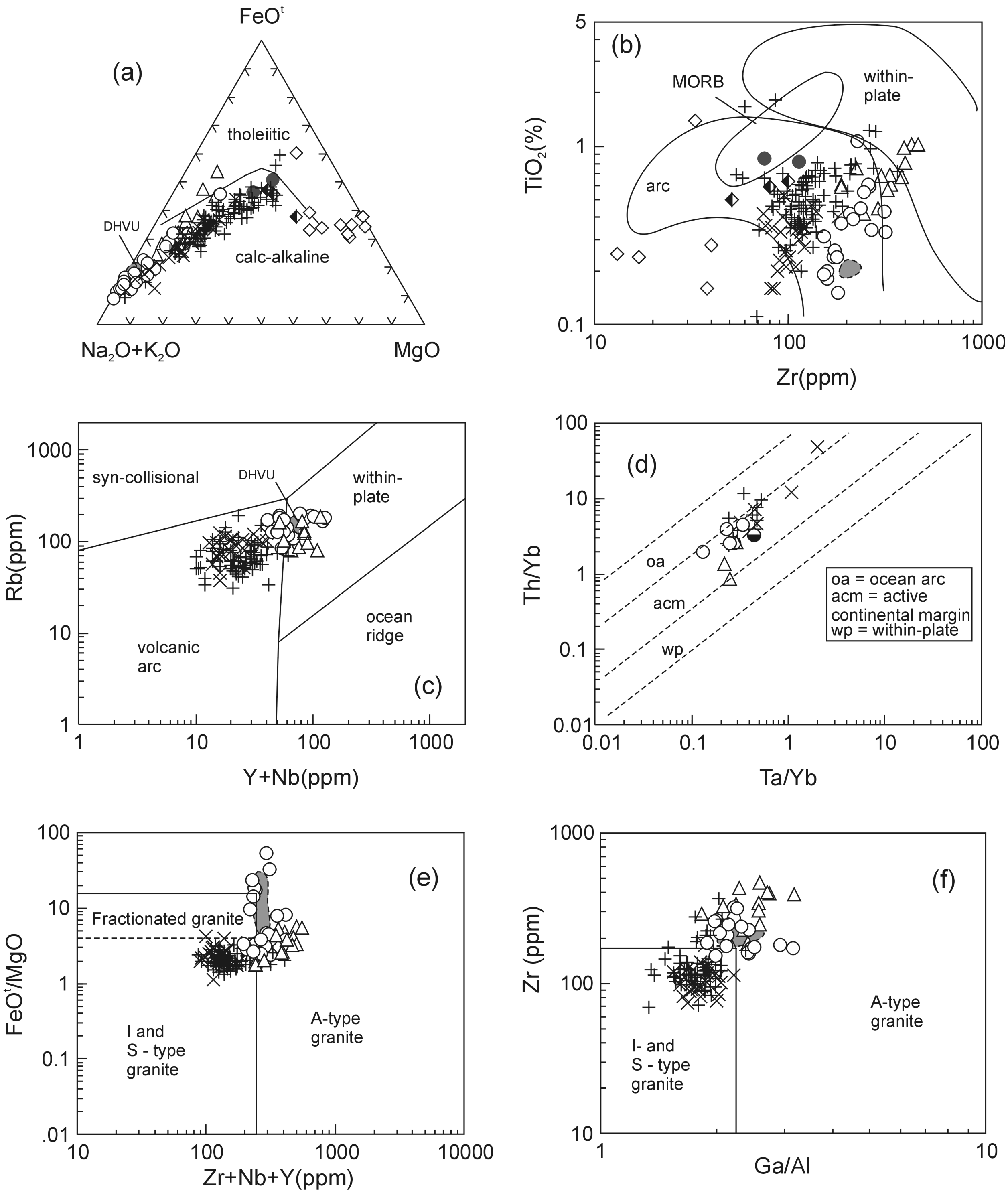

Fig. 8 *Diagrams to indicate chemical affinity and/or tectonic setting. Fields are from (a) Irvine and Baragar (1971), (b) Pearce (1982), (c) Pearce et al. (1984), (d) Gorton and Schandl (2000), and (e, f) Whalen et al. (1987). Only intermediate and felsic samples (>60% SiO_2) are plotted on (c) to (f). Symbols are as in Figs. 5 and 6.*

Duck Lake Gabbro

A pegmatoid area within texturally and compositionally varied gabbro near the northwestern margin of the Duck Lake Pluton was sampled for dating. Dated sample DL97-1 was mostly coarse-grained plagioclase-rich gabbro, locally with abundant hornblende and minor quartz. Zircon grains recovered from the sample were mostly colourless to very pale brown and subhedral to anhedral in shape, the latter suggesting relatively late magmatic growth. Individual grains ranged from approximately 75–150 μm in maximum dimension. All grains were relatively clear and inclusion-free. However, many zircon grains showed minor, thin overgrowths of probable metamorphic origin. All grains were therefore given extensive air abrasion treatment (up to ca. 35 hours) to remove all optical signs of rims, and the best quality grains were subsequently re-picked from these populations, for chemistry.

Analysis of four fractions, each comprising between 52–70 grains, yielded results that are tightly clustered, lying on or immediately below concordia, and have $^{207}Pb/^{206}Pb$ ages which range narrowly between 538.9 and 540.4 Ma (Table 4, Fig. 9a). The minor discordance displayed by the data (0.3–0.9%) can be modelled by recent (modern-day) Pb-loss. The zircon data collectively define a weighted mean $^{207}Pb/^{206}Pb$ age of 539.6 ± 1.2 Ma, which we interpret to represent the igneous crystallization age of the Duck Lake Gabbro.

Fairville Granite

Sample NB92-9012 was collected from the Fairville Granite in a road cut south of Green Head Island. It consisted of coarse-grained inequigranular biotite monzogranite, typical of the pluton. It yielded a zircon population composed of colourless to very pale yellow euhedral dipyramidal prisms, with length/breadth ratio of about 3.3. The grains showed good to excellent clarity, with clear tube- or bubble-like inclusions and no visible evidence of inherited cores. Two abraded zircon fractions (Z1, Z3) were hand picked, avoiding any grains with inclusions, and a third abraded fraction (Z2) contained minor inclusions. Analyses of Z1 and Z3 are slightly discordant (<3.3%) with $^{207}Pb/^{206}Pb$ ages of ca. 570 Ma and 560 Ma, respectively (Table 4). Analysis of fraction Z2 is 11.4% discordant and has a significantly older $^{207}Pb/^{206}Pb$ age of ca. 631 Ma (Table 4). The three fractions define a simple discordia line with lower and upper intercept ages of 548 ± 2 Ma and 1997 +280/-215 Ma, respectively (Fig. 9b). The lower intercept age is the best estimate of the minimum age of emplacement of the Fairville Granite. The upper intercept indicates the presence of a significant component of inherited zircon with an average Early Proterozoic age.

Lutes Mountain Diorite

Dated sample NB00-11 was collected from a large quarry at the summit of Lutes Mountain north of Moncton. It was a medium-grained diorite that consisted mainly of plagioclase and blue-green amphibole, with minor interstitial quartz and accessory titanite, zircon, apatite, and opaque minerals. Five fractions of zircon were analyzed from the sample. Each of three fractions consisted of three or four grains of medium-sized (100 x 40 μm) prismatic zircons. The other two fractions (35 and 110 μm) consisted of multi-faceted equant grains (Table 4). One fraction is concordant at 542 Ma and two others are nearly concordant. Two additional analyses are discordant along a recent Pb-loss line. One fraction has large U-Pb errors because of an imprecise uranium analysis. All five analyses fit on a discordia line with an upper intercept of 542.2 +1.8/-1.4 Ma and a lower intercept suggestive of recent Pb-loss. We interpret the upper intercept age to be the time of crystallization of the Lutes Mountain Diorite.

Ludgate Lake Granodiorite

Sample NB91-9010 was collected from the Ludgate Lake Granodiorite at a roadcut on highway 1, about 300 m west of Ludgate Lake. It was a medium-grained inequigranular biotite-hornblende granodiorite, and contained two morphologically distinct zircon populations. The most abundant grains (>60%) are colourless, euhedral, needle-shaped, dipyramidal simple prisms, with an average length to breadth ratio of about 6. They exhibited excellent clarity with minor clear tubes and bubbles as inclusions, and no visible cores. The other 40% of the zircon grains are stubby to slightly elongate, euhedral, clear, colourless multifaceted dipyramids with an average length to breadth ratio of 2. They have clear tubes and bubbles as inclusions, and no visible cores. Three fractions were analyzed, one from the needle-shaped prisms (Z1) and two from the stubby population (Z2 and Z3). The analyses are clustered and slightly discordant (<2%) with $^{207}Pb/^{206}Pb$ ages of ca. 548 to 544 Ma.

The sample also contained titanite, light amber to dark brown, clear to slightly cloudy with an anhedral to subhedral shape, and no visible inclusions or cores. Two fractions (T1 and T2) were analyzed, of which T1 was more abraded than T2. Both fractions are slightly discordant, although T1 yields a $^{207}Pb/^{206}Pb$ age of ca. 545 Ma. The zircon and titanite fractions together define a discordia line with an upper intercept of 546 ± 2 Ma, which is interpreted to be the crystallization age of the Ludgate Lake Granodiorite. The lower intercept of ca. 30 Ma is uncertain due to the length of projection, but probably reflects recent Pb loss. The agreement of the titanite age and the upper intercept age suggests rapid cooling, at least through the closure temperature of titanite, as also confirmed by $^{40}Ar/^{39}Ar$ ages of hornblende (see below).

McCarthy Point Granodiorite

Dated sample NB99-5 was collected at the shoreline on the western side of McCarthy Point in Pocologan Harbour. It was a medium- to coarse-grained biotite-hornblende granodiorite typical of the pluton, and contained zircon grains of several different morphologies. In general, smaller grains were clear and free of inclusions, whereas larger grains tended to be slightly metamict. Seven zircon fractions were analyzed, of which five consisted of one or two grains and the remaining two were multi-grain fractions. None of the fractions shows evidence of inheritance.

Table 4. U-Pb isotopic data

Analysis#, Fraction (number of grains)	weight (mg)[1]	Total[1] U (ng)	Total[2] Pb (pg)	Total[2] Com.Pb (pg)	U (ppm)	Pb (ppm)	$^{206}Pb/^{204}Pb$ [2]	$^{208}Pb/^{206}Pb$ [3]	Atomic Ratios $^{206}Pb/^{238}U$ [3]	% Error[4]	$^{207}Pb/^{235}U$ [3]	% Error[4]	$^{207}Pb/^{206}Pb$ [3]	% Error[4]	Ages (Ma) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	r[5]
Duck Lake Gabbro (DL97-1; UTM: E266425, N5028975)																		
1) Z-A1, small, sub- to anhedral fragments (52)	0.076	35.9	3370	19	474	44	10215	0.194	0.08674	0.182	0.69697	0.236	0.05827	0.096	536.3	537.0	540.0	0.926
2) Z-B1, small, sub- to anhedral fragments (70)	0.064	29.0	2750	13	454	43	12208	0.206	0.08695	0.186	0.69826	0.236	0.05824	0.092	537.5	537.7	538.9	0.934
3) Z-C1, small, sub- to anhedral fragments (55)	0.023	18.1	1840	18	799	81	5562	0.299	0.08658	0.356	0.69535	0.398	0.05825	0.144	535.3	536.0	539.0	0.932
4) Z-C2, small, sub- to anhedral fragments (55)	0.023	13.4	1270	4	573	54	20114	0.215	0.08668	0.234	0.69658	0.282	0.05828	0.122	535.9	536.7	540.4	0.904
Lutes Mountain Diorite (NB00-11; UTM: E355450, N5113950)																		
1) Small multi-faceted equant (7)	0.036	3243	297.4	1.69	90	8	10761	0.157	0.08775	0.373	0.70567	0.384	0.05832	0.091	542.2	542.2	542.0	0.972
2) Large multi-faceted equant (4)	0.041	2618	246.4	1.78	64	6	8205	0.195	0.08723	0.342	0.70163	0.380	0.05834	0.163	539.1	539.8	542.4	0.904
3) Medium prisms (3)	0.018	1718	161.7	2.06	95	9	4652	0.198	0.08707	0.335	0.70044	0.364	0.05834	0.139	538.2	539.1	542.7	0.924
4) Medium prisms (4)	0.020	1192	111.5	1.88	60	6	3473	0.209	0.08582	0.303	0.69025	0.357	0.05834	0.183	530.7	533.0	542.4	0.859
5) Medium prisms (3)	0.018	1448	131.3	1.77	80	7	4435	0.181	0.08504	1.161	0.68418	1.167	0.05835	0.115	526.1	529.3	543.0	0.995
McCarthy Point Granodiorite (NB99-5; UTM: E690750, N4998450)																		
1) Large clear equant (2)	0.016	8.44	729.9	9.39	534	46	4830	0.138	0.08399	0.138	0.66969	0.214	0.05783	0.162	519.9	520.5	523.2	0.653
2) Medium clear prisms (8)	0.018	4.41	391.0	4.54	240	21	5194	0.174	0.08357	0.205	0.66640	0.262	0.05783	0.162	517.4	518.5	523.5	0.785
3) Large clear equant (1)	0.008	1.04	892.5	5.38	132	113	10322	0.135	0.08349	0.061	0.66641	0.089	0.05789	0.065	516.9	518.5	525.6	0.686
4) Clear flat octahedrons (2)	0.012	1.83	167.5	10.62	153	14	923	0.174	0.08332	0.604	0.66495	0.702	0.05788	0.349	515.9	517.6	525.3	0.868
5) Large metamict equant (1)	0.009	1.49	1247	9.66	165	139	8027	0.136	0.08177	0.100	0.65169	0.116	0.05780	0.060	506.7	509.5	522.2	0.858
6) Medium metamict prism fragments (6)	0.023	6.22	509.6	11.51	276	23	2819	0.106	0.08167	0.300	0.65118	0.311	0.05783	0.080	506.1	509.2	523.1	0.966
7) Large metamict prisms fragments (2)	0.017	2.20	1840	18.91	130	108	5983	0.132	0.08120	0.175	0.64628	0.209	0.05772	0.114	503.3	506.2	519.2	0.838
Fairville Granite (NB92-9012; UTM: E727875, N5015845)																		
1) Long, euhedral, abraded	0.153	na	na	86.00	182.0	17.2	1829	0.165	0.08949	32.000	0.72910	30.000	0.05909	10.000	552.0	556.0	570.0	
2) Long, euhedral, abraded	0.211	na	na	49.00	143.0	13.5	3448	0.169	0.08896	30.000	0.72140	26.000	0.05882	8.000	549.0	552.0	560.0	
3) Gem prisms, abraded	0.173	na	na	60.00	196.0	18.8	3254	0.159	0.09114	38.000	0.76370	34.000	0.06078	34.000	562.0	576.0	631.0	
Ludgate Lake Granodiorite (NB92-9010; UTM: E717810, N5008725)																		
1) Long, euhedral, abraded	0.136	na	na	111.00	161.0	15.3	1098	0.210	0.08731	46.000	0.70410	40.000	0.05849	14.000	540.0	541.0	548.0	
2) Stubby, abraded	0.421	na	na	103.00	159.0	14.9	3577	0.185	0.08732	32.000	0.70430	28.000	0.05850	8.000	540.0	541.0	548.0	
3) Clear gems, abraded	0.246	na	na	66.00	168.0	15.9	3436	0.202	0.08711	30.000	0.70130	26.000	0.05839	8.000	538.0	540.0	544.0	
4) brown, abraded	0.345	na	na	526.00	385.0	40.2	1376	0.353	0.08585	30.000	0.69130	28.000	0.05840	8.000	531.0	534.0	545.0	
5) Brown, abraded	0.176	na	na	365.00	307.0	33.2	823	0.389	0.08686	42.000	0.70110	40.000	0.05855	14.000	537.0	539.0	550.0	

[1] Weight estimated from measured grain dimensions and assuming density = 4.67g/cm3, except for DL97-1 fractions, which were weighed on a microbalance. ~20% uncertainty affects only U and Pb concentrations

[2] Corrected for fractionation (0.18± 0.09%/amu - Daly) and spike (Pb fractionation 0.09 ±0.03%/amu for GSC)

[3] Corrected for fractionation, blank, and initial common Pb

[4] Errors quoted at 2σ

[5] $^{207}Pb/^{235}U$ - $^{206}Pb/^{238}U$ correlation coefficient of Ludwig (1989)

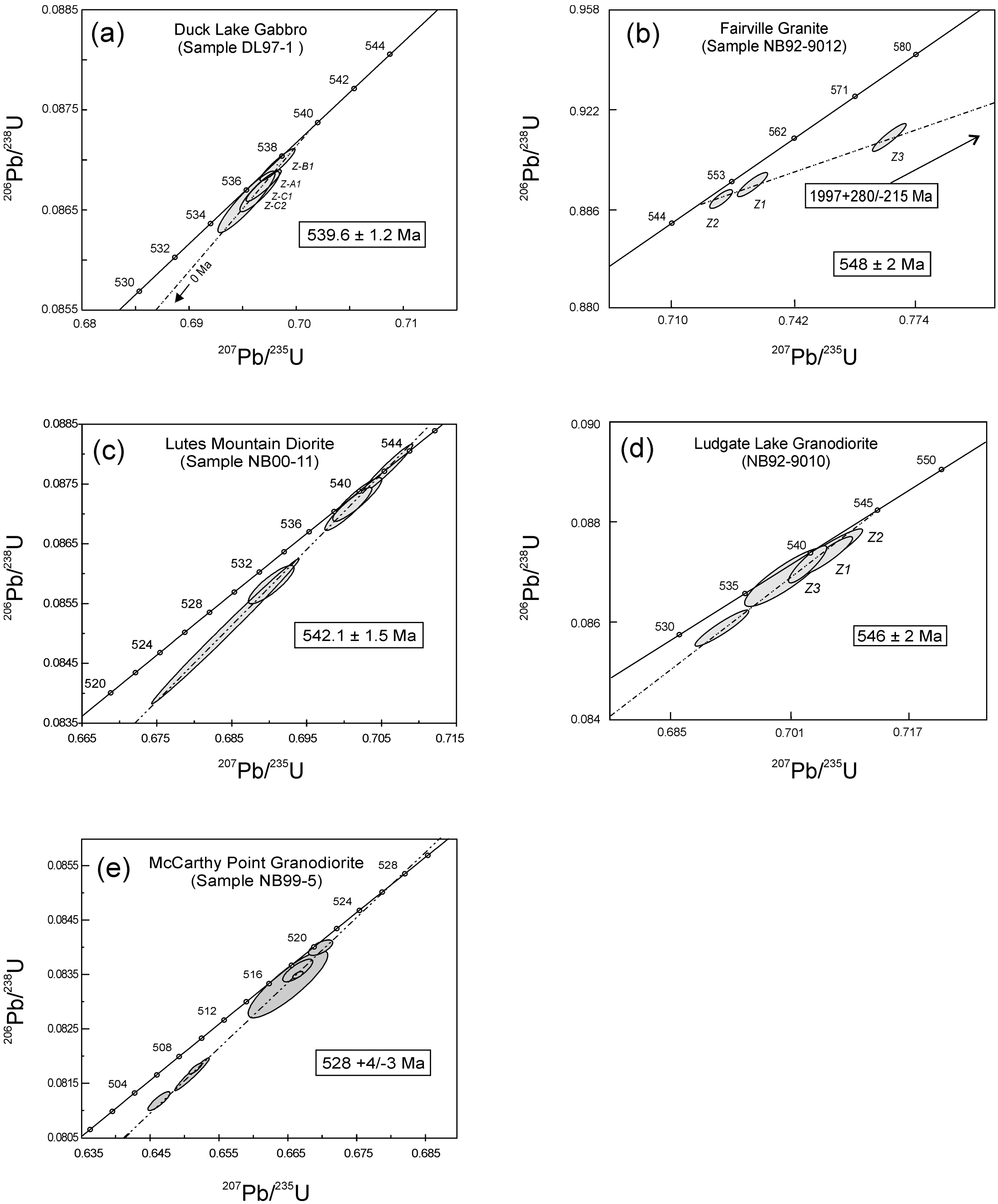

FIG. 9 *Concordia diagrams for samples from (a) Duck Lake Pluton, (b) Fairville Granite, (c) Lutes Mountain Diorite, (d) Ludgate Lake Granodiorite, and (e) McCarthy Point Granodiorite. Data are given in Table 4.*

The metamict grains are more discordant than the clear grains, although both types were highly abraded. The seven fractions form a discordant trend with an upper intercept of 528 +4/-3 Ma, which we interpret to represent the time of crystallization of the pluton.

Age Data Compilation

Including the data presented here and previously published dates, ten U-Pb (zircon) ages have been obtained from the Golden Grove Plutonic Suite, although the age from the Musquash Harbour syenogranite has a large error associated with it (Table 1; Fig. 10). The spread of ages between about 550 Ma and 525 Ma is real, in that the error ranges of the older and younger dates do not overlap (Fig. 10). No strong pattern of age in comparison to pluton composition or location is apparent. For example, although the two youngest ages are both from plutons in the southwestern part of the terrane, one of the oldest plutons (Harvey Hill) is in the same area.

Additional constraints on the minimum ages of pluton emplacement are provided by $^{40}Ar/^{39}Ar$ ages from hornblende in the plutons, in some cases by more than one age determination from the same pluton. Taking errors into account, the $^{40}Ar/^{39}Ar$ cooling ages show a range very similar to that of the U-Pb crystallization ages, from close to 550 Ma to about 520 Ma. They indicate that the plutons cooled rapidly through at least the argon retention temperature in hornblende (ca. 525°C; McDougall and Harrison 1988). Hornblende and phlogopite ages from the host rocks of the pluton (both the Green Head Group and the Brookville Gneiss) show similar ages (Fig. 10), consistent with the interpretation that they record pervasive contact metamorphism. The similarity in zircon and titanite U-Pb ages and $^{40}Ar/^{39}Ar$ cooling ages suggests that the plutons were emplaced are relatively shallow depth and cooled rapidly. Muscovite $^{40}Ar/^{39}Ar$ ages are somewhat younger ca. 520 Ma to 505 Ma, perhaps reflecting a decrease in the rate of cooling through the argon retention temperature for muscovite (ca. 325°C; Snee *et al.* 1988). Alternatively, the younger ages may reflect a subsequent reheating event.

The similarity in age at ca. 550 Ma between the Dipper Harbour volcanic unit and the syenogranitic plutons is consistent with a comagmatic relationship between them. The relationship is also suggested by the chemical similarities discussed above.

DISCUSSION

The age data show that the Fairville Pluton is older than the other dated plutons. Like the Fairville and similar Chalet Lake plutons, the syenogranitic to monzogranitic plutons are different from the other plutons, and are also probably older, although the age of 544 ± 4 Ma from the Harvey Hill pluton (Currie and McNicoll 1999) suggests that the "A-type" magmatism overlapped with the more voluminous dioritic to monzogranitic plutons.

Eby and Currie (1996) postulated that plutons emplaced in the early part of the magmatic event in the Brookville terrane have characteristics typical of continental margin magmatism, with the exception of the Fairville pluton. They postulated that the igneous pulse terminated with A-type magmatism represented by the Harvey Hill and Prince of Wales plutons. However, this scenario is no longer viable, as it is clear that the Harvey Hill and Fairville plutons are the same age, as are probably the Musquash Harbour, Jarvies Lake, Cranberry Head, and Fishing Cove plutons, and Dipper Harbour volcanic unit. Hence it appears that magmatism in the Brookville terrane began with A-type characteristics (presumably continental extension) but at virtually the same time, continental margin-type subduction began, and continued to about 527 Ma to generate the voluminous gabbroic to monzogranitic (dominantly granodioritic) plutons that comprise most of the Golden Grove Plutonic Suite.

Although Eby and Currie (1996) and Currie and McNicoll (1999) suggested that the plutons of the Brookville terrane are related to those in the adjacent Caledonia terrane and the New River terrane to the north, Barr and White (1996) argued that they are younger and part of a separate and unrelated tectonic regime. One of the strongest arguments in support of the latter interpretation is the fact that non-orogenic Cambrian sedimentary rocks were being deposited in the Caledonia and New River terranes while most of the Golden Grove Plutonic Suite was being formed in an active subduction zone; that argument is further supported by the new ages presented here. Detailed comparisons among the plutons of the Golden Grove Plutonic Suite and those of the adjacent Caledonia and New River terranes will be the topic of a subsequent paper.

ACKNOWLEDGEMENTS

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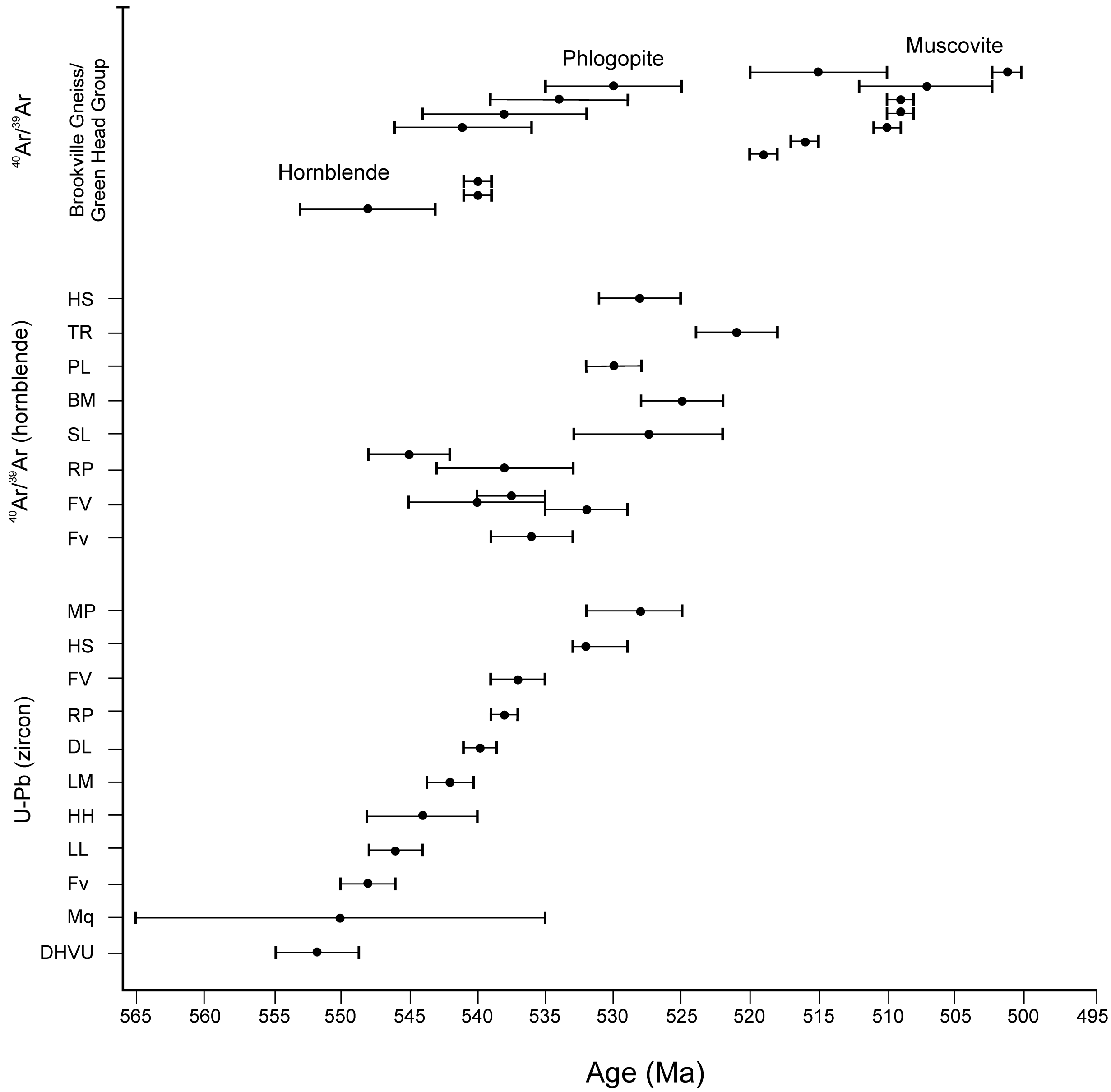

FIG. 10 *Histogram of U-Pb and $^{40}Ar/^{39}Ar$ ages from plutons and their host rocks in the Brookville terrane. Abbreviations: BM, Belmont Tonalite; BVG, Brookville Gneiss; DHVU, Dipper Harbour volcanic unit; DL, Duck Lake Pluton; FG, Fairville Granite; FV, French Village Quartz Diorite; GHG, Green Head Group; HH, Harvey Hill Syenogranite; HS, Hanson Stream Granodiorite; LL, Ludgate Lake Granodiorite; LM, Lutes Mountain Diorite; MP, McCarthy Point Granodiorite; Mq, Musquash Harbour Pluton; PL, Perch Lake Granodiorite; RP, Rockwood Park Granodiorite; SL, Shadow Lake Granodiorite; TR, Talbot Road Granodiorite. Data were compiled from this study and* Bevier et al. *(1991), Currie and Hunt (1991), Currie and McNicoll (1999), Dallmeyer and Nance (1992), Dallmeyer et al. (1990), Nance and Dallmeyer (1994), White (1996), and White et al. (1990).*

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