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THE HARVEY VOLCANIC SUITE, NEW BRUNSWICK. II. POSTMAGMATIC ADJUSTMENTS IN THE MINERALOGY AND BULK COMPOSITION OF A HIGH-FLUORINE RHYOLITE

CHRISTINE PAYETTE AND ROBERT F. MARTIN
Department of Geological Sciences, McGill University, 3450 University Street, Montreal, Quebec H3A 2A7

ABSTRACT

The Harvey volcanic suite, New Brunswick, of Early Carboniferous age, consists of three units: 1) York Mills (base): volcanogenic sediments, minor ash-flow and laminated rhyolite; 2) Cherry Hill: ash-flow and ash-fall tuffs, quartz-feldspar porphyry, and 3) Harvey Mountain, rhyolitic lava flows. Quartz paramorphic after tridymite is present throughout the flow, and may indicate a high temperature of emplacement and devitrification (870–900°C). The feldspars are not primary, but define a low-temperature assemblage that failed to equilibrate structurally. Intermediate microcline is only very locally developed. The chemical composition suggests highly evolved rhyolites: high Si ($>76\%$ SiO_2), low Fe ($<2\%$ Fe_2O_3), Mg ($<0.05\%$ MgO), Ti ($<0.15\%$ TiO_2), and Ca ($<2\%$ CaO), high Rb, Nb, Y, Th, and low Ba, Sr and Zr. The composition of the glass trapped in the quartz phenocrysts indicates a fluorine-rich (up to 2% F) potassic peraluminous rhyolitic magma (71% SiO_2, 6.5% K_2O, 14.9% Al_2O_3). Comparison of the glass and bulk-rock compositions shows a net dilution of all elements by SiO_2 added after devitrification. The mineralogy, chemical composition, peraluminous character and F-enrichment of the Harvey rocks reflect the characteristics of the F-rich magma. The Harvey rocks were probably derived by partial melting of continental crust in a rifting (extensional) environment, in response to the influx of mantle-derived basic magmas.

Keywords: Harvey volcanic suite, Carboniferous, ignimbrites, tridymite, evolved rhyolites, peraluminous, fluorine, topaz rhyolites, alkali feldspar, New Brunswick.

SOMMAIRE

La suite volcanique de Harvey, Nouveau-Brunswick, d'âge Carbonifère inférieur, se compose de trois formations: York Mills (sédiments volcanogéniques, rhyolite laminée et une ignimbrite mineure), Cherry Hill (tuffs soudés et cendres, porphyre à quartz et feldspaths) et Harvey Mountain (coulées de lave rhyolitique). Des bâtonnets de quartz formés aux dépens de la tridymite se retrouvent couramment dans les coulées de lave maintenant dévitrifiées, ce qui indique des températures de mise en place et de dévitrification élevées (870–900°C). La composition chimique est celle de rhyolites évoluées: hautes teneurs en Si ($>76\%$ SiO_2), Rb, Nb, Y et Th et de faibles teneurs en Fe ($<2\%$ FeO), Mg ($<0.05\%$ MgO), Ti ($<0.15\%$ TiO_2), et Ca ($<2\%$ CaO), Ba, Sr et Zr. La composition du verre piégé dans les phénocristaux de quartz indique un magma rhyolitique hyperalumineux, potassique (71% SiO_2, 6.5% K_2O, 14.9% Al_2O_3) riche en fluor (jusqu'à 2% F). La comparaison des compositions du verre et des roches totales montre une nette dilution de tous les éléments par l'addition de SiO_2 lors de la dévitrification. La minéralogie, composition chimique, l'hyperaluminosité et l'enrichissement en fluor des roches de Harvey reflètent les caractéristiques d'un magma initial riche en fluor. Ces roches furent probablement dérivées par fusion partielle de la croûte continentale dans un milieu d'extension, en réponse à un influx de magmas basiques dérivés du manteau.

Mots-clés: suite volcanique de Harvey, Carbonifère, ignimbrites, tridymite, rhyolites évoluées, fluor, rhyolites à topaze, feldspath alcalin, Nouveau-Brunswick.

INTRODUCTION

The Early Mississipian Harvey volcanic suite occurs on the northern edge and stratigraphically at the base of the Central Carboniferous basin, 55 km southwest of Frederiction, New Brunswick (Fig. 1). Felsic volcanic to volcanogenic rocks outcrop in a N–NE-trending homoclinal lens-shaped body 16 km in length and 2 km in width. The village of York Mills and Harvey Mountain mark the southwestern and northeastern extremities of the lens, respectively.

Although the study area has been examined by Robb (1870), Bailey & Matthew (1873, 1905), Freeze (1936), Laughlin (1960), Clark (1961), Kuan (1970) and Beaudin *et al.* (1980), still relatively little is known about the mineralogy, chemistry and origin of these rocks. This study contains information on the petrography, chemical composition, origin and tectonic setting of these rocks. Because the existing data on this suite are mostly contained in theses and unpublished company reports, a brief summary of the stratigraphy is provided in the following paragraphs.

The first subdivision of the Harvey volcanic rocks was made by Kuan (1970), who named and subdivided the Harvey volcanic rocks into the York Mills (lower) and Harvey Mountain (upper) units (Fig. 1, units 2 and 4). Kuan included in the York Mills unit red siltstones, sedimentary and volcanogenic sedimentary rocks; the Harvey Mountain unit consisted of two ash-flow sheets, agglomerates, ash-fall tuffs and lava flows.

Beaudin *et al.* (1980) redefined the stratigraphic sequence in light of more detailed mapping and distinguished a third unit, the Cherry Hill unit (Fig. 1, unit 3), between the other two. In their view, the

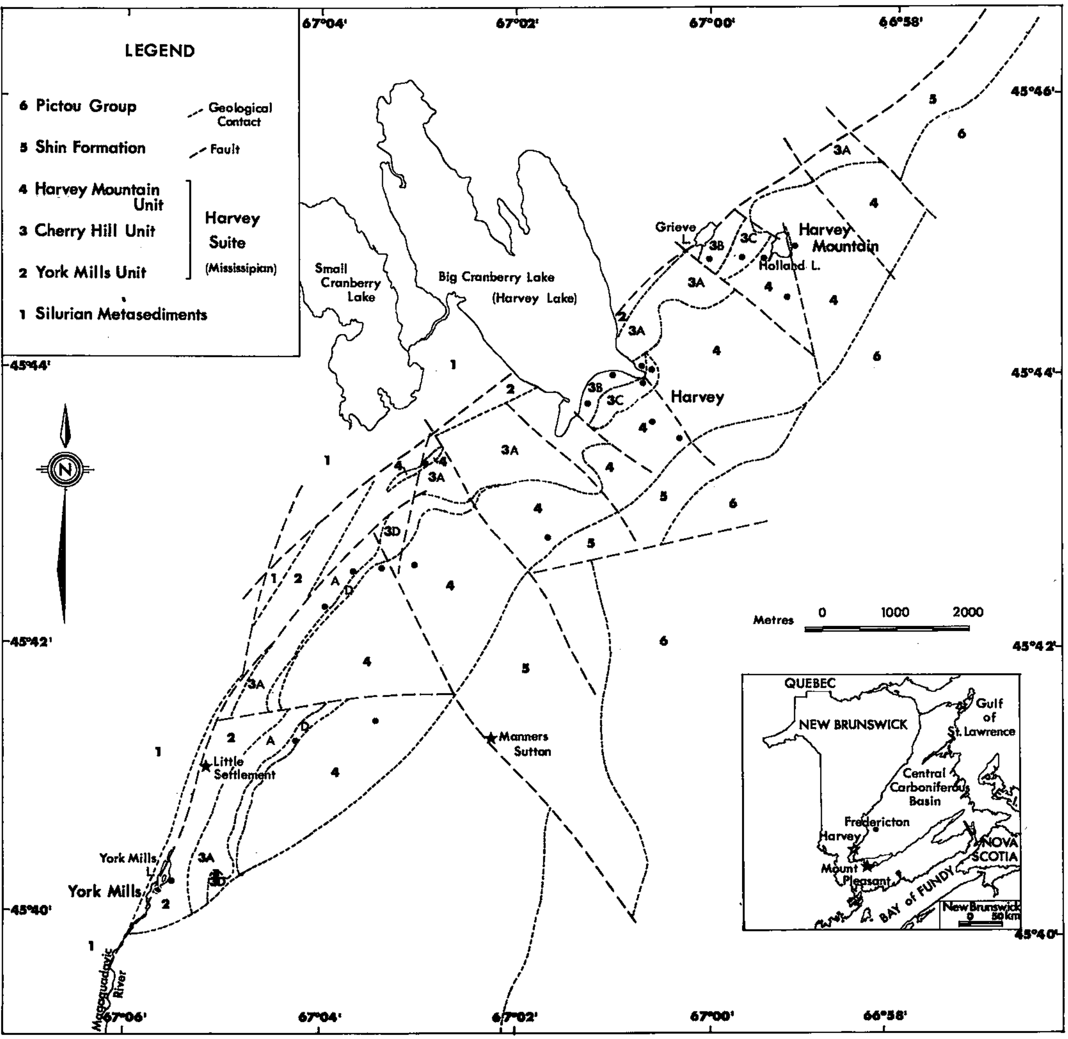

FIG. 1. Location map of the Harvey suite and Mount Pleasant. The Cherry Hill unit is subdivided in 4 subunits: A. volcanogenic sediments. B. ash-flow and ash-fall tuffs, C. quartz-feldspar porphyry, D. ash-fall tuff. Stars indicate the location of Little Settlement and Manners Sutton. Black dots indicate sample location (modified after Beaudin *et al.* 1980).

York Mills unit includes sedimentary rocks, lithic tuffs and laminated rhyolites; the Cherry Hill unit comprises volcaniclastic and volcanogenic sedimentary rocks, ash-flow and ash-fall tuffs and a quartz–feldspar porphyry; the Harvey Mountain unit contains a pyroclastic breccia and laminated rhyolites with intercalated ash-fall tuffs. Beaudin *et al.* (1980) subdivided the Cherry Hill unit into five members: A) volcanogenic sediments (estimated maximum thickness of 10 m), B) the two sheets of ash-flow tuff (ignimbrite), C) volcaniclastic sediments (maximum 20 m), D) quartz–feldspar porphyry and E) ash-fall tuff (about 40 m). They further separated this unit into a proximal volcanic facies, of small lateral extent, consisting of the two ash-flow sheets (3B, Fig. 1) and the quartz–feldspar porphyry (3C, Fig. 1), for an overall thickness of 60 to 150 m at Grieve Lake and Cherry Hill, and a distal volcanic facies (3A, 3D, Fig. 1), the lateral equivalent to the proximal facies, made up of ash-fall tuff (3D, Fig. 1) and volcanogenic sediments (3A, Fig. 1), with an approximate thickness of 45–60 m. The two facies show important and rapid lateral variations.

The subdivision used here has been slightly modified after that of Beaudin *et al.* (1980). Four of the original five members of Beaudin *et al.* are retained

(Fig. 1). The original unit 3C is abandoned, as we found those rocks to be petrographically and chemically very similar to those of the Harvey Mountain unit (map unit 4). The original units 3D and 3E of Beaudin *et al.* (1980) have been renumbered 3C and 3D in Figure 1. Felsic volcanic rocks are dominant, but related detrital, volcanogenic sediments occur in the basal York Mills unit. The three units define a 200-m-thick succession of tuffaceous sediments, felsic tuffs and intrusive and extrusive rhyolites (Beaudin *et al.* 1980). Stratigraphic and petrological data suggest that the Harvey volcanic rocks can be correlated with those of the Piskahegan Group, within the Mount Pleasant caldera (Fig. 1; van de Poll 1967, Kuan 1970, Pajari 1973, Gemmell 1975, Beaudin *et al.* 1980, Ruitenberg & McCutcheon 1985).

The Harvey volcanic suite is underlain by Silurian metasediments (unit 1, Fig. 1) and overlain successively by red beds (unit 5, Fig. 1) that can be traced laterally into the Mississipian–Pennsylvanian Shin Formation southwest of the map area and grey sandstone of the Pennsylvanian "Pictou Group" (unit 6, Fig. 1) (van de Poll 1972, Kuan 1970, Pajari 1973, Beaudin *et al.* 1980). The contacts between the units are commonly not exposed, and the quality of exposure in the area is generally poor.

During Carboniferous times, the basin underwent regional extension that resulted in large-scale normal and, later, strike-slip faults, and numerous associated small grabens. The Harvey volcanic unit forms part of the Fredericton sub-basin (Fig. 1); it is limited to the north-northwest by the Fredericton–Norumbega fault, one of the major regional strike-slip faults, mapped at York Mills and Little Settlement as a mylonite zone (Beaudin *et al.* 1980).

Interest in the area was spawned in 1954, when uranium occurrences were discovered; no deposit of economic significance was found. The uranium mineralization occurs as pitchblende associated with pyrite and arsenopyrite in fluorite veins.

DESCRIPTION OF THE UNITS

York Mills unit

This unit outcrops best at York Mills (unit 2, Fig. 1); it is about 60 m in thickness (Beaudin *et al.* 1980) and dominantly composed of coarse red sandstones, conglomerates and shales. These rocks outcrop only locally and are usually poorly exposed. Detrital grains in the sandstone consist of fragments of rhyolite and phenocrysts of feldspar and quartz.

This unit also contains a minor but significant volcanic component. Centimetre-thick beds of lapilli tuff are present throughout this unit. A lithic tuff with dark green and red rhyolitic fragments is exposed at York Mills (Fig. 1); it includes rounded to angular metasedimentary and granitic boulders up to 15 cm across. This tuff is recognized in a "mylonitized" zone related to the Fredericton–Norumbega fault zone (Beaudin *et al.* 1980). A slightly welded to nonwelded ash-flow tuff outcrops on the western side of York Mills Lake (Fig. 1). It contains fragments of volcanic rocks and isolated feldspar phenocrysts in a devitrified groundmass. A laminated rhyolite and a flow breccia(?) that overlie the tuff are exposed on the eastern side of the Magaguadavic River. Small angular cavities lined with quartz, albite and fluorite crystals are common in the interstices. Chemical analyses were carried out on representative samples of the ash-flow tuff (2 samples) and the laminated rhyolite (4 samples). Their composition is listed below.

Cherry Hill unit

The best exposures of the Cherry Hill unit are along the southern tip of Big Cranberry Lake (unit 3, Fig. 1). This unit is mainly composed of two ash-flow subunits with associated layers of ash-fall tuff, and a quartz–feldspar porphyry.

The base of the Cherry Hill unit is composed of volcanogenic sediments (unit 3A, Fig. 1) and of a lithic tuff. The volcanogenic sediments show faint laminations in thin section, and are composed of devitrified, lithified material (Beaudin *et al.* 1980). The lithic tuff contains broken fragments of rare quartz, K-feldspar and plagioclase phenocrysts, angular to subrounded fragments of siltstone, rhyolite (up to 6 mm across) and presumed basaltic material in a fine-grained pinkish matrix. Four samples of the volcanogenic sediments were analyzed.

Two superposed ash-flow sheets were recognized by both Kuan (1970) and Beaudin *et al.* (1980): an older sheet 5–6 m thick is covered by one 100 m thick. Both have a soft lithic base and a densely welded porphyritic portion. Poorly to well-developed columnar joints (dip 20° SE) were noted at the top of the second sheet. Locally, this unit has the appearance of a massive quartz-feldspar porphyry (3C). The average composition of seven samples of the upper ash-flow is presented below.

A moderately welded tuff (3B), part of the lower sheet, has also been recognized along the shore of Harvey Lake. The shards are of large size, somewhat flattened, devitrified, and show a clear axiolitic texture. The glass in these shards has been replaced by a mica-rich material common in all rocks of the Harvey volcanic unit (illite and quartz; Kuan 1970, Pajari 1973). Numerous fragments of volcanic and metasedimentary origin, pumice fragments, broken spherulites, quartz, K-feldspar and plagioclase phenocrysts are characteristic of the unit. Many fragments and feldspar(?) phenocrysts have been replaced by an aggregate of fine green needles.

Samples of the ash-flow sheets (3B, Fig. 1) show a eutaxitic texture (Ross & Smith 1961) that is defined by parallel, flattened, devitrified shards and pumice fragments molded against phenocrysts and lithic fragments. Lapilli-sized clasts of flattened, devitrified pumice are common. Small spherulites line the periphery of the lapilli, and well-developed quartz and albite crystals are concentrated along their axis, the axiolitic "seam". The area between the axis and the periphery is filled either by a mica-rich cryptocrystalline material interpreted to be illite and quartz (Pajari 1973), a vapor-phase deposit of quartz or, in the largest fragments, colorless to purple fluorite and rare calcite. A few fragments of metasedimentary or volcanic (basaltic?) origin are found. Rare broken phenocrysts of quartz and feldspar and small isolated patches of fluorite grains also occur in the matrix. The feldspar phenocrysts are commonly altered to green micaceous aggregates locally associated with fluorite.

The quartz–feldspar porphyry (QFP, unit 3C) may corrrespond to the most densely welded portion of an ash-flow tuff. It contains between 15 and 25% phenocrysts of euhedral quartz (paramorphic after β-quartz) and feldspar phenocrysts (up to 2 mm across) set in purplish matrix of devitrified welded shards molded around the phenocrysts. Also typical of the porphyry are pumice fragments and rare lithic fragments. A few fragments of previously welded tuff and rhyolite occur throughout the matrix. Pumice lapilli are also common, similar to those described in the ash-flow unit; fluorite, quartz and albite crystals also fill in the cavities. Rare fragments of basaltic(?) origin are scattered in the matrix. The quartz phenocrysts commonly contain melt (glass) inclusions (Payette & Martin 1986). The mineralogy of the feldspars is discussed below. Zircon occurs as an accessory mineral. Twelve samples of the porphyry were analyzed.

Unit 3D (Fig. 1) is composed of massive, devitrified and recrystallized ash-fall tuff of pale violet to pinkish red color, with a spherulitic texture and rare quartz phenocrysts. This unit also includes a local breccia(?) (southernmost part of 3D, Fig 1), with fragments of devitrified laminated rhyolite. The interstices are filled by locally alternating colorless to brownish yellow layers of microcrystalline quartz (chalcedony?) arranged in a botryoidal texture. The average composition of five samples is discussed in a later section.

Harvey Mountain unit

The Harvey Mountain unit outcrops best at Harvey Mountain, east and south of Holland Lake (unit 4, Fig. 1). There, a high cliff is dominated by laminated rhyolite and minor intercalated ash-fall tuffs, with an estimated aggregate thickness of 75–150 m (Beaudin *et al.* 1980). The rhyolite flows exhibit a well-developed, continuous laminated texture, defined by an alternation of well-defined greenish grey layers of coarse spherulites (up to 3–4 mm across, spherulitic textures; Lofgren 1971) and aphanitic devitrified layers (axiolitic texture, Ross & Smith 1961) (Fig. 2A) with rare lithic fragments. Layers of relatively coarse vapor-phase-deposited albite(?) and K-feldspar appear at the interface between spherulitic and aphanitic layers, and are typical of this unit. The formation of interstitial cavities and the growth of second-generation feldspars and tridymite reflect the volume reduction associated with devitrification (Lofgren 1971).

Typical textural features common to all examples of this unit include distinctive flow-banding, a striking development of coarse K-feldspar at the interface of aphanitic and spherulitic layers (Fig. 2A), an abundance of fluorite lining the cavities and the presence of tablets of quartz paramorphic after tridy-

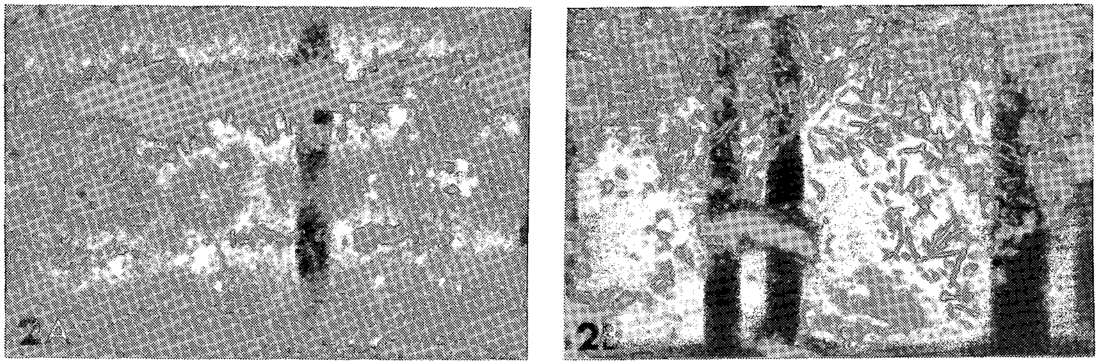

FIG. 2. Harvey Mountain unit lava flow. A. Alternation of spherulitic and aphanitic devitrified layers. Interstices are filled with quartz, but commonly also contain mica-rich cryptocrystalline material and crystals of fluorite. B. Randomly oriented tablets of quartz paramorphic after tridymite, set in grains of feldspar.

mite. The presence of all these characteristics in the original unit 3C of Beaudin *et al.* (1980) led to our reassignment of this member of the Harvey Mountain unit. The average chemical composition of twenty-five samples is presented in a later section.

THE INVERTED TRIDYMITE

Quartz paramorphic after tridymite (Fig. 2B) in the lava flow of the Harvey Mountain unit resembles that described by Wager *et al.* (1953), Stevenson (1963) and Pouliot (1968). The characteristic acicular habit of tridymite and alkali feldspar intergrown in spherulites was retained during cooling, as was the tabular habit of the crystals of tridymite (Fig. 2B) that are randomly oriented in and among laths of alkali feldspar in interstices between spherulites. The occurrence of tridymite, if formed in its stability field, indicates crystallization (devitrification) and, implicitly, emplacement at a high temperature, at least 870 to 900°C (Fenner 1913, Pouliot 1968, Deer *et al.* 1980).

FELDSPAR MINERALOGY

The Harvey rocks are dominated by quartz, sodium- and potassium-rich feldspar, accessory zircon and rare altered biotite (?), with a few granitic and basaltic(?) fragments set in a matrix of devitrified glass shards and pumice fragments or spherulites and aphanitic layers. The porphyritic unit is dominated by quartz and alkali feldspar phenocrysts. The rocks contain no primary ferromagnesian minerals. Quartz, albite, orthoclase (commonly less abundant than albite), fluorite and opal also occur as vapor-phase deposits.

As the Harvey volcanic rocks have a high-temperature origin, they should contain a disordered and compositionally intermediate (Na–K)-feldspar as a phenocryst phase. The groundmass feldspar in the Harvey Mountain rhyolites should be similar because devitrification in this unit probably occurred at a high subsolidus temperature. The detailed feldspar mineralogy of twenty-one samples was determined to evaluate just how close the Harvey volcanic rocks conform to this prediction, and to what extent they have re-equilibrated during the subsolidus events.

To evaluate the degree of Al–Si order, powder X-ray-diffraction patterns were run on hand-picked phenocryst fragments (or the whole rock, where the grain size is aphanitic). Selected sets of cell dimensions have been listed in Table 1. Compositional and structural variables (Table 2) were inferred from the cell constants (Guinier–Hägg focusing camera, synthetic spinel internal standard, $a = 8.0833$ Å at room temperature, Cu$K\alpha_1$ radiation).

The use of a focusing camera normally ensures that the diffraction maxima are sharp and well resolved, and sufficiently numerous that a least-squares refinement of the cell parameters can be obtained. In the case of the Harvey suite, however, problems were encountered; less than half of the sets of refined cell-dimensions are included in Table 1.

TABLE 1. CELL PARAMETERS OF Na-RICH AND K-RICH FELDSPARS FROM THE HARVEY RHYOLITIC SUITE, NEW BRUNSWICK

Description			a(Å)	b(Å)	c(Å)	α(°)	β(°)	γ(°)	V(Å^3)	Δ2θ	a^*(Å^{-1})	b^*(Å^{-1})	c^*(Å^{-1})	α*(°)	β*(°)	γ*(°)	ψ
37	matrix	Ab	8.1383	12.8072	7.1525	94.177	116.651	88.100	664.52	0.013	0.137483	0.078289	0.156762	86.279	63.412	90.031	1.264
			0.0013	0.0047	0.0010	0.022	0.014	0.017	0.20		0.000030	0.000029	0.000022	0.024	0.014	0.018	
20	vapor	Ab	8.1313	12.7985	7.1494	94.214	116.588	87.925	663.54	0.013	0.137526	0.078347	0.156734	86.325	63.487	90.213	1.195
			0.0020	0.0045	0.0014	0.028	0.022	0.030	0.25		0.000040	0.000026	0.000029	0.022	0.022	0.024	
2	pheno-	Ab	8.1438	12.8071	7.1442	94.009	116.591	88.646	664.65	0.015	0.137323	0.078276	0.156878	86.194	63.436	89.507	1.452
	cryst		0.0009	0.0015	0.0010	0.015	0.011	0.012	0.11		0.000018	0.000010	0.000020	0.014	0.011	0.011	
2	pheno-	Ab	8.1396	12.7968	7.1437	94.075	116.616	88.594	663.54	0.030	0.137422	0.078345	0.156930	86.146	63.415	89.531	1.462
	cryst		0.0029	0.0054	0.0032	0.059	0.040	0.041	0.41		0.000066	0.000034	0.000090	0.058	0.040	0.039	
22	pheno-	Ab	8.1444	12.7772	7.1526	94.085	116.599	88.076	663.84	0.018	0.137318	0.078464	0.156669	86.393	63.465	90.107	1.204
	cryst		0.0017	0.0028	0.0012	0.020	0.015	0.027	0.17		0.000033	0.000017	0.000024	0.019	0.015	0.026	
22	matrix	Or	8.5876	12.9732	7.2070	90	115.929	90	722.10	0.021	0.129481	0.077082	0.154284	90	64.071	90	
			0.0023	0.0026	0.0018		0.027		0.24		0.000034	0.000016	0.000035		0.027		
43	pheno-	IM	8.5980	12.9659	7.2163	90.524	116.032	88.341	722.54	0.011	0.129489	0.077159	0.154224	90.227	63.972	91.590	
	cryst		0.0011	0.0019	0.0008	0.014	0.011	0.013	0.13		0.000022	0.000011	0.000017	0.015	0.011	0.014	
43	pheno-	Ab	8.1410	12.7897	7.1579	94.193	116.609	87.947	664.55	0.009	0.137388	0.078399	0.156577	86.338	63.463	90.198	1.195
	cryst		0.0010	0.0011	0.0008	0.012	0.009	0.010	0.10		0.000020	0.000007	0.000019	0.012	0.009	0.009	
43	matrix	Or	8.6059	12.9661	7.2074	90	116.051	90	722.54	0.010	0.129339	0.077124	0.154436	90	63.949	90	
			0.0018	0.0017	0.0010		0.010		0.14		0.000027	0.000010	0.000018		0.010		
43	matrix	Ab	8.1325	12.7875	7.1500	93.984	116.550	88.491	663.54	0.014	0.137462	0.078392	0.156674	86.300	63.488	89.697	1.359
			0.0016	0.0033	0.0012	0.034	0.017	0.028	0.23		0.000023	0.000021	0.000029	0.031	0.018	0.026	
12	spheru-	Ab	8.1366	12.8436	7.1461	93.936	116.585	88.768	666.22	0.011	0.137439	0.078048	0.156824	86.214	63.436	89.407	1.472
	lites		0.0017	0.0039	0.0017	0.028	0.015	0.027	0.19		0.000023	0.000023	0.000037	0.024	0.015	0.024	
12	inter-	Or	8.5856	12.9781	7.2062	90	116.004	90	721.65	0.021	0.129594	0.077053	0.154401	90	63.996	90	
	stices		0.0041	0.0044	0.0020		0.031		0.35		0.000066	0.000026	0.000051		0.031		
14	inter-	Or	8.5810	12.9754	7.2069	90	116.141	90	720.35	0.016	0.129815	0.077069	0.154566	90	63.859	90	
	stices		0.0028	0.0027	0.0017		0.029		0.27		0.000040	0.000016	0.000055		0.029		
14	inter-	Ab	8.1378	12.7929	7.1616	94.299	116.671	87.905	664.36	0.015	0.137516	0.078389	0.156596	86.240	63.405	90.186	1.231
	stices		0.0020	0.0062	0.0014	0.026	0.018	0.029	0.27		0.000042	0.000038	0.000030	0.025	0.018	0.028	

Legend: Ab albite, Or orthoclase, IM intermediate microcline. In the sample description, "vapor" refers to a vapor-phase deposit, "interstices" refers to relatively coarse crystals, probably deposited from the vapor phase, found between spherulites. Samples represent units 3A (37), 3B (20), 3C (2, 22, 43) and 4 (12, 14). $\psi \equiv 2\theta_{131} - 2\theta_{1\bar{3}1}$, in degrees. Δ2θ average standard error associated with diffraction maxima, in degrees. Refinement carried out with program of Appleman & Evans (1973). Cu$K\alpha_1$ radiation.

TABLE 2. FELDSPAR ASSEMBLAGES IN SELECTED RHYOLITIC ROCKS FROM THE HARVEY SUITE, NEW BRUNSWICK

Samp	Unit	Sample description	Assemblage	$t_1$0
9	2	clast of flow-banded rhyolite	Ab > Or	
37	3A	volcanogenic sediment: matrix	$\underline{\text{Ab}}$ > Or	
		green clast in tuffaceous sediment	Ab only	
38	3A	cream-colored clast	Ab > Or	
		reddish clast	Or ≃ Ab	
20	3B	pink vapor-phase deposit	$\underline{\text{Ab}}$ > Or	
		white vapor-phase deposit	Ab > Or	
		purplish matrix	Ab > Or	
2	3C	quartz-feldspar porphyry: pheno	$\underline{\text{Ab}}$ only	
		composite of many phenocrysts	$\underline{\text{Ab}}$ only	
		matrix (devitrified)	Or, trace Ab	
22	3C	phenocryst	$\underline{\text{Ab}}$ only	
		matrix (devitrified)	$\underline{\text{Or}}$, trace Ab	0.43
13	3C	phenocryst	Ab > IM	0.87
		reddish matrix	Ab > IM	0.55
43	3C	phenocryst	$\underline{\text{Ab}}$ > $\underline{\text{IM}}$	0.83
		reddish matrix	$\underline{\text{Ab}}$ ≃ $\underline{\text{Or}}$	0.44
12	4	grey bands of spherulites	Or ≃ $\underline{\text{Ab}}$	
		interstices to spherulites	$\underline{\text{Or}}$ > Ab	0.42
14	4	spherulites	Or ≃ Ab	
		interstices to spherulites	$\underline{\text{Or}}$ ≃ $\underline{\text{Ab}}$	0.44

Samp: sample number, unit: map unit represented by the sample. Symbols: Ab albite, Or orthoclase, IM intermediate microcline. An underlined symbol indicates that the relevant cell-parameters are listed in Table 1. The value $t_1$0 refers to the proportion of Al in the $T_1$0 position of the orthoclase or intermediate microcline; it is calculated according to the equations of Blasi (1977). The value of $t_1$0 expected in low microcline is 1; in fully disordered sanidine, it is 0.25. Values are not listed for albite because of the possibility that small amounts of calcium might be in the structure.

Other refinements are not presented because too few diffraction peaks could be unambigously indexed, leading to unacceptably large errors. This problem can be explained by a combination of the following factors: 1) as silicification is an important process in many specimens, the volume of feldspar in a 1-mm^3 sample of a rock is reduced. 2) The presence of disseminated hematite leads to a high background on the powder pattern, such that many faint lines become illegible. 3) Products of devitrification are probably metastable structurally if not compositionally, and most likely are heterogeneous on a small scale. This leads to broadened, lower-intensity peaks. 4) Albitization is widespread, and the removal of some K by ion exchange means that the volume of the K-feldspar is reduced over that of albite. Note that the heterogeneities mentioned in point 3 are bound to affect the K-feldspar more than the albite, because the K-feldspar departs more importantly from its equilibrium degree of Al–Si order than the albite.

The entire set of results can certainly be used qualitatively if not quantitatively. The specific association of feldspar minerals in each specimen is recorded in Table 2, along with an indicator of degree of Al–Si order of the K-feldspar where this is allowed by the precision of the refined cell-parameters.

With few exceptions, the samples taken contain two feldspars, one sodic, the other potassic. Compositionally, the sodic phase is virtually free of potassium and calcium. Microprobe data are available to confirm this XRD finding in the case of albite in specimens 2 and 13 (mean of 15 compositions $Ab_{99.4}Or_{0.3}An_{0.3}$). The K-feldspar contains some sodium, as expected, but probably less than 5 mole % Ab. The only microprobe determination (sample 2) gives $Or_{98.2}Ab_{1.8}$. There is certainly no trace remaining of the original high-temperature sanidine, inferred to have had a composition in the range Or_{65} to Or_{70}. In terms of composition of the coexisting phases, the Harvey rocks contain a low-temperature (<300°C) assemblage (*e.g.*, Martin 1974).

In almost all cases where the two feldspars coexist, the volume occupied by albite exceeds that of the K-feldspar. This is an indication that many of the Harvey volcanic rocks have undergone mild readjustments in the relative proportion of Na and K. This is well reflected in the bulk composition of the rhyolites (see Discussion).

Structurally, both sodic and potassic feldspars show clear evidence of metastability. In the time available during the cooling of this near-surface volcanic edifice, the feldspars did order partly, but failed to reach the equilibrium state, low microcline and low albite. In almost all cases, the K-rich feldspar is orthoclase (nomenclature of Ribbe 1983). It is relatively well ordered; $2t_1$ is close to 0.88 (maximum disorder: $2t_1 = 0.50$). A proportion of Al in the two T_1 sites of orthoclase of 0.88 is close to the limit normally encountered in monoclinic K-feldspar, and implies that the K-feldspar has gone to the limit short of a transformation to a triclinic structure, which is a major reconstructive step. The inversion to microcline, expected near 400°C, failed to occur except in the vicinity of specimens 13 and 43 near Harvey Mountain (Fig. 1).

Specimens 13 and 43 of the quartz-feldspar porphyry both contain intermediate microcline. In specimen 13, both phenocryst and matrix contain intermediate microcline (t_1O 0.87 and 0.55, respectively; t_1O is 1 in low microcline). In specimen 43, the phenocryst is intermediate microcline (t_1O 0.83), but the matrix still contains well-ordered orthoclase (t_1O 0.44, Table 2). Samples 13 and 43 both seem to violate a rule of thumb that applies to subsolidus assemblages containing K-feldspar: the finer the grain size, the more evolved is the degree of Al–Si order. One way to explain the anomaly is to propose that because of silicification, the porosity and permeability of the matrix were greatly reduced, thus impeding the interaction of feldspar with fluid that must proceed to transform a disordered feldspar into an ordered one. The same reason may apply to the Harvey suite as a whole, as an explanation of the scarcity of microcline.

Similarly, the sodic feldspar is "stranded" in a metastable, transitional state. This can be illustrated in a $\beta^* - \gamma^*$ plot (Fig. 3), the best diagram to separate the effects of composition and degree of Al–Si order in sodic plagioclase (Smith 1974). The points should plot close to ordered An_0, but none do. Instead, they define a "shotgun" pattern that departs significantly from the locus of ordered structures. The points seem to indicate that the albite does contain small amounts of calcium *and* are somewhat disordered, but the relative importance of these two variables cannot be ascertained without considerably more effort.

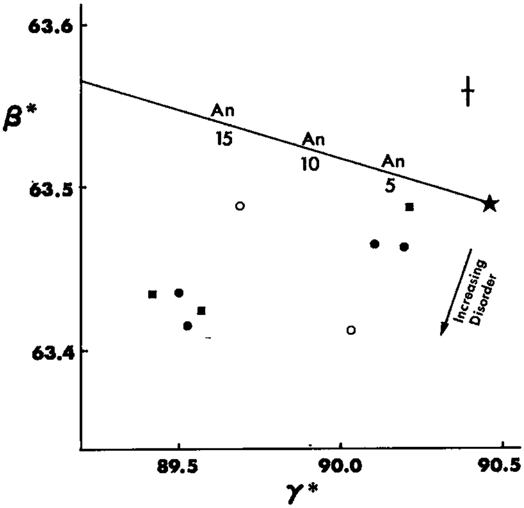

FIG. 3. β^* - γ^* diagram showing the co-ordinates of the albite encountered. Completely disordered albite (An_0) has the co-ordinates $\beta^* = 63.5°$, $\gamma^* = 88°$. Filled circles: phenocryst, open circle: matrix, square: other. Star: fully ordered albite (An_0). Values expressed in degrees.

Two more specimens of the quartz–feldspar porphyry contain an anomalous assemblage: specimens 2 and 22, from virtually the same locality near Harvey Lake (Fig. 1), contain a phenocryst phase that is 100% albite, *i.e.*, that is devoid of a K-feldspar component. On the other hand, the matrix to these phenocrysts contains a mere trace of albite and is largely all K-feldspar + quartz. In light of earlier comments and of the expected phenocryst composition for a melt composition such as that trapped in the quartz phenocrysts in specimens 2 and 13 (Payette & Martin 1986), the following steps would account for the feldspar mineralogy of these two specimens: 1) Sanidine phenocrysts set in an initially glassy, relatively potassic matrix. 2) Devitrification of the matrix, with exsolution and partial ordering in the phenocrysts. 3) Local Na-for-K exchange, sufficiently intense to transform phenocryst (and, presumably, the feldspars in the devitrified matrix) to 100% albite. This would have left the matrix very porous because of shrinkage when Na substitutes for K in the feldspar structure. 4) Lower-temperature episode of K-for-Na exchange, which affected the matrix thoroughly because of its porosity, but left the phenocrysts essentially untouched. The sequence proposed *i.e.*, high-temperature Na metasomatism followed by low-temperature K metasomatism, matches that in many well-documented examples of subsolidus modifications in alkali rhyolite and granite (White & Martin 1980, Martin & Bowden 1981).

CHEMICAL COMPOSITION OF THE HARVEY RHYOLITES

In order to better characterize the Harvey rocks, the chemical composition of 59 representative samples of the various units was obtained by X-ray fluorescence. Only the volcanic rocks were considered in this study (Table 3). Complete chemical data are available at nominal charge from the Depository of Unpublished Data, CISTI, National Research Council of Canada, Ottawa, Ontario K1A 0S2.

TABLE 3. AVERAGE CHEMICAL COMPOSITION[1] OF THE VARIOUS MEMBERS OF THE HARVEY VOLCANIC SUITE, NEW BRUNSWICK

Unit	21r	2af	3A	3B	3C	3D	4	3Cg
SiO_2 %	80.40	76.52	77.79	76.07	79.73	82.65	77.51	71.30
TiO_2	0.05	0.07	0.07	0.08	0.08	0.05	0.07	0.04
Al_2O_3	10.12	12.31	12.34	12.31	10.65	8.93	11.83	14.80
Fe_2O_3	1.24	1.82	1.10	1.72	1.45	0.75	1.27	0.40
MnO	0.01	0.02	0.01	0.02	0.01	0.02	0.00	0.03
MgO	0.10	0.27	0.04	0.05	0.14	0.12	0.23	0.01
CaO	0.14	0.10	0.08	0.69	0.23	0.17	0.20	0.40
Na_2O	2.12	0.48	2.38	3.03	1.74	1.69	1.92	3.60
K_2O	4.59	6.65	5.46	4.86	4.74	4.19	5.75	6.50
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
L.O.I.	1.12	2.23	1.02	1.23	1.21	1.21	1.16	-
F	-	-	-	-	-	-	-	2.0[2]
Cl	-	-	-	-	-	-	-	0.2
total	99.90	100.48	100.30	100.07	99.99	99.79	99.95	99.29
A/CNK	1.19	1.53	1.24	1.15	1.31	1.37	1.24	1.10
Ba ppm	29	170	42	37	7	21	20	
Nb	40	70	47	87	49	34	44	
Zr	103	149	122	159	144	92	119	
Y	87	114	76	179	110	78	116	
Sr	123	46	23	29	32	114	71	
Rb	362	527	542	485	422	329	584	
Th	37	31	37	39	26	32	39	
Pb	20	46	16	42	31	18	32	
n	4	2	4	7	12	5	25	97

Units: 21r laminated rhyolite, 2as ash-flow, 3A volcanogenic sediments, 3B ash-flow tuffs, 3C ash-flow tuffs (porphyritic), 3D ash-fall tuff, 4 lava flow, 3Cg glass contained in the quartz phenocrysts of the quartz-feldspar porphyry, unit 3C (Payette & Martin 1986). L.O.I. loss on ignition. *n* number of samples analyzed. [1] All data obtained by X-ray-fluorescence analysis, except for 3Cg, obtained by electron microprobe analysis. Total Fe expressed as Fe_2O_3, except for 3Cg, where it is expressed as FeO. XRF analyses performed by T. Ahmedali, McGill University. Analytical precision (1σ, wt.%), as calculated from 20 replicate analyses of one sample disc, are: SiO_2 0.05, TiO_2 0.003, Al_2O_3 0.03, MgO 0.058, Fe_2O_3 0.01, MnO 0.001, CaO 0.01, Na_2O 0.06, K_2O 0.001, P_2O_5 0.004. Detection limit for Ba in fused samples: 10 ppm; detection limit for trace elements on pressed-powder pellets: 5 ppm. [2] maximum concentration recorded.

The Harvey rocks are rich in silica and potassium (76–83% SiO_2, 3–7% K_2O, respectively) and poor in titanium (<0.2% TiO_2), magnesium (<0.5% MgO), calcium (<2% CaO) and phosphorus (<0.03% P_2O_5) (Table 3). Their average composition indicates a peraluminous character (A/CNK between 1.19 and 1.53). The trace-element data indicate enrichment in Nb, Y, Rb and Th and a strong depletion in Ba, Sr and Zr (Table 3), typical of highly evolved rhyolites (Miller & Mittlefehldt 1984, Pichavant & Manning 1984).

The SiO_2 values of the laminated rhyolite of the York Mills unit range from 80 to 83.7%. The SiO_2 values of the ash-flow subunit in the York Mills (>76.5%) are more similar to those of the Cherry Hill (ash-flow tuff 76%, porphyry 79%), and Harvey Mountain units (lava flow 77.5%). The Al_2O_3 values are more uniform, except for those units where SiO_2 is close to or exceeds 80% (units 2, 3C, 3D); Al_2O_3 content ranges from 12 to 12.8% in the Cherry Hill unit, except for the porphyry subunit, which contains 10 to 11%, and the Harvey Mountain unit (11.6 to 12.6%). The Al_2O_3 content is more variable, from 6 to 10%, in the York Mills unit and unit 3D of the Cherry Hill sequence, all cases where the SiO_2 content is high. All three divisions of the Harvey volcanic suite have low contents of iron (0.2–2% Fe_2O_3), magnesium (0–0.5% MgO), manganese (0–0.05% MnO), titanium (0.04–0.15% TiO_2) and calcium (0–2% CaO). Sodium and potassium are more variable, and range from 0 to 4.4% Na_2O and 3 to 7.2% K_2O. Ba, Sr and Zr are generally found in low concentrations: 0–185 ppm Ba, average less than 50, 15–400 ppm Sr, average less than 70, 78 to 174 ppm Zr, average 130, respectively; in contrast, Nb, Rb, Y and Th are present in relatively high concentrations: Nb 26–107, average 50 ppm, Rb 400–691, average 500, with a few exceptions with less than 400 ppm, Y 40–243, average 110, Th 21–47, average 35 ppm. F, Cl and *REE* contents were not determined on the whole rocks. The trace-element content is variable within each map unit and subunit. Each subunit of the Cherry Hill unit displays a well-defined range of concentration for each element, but neither the major units nor the subunits may be distinguished on this basis, owing to overlap (*e.g.*, unit 4 covers the whole range of all other units or subunits). The variable Ca content is explained by the presence or absence of fluorite (a secondary mineral) in the vugs and in the matrix.

As with all ignimbritic rocks, various postmagmatic processes such as devitrification and deposition from the vapor phase have played an important role in modifying the chemical composition of those originally glassy volcanic rocks, and this is especially the case with the major elements. The SiO_2 values observed for many samples in units 2, 3C and 3D are unusually high (80 to 84%), and not representative of magmatic values. The net effect of adding Si to a rhyolite will be to dilute all other elements. The glass preserved in the melt inclusions in quartz phenocrysts of the quartz–feldspar porphyry (unit 3C; Payette & Martin 1986) offers unique insight into the true composition of the melt as it was at the time of growth of the phenocrysts (Clocchiatti 1975, Roedder 1979), before any perturbing postmagmatic processes. A comparison of the composition of the bulk rock and the glass (Table 3) reveals important differences in the concentration of the major elements (the minor-element contents of the glass are not available).

DISCUSSION

Although the Harvey volcanic rocks have a high-temperature origin, their feldspar mineralogy is not primary. In fact, the alkali feldspar(s) found in phenocrysts, in products of devitrification of glass, and in vapor-phase deposits have all interacted with a fluid phase at a low temperature, and have become better ordered to some extent. Both sodic and potassic feldspars still fall short of the fully ordered configurations, however, suggesting that the length of time available for ordering was relatively short (hundreds of years?). Unfortunately, this aspect cannot be quantified with the information available. More work needs to be done on the sodic feldspar phase, which seems unusually far from pure, ordered albite for a product of crystallization of such an evolved, low-calcium granitic liquid (Payette & Martin 1986).

It is known that the ordering reaction does become very sluggish below 300°C (*e.g.*, Martin 1974), even that in sodic feldspar, which is more reactive than the K-rich feldspar. Mobilization of alkalis in the Harvey rocks resulted in the replacement of K-feldspar by albite, but, with one exception, this process was not sufficiently intense or did not last long enough to lead to the elimination of K-feldspar, as has been found in uranium-enriched ignimbrites (which become albitites; *e.g.*, White & Martin 1980). The mildness of the metasomatic adjustments is consistent with the lack of economic grades of uranium mineralization at Harvey.

The reactions recorded in the feldspar assemblage were caused by hot aqueous fluids that had the ability to transport silica. The SiO_2 values observed in the rocks of York Mills unit (up to 84 wt.%) and in some other units, such as 3D, suggest extensive silicification. Petrographically, this is illustrated by the presence of microcrystalline quartz in the groundmass of some rocks (chalcedony in unit 3D).

Experimental studies have shown that the alteration of silicic glass proceeds first by hydration of the glass, followed by the development of spherulites and, possibly, granophyric textures (Lofgren 1971). Devitrification is accomplished by diffusion of the alkali ions (Jezek & Noble 1978), usually with minor overall chemical changes of the bulk-rock compositions (Ewart 1971, Fisher & Schmincke 1984). However, loss of Na, Si, Al (Lofgren 1970, Zielinski 1979) and halogens (Noble *et al.* 1967, Lipman *et al.* 1969) have been reported in some instances.

Major- and trace-element variation diagrams (Fig. 4) may be used to demonstrate the consequences of silicification on the bulk composition of the rhyolites at Harvey. In the case of Na and K, a much bet-

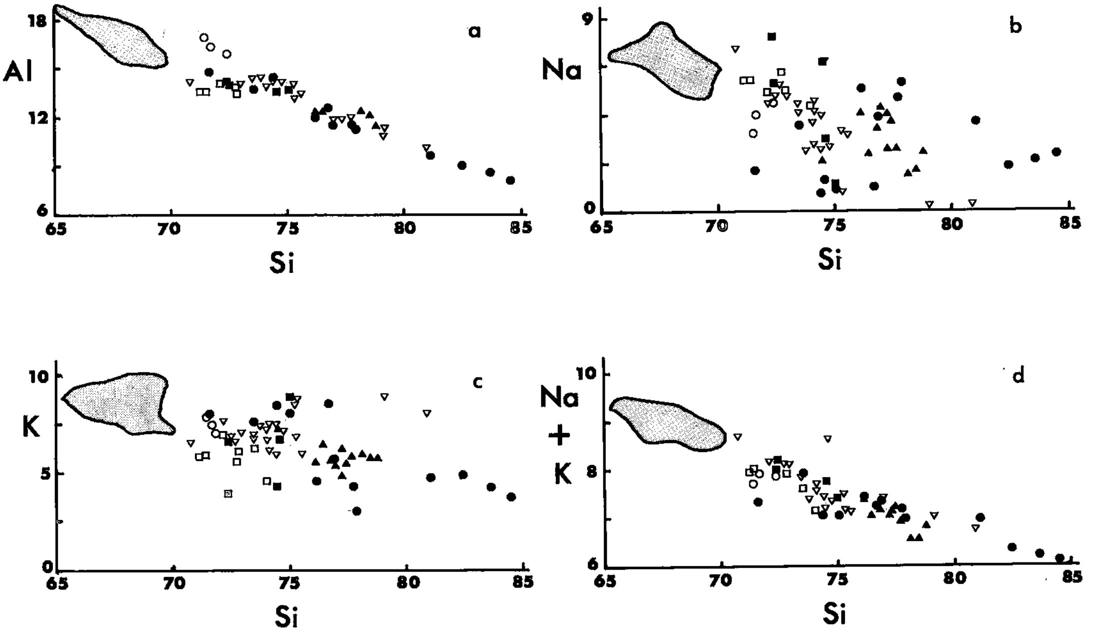

FIG. 4. Dilution effect of increasing Si on Al, Na and K (cation %). All other elements show the same effect. Shaded pattern and the open circles represent glass compositions (Payette & Martin 1986; see also Table 3). Filled circles: bulk compositions of the Harvey rocks. a. Al *versus* Si, b. Na *versus* Si, c. K *versus* Si, d. (Na + K) *versus* Si.

ter negative correlation exists between the SiO_2 content and the sum (Na + K) than with either Na or K taken individually. Whereas the main consequence of depositing silica in pore spaces is to decrease the relative proportion of all other elements present, the alkalis have been further disturbed by an ion-exchange reaction, possibly taking place at the same time as the addition of silica. All this silica must have been selectively dissolved from rhyolitic material deeper in the section upon *its* devitrification (Ross & Smith 1961), presumably at a higher temperature than that at the site of SiO_2 deposition. If the composition of the Harvey suite did correspond, on average, to the composition of glass in the inclusions in quartz (Payette & Martin 1986), then the deeper parts of the section must contain quartz-poor, relatively feldspathic tuffs. An important finding is that at Harvey, the bulk compositions are not primary, and in most cases are quite far from being so.

Comparison with topaz rhyolites

The mineralogy, chemical composition (Table 3), enrichment in F and Rb, depletion in Ba, Sr, Ca and Mg, the peraluminous character of both the glass in the melt inclusions and the whole suite of Harvey rocks, the presence of high concentrations of F (up to 2%) in the glass and the abundant fluorite in both the matrix and open vugs as a vapor-phase deposit, all point to the similarity of the Harvey group to topaz rhyolites (see Burt *et al.* 1982, Christiansen *et al.* 1983, 1984, Naumov *et al.* 1984, Payette & Martin 1986). It is true that topaz has yet to be found, but other F-rich phases have been identified in the melt inclusions (Payette & Martin 1986).

A comparison of the major- and trace-element compositions of the Harvey glass and rhyolites to those of topaz rhyolite, ongonite, calc-alkaline and peralkaline rhyolites (Christiansen *et al.* 1983) is illustrated in Figure 6 of Payette & Martin (1986). F-rich (topaz) rhyolites differ from peralkaline rhyolites by their higher F, Rb, U and Th contents, and lower Sr, Ba, Eu, Cl, Zr, Nb, Fe, Mg, Ti, Zn and *LREE* (Hildreth 1981, Christiansen *et al.* 1983). Topaz rhyolites are usually high in SiO_2 (>74%), Na_2O (~3.6%), K_2O/Na_2O ratio (>1) and fluorine (0.1-1%) and low in TiO_2 (<0.2%), CaO (<0.9%), MgO (<0.2%) and P_2O_5 (<0.01%) (Christiansen *et al.* 1983). Devitrification and hydrothermal alteration of the originally glassy rocks of Harvey most probably caused the observed discrepancies in Al, Na, Ca, Rb and Sr (*cf.* significant loss of alkalis, Rb and Al: Lipman *et al.* 1969, Lofgren 1971, Zielinski 1982) when compared to the average composition of topaz rhyolites, obtained using fresh rhyolitic glass and felsites (Christiansen *et al.* 1983). Y is more concentrated at Harvey (up to 250 ppm) than expected for a topaz (F-rich) rhyolite, but this might

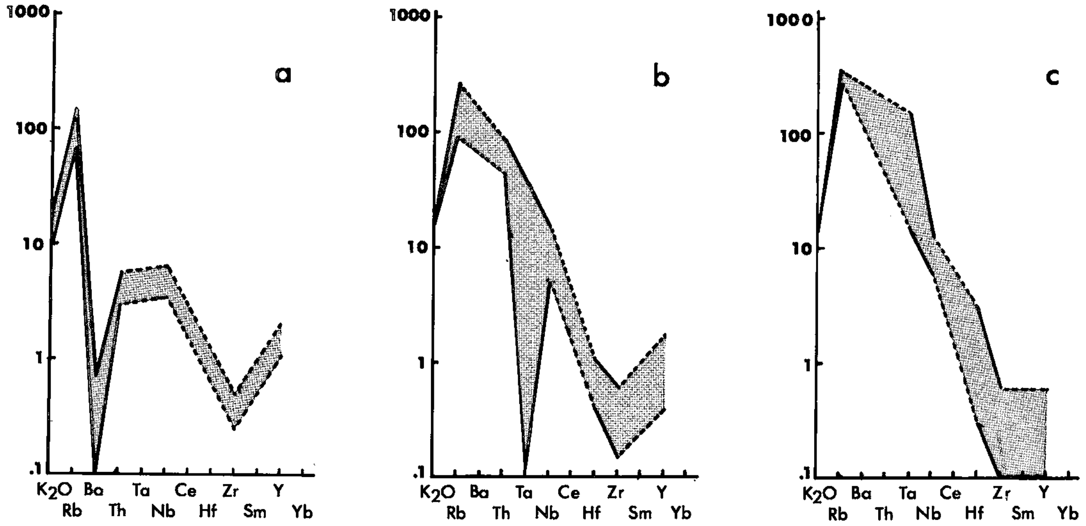

FIG. 5. Trace-element concentrations of the Harvey volcanic rocks (a), topaz rhyolites (b) and ongonites (c) normalized to the ocean-ridge granite values of Pearce *et al.* (1984): Data for some elements are missing (broken lines). Data for topaz rhyolites and ongonites from Christiansen *et al.* (1983).

be related to the presence of accessory Y-bearing phases such as zircon, as a solid solution toward xenotime, and britholite (Payette & Martin 1986). The high concentrations of K, Rb, Th and the low concentrations of Ba and Zr are especially well defined in Figure 5a. All three groups shown in Figure 5 show a K, Rb, Th enrichment and a depletion in Zr. Unfortunately, as the dashed lines indicate, there are still some elements for which the data base is fragmentary in one suite or another.

Yet another way of comparing these rocks to other types of rhyolite is to plot the Rb and Zr concentrations in all units and formations of the Harvey Group (Fig. 6). The Harvey rocks define a cluster of points that overlaps the population of F-rich rhyolites (topaz rhyolites) of Christiansen *et al.* (1983). Note, however, that some topaz rhyolites are more evolved than the Harvey rhyolites, on the basis of their Rb content.

That the parent magma was fluorine-rich is supported by the concentration of F in the glass (up to 2%), the presence of crystals and patches of fluorite in the devitrified rocks and of a F-bearing liquidus mineral in the melt inclusions (Payette & Martin 1986). Separation of a F-rich fluid phase and its rise to the upper parts of the magma chamber may provide an efficient means of concentrating fluorophile trace-elements (Be, Li, U, Th, Sn, *etc.*) by volatile-complexing with F (Bailey 1977, Mahood 1981, Burt *et al.* 1982, Christiansen *et al.* 1983, 1984, Pichavant & Manning 1984). The fluorine may have become concentrated in the top part of a magma reservoir either by "thermogravitational diffusion" (Hildreth 1981) or crystal fractionation (Christiansen *et al.* 1983, 1984).

Comparison with Mount Pleasant

Petrographically, the Harvey volcanic suite is quite similar to a typical nonproductive (*i.e.*, unmineralized in Sn–W) topaz rhyolites vent-complex (Burt *et al.* 1982). For example, some rhyolites are strongly flow-banded (unit 4) and have a crystal-poor spherulitic groundmass. Fluorite is common to locally abundant, both in the lava flow and in the underlying ash-flow unit, and local anomalies in uranium have been reported (Kuan 1970, Beaudin *et al.* 1980). The Mount Pleasant caldera and the associated Sn–W–Mo deposit (Fig. 1) could represent a productive vent-complex (Pouliot *et al.* 1978, Burt *et al.* 1982, Samson *et al.* 1985). The Harvey Group and the Mount Pleasant rocks occur at the same stratigraphic level and are considered of the same age (early Mississipian, 340–330 Ma); their genetic relationship has been suggested repeatedly (Kuan 1970, Pajari 1973, Gemmell 1975, Beaudin *et al.* 1980), though not documented. The ash-flow tuffs of the Mount Pleasant caldera are petrographically and geochemically very similar to the Harvey rocks (Gemmell 1975, S.R. McCutcheon, pers. comm.), but there must be subtle differences that determine whether a rhyolitic vent-complex becomes productive or nonproductive. A search for these indicators will form the basis of a future study.

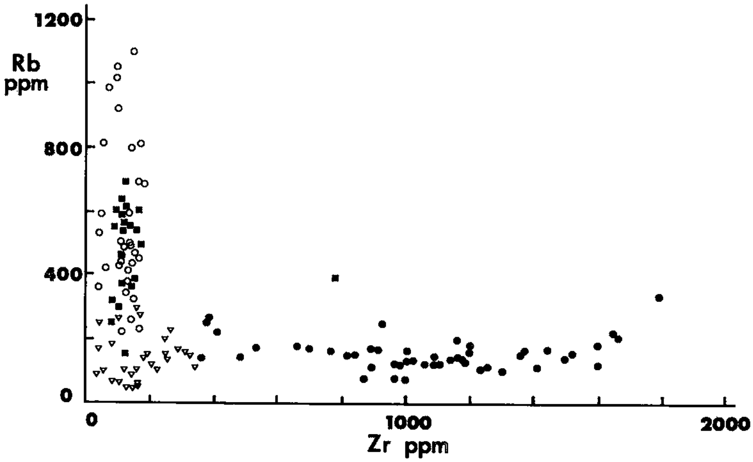

FIG. 6. Rb–Zr distributions of F-rich metaluminous (open circles), metaluminous (open triangles) and peralkaline rhyolites (closed circles). Harvey data: closed squares (modified after Christiansen *et al.* 1983).

Origin and tectonic setting

The geochemical data reported here allow some interpretations to be made concerning the tectonic setting of magmatism. In particular, the Rb *versus* (Y + Nb) and Nb *versus* Y discriminants (Fig. 7) effectively attribute the Harvey rocks to the Within-Plate-Granite (WPG) category of Pearce *et al.* (1984). This approach assumes that these elements at Harvey have not been seriously affected by the subsolidus processes described in this paper. Also considered typical of WPG-type rhyolites are the high contents of K, Rb and Th and depletions in Ba and Sr. WPG-type rhyolites may be considered extrusive members of anorogenic plutonic suites (Martin & Piwinskii 1972, Loiselle & Wones 1979).

Although there is no question concerning the tectonic setting of the Harvey suite, the ultimate origin of the volcanic rocks is more contentious, in view of our lack of information on isotopic systems. The Harvey suite contains small xenoliths of basic rocks, and basalt flows have been mapped at the same stratigraphic level as the Harvey volcanic rocks to the northeast and southwest. Burt *et al.* (1982) and Christiansen *et al.* (1983) proposed an origin for topaz rhyolites linked to the emplacement of basaltic magma in the crust at an early stage of lithospheric extension. Was the role of the mantle-derived basaltic magma simply that of a heat source, which initiated anatectic reactions on a sufficiently large scale to account for the volume of rhyolite produced (Burt *et al.* 1982, Christiansen *et al.* 1983, 1984)? Or did the basaltic magma differentiate very efficiently near the surface to give a suite of derivative magmas (Martin & Piwinskii 1972, Higgins 1978)? We have favored the first hypothesis for the Harvey suite (Payette & Martin 1986) in view of the peraluminous nature of the melt, preserved as glass in quartz phenocrysts. Also considered relevant is the potassic composition of the melt. Both criteria are usually considered earmarks of an anatectic granitic liquid formed at the expense of a sedimentary succession containing metapelites (*e.g.*, Miller 1985) A weaker criterion would be the clear bimodality between the suite and the basaltic flows that could be related to it. The Mount Pleasant suite has an initial $^{87}Sr/^{86}Sr$ ratio of 0.713 (Kooiman *et al.*, in press). Such a high value is consistent with the direct involvement of metasedimentary crustal material in the genesis of those rhyolites. Note that the metasedimentary material may have been metasomatized by mantle-derived, F-bearing fluids (Bailey 1978) prior to anatexis.

In the reservoir of rhyolitic magma, important zonation of F and lithophile elements such as the heavy rare-earths, uranium and thorium could have occurred through crystal–liquid equilibrium involving monazite, titanite, zircon and britholite, and through volatile complexing and other poorly understood processes (Hildreth 1981, Mahood 1981, Christiansen *et al.* 1983, 1984, Pichavant & Manning 1984). Documentation of such zonation would be difficult to obtain at Harvey in view of the analytical problems in determining concentrations of such trace elements in the glass inclusions, and the disturbances in trace-element distributions in the whole rocks expected as a result of the postmagmatic reactions.

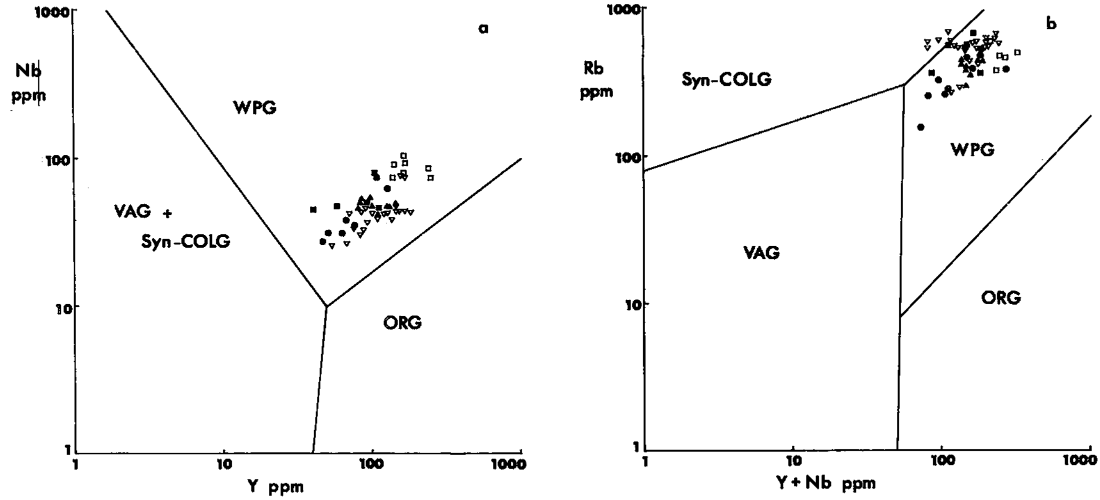

FIG. 7. Nb–Y (a), Rb–(Y + Nb) (b) discriminant diagrams (after Pearce *et al.* 1984). WPG: within-plate granites, ORG: orogenic granites, VAG: volcanic arc granites, Syn-COLG: syn-collision granites. Closed circle: units 2, 3B; closed square, unit 3A; open square, unit 3B, closed triangle, unit 3C, inverted open triangle, unit 4.

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