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RODINGITIZATION OF GRANITE AND SERPENTINITE IN THE JEFFREY MINE, ASBESTOS, QUEBEC

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ABSTRACT

A mineralogical and petrological study of a rodingitized felsic dyke in the Jeffrey mine, Asbestos, Québec, suggests a complex and protracted metasomatic history. Early Na metasomatism of the plagioclase in the dyke rock was followed by rodingitization and redistribution of K, to give unusual clinopyroxene + microcline-rich assemblages. A second period of rodingitization followed a brecciation event that may have accompanied the final emplacement of the ophiolitic complex. The host serpentinite in the hanging wall underwent rodingitization to a clinopyroxenite in which the relict chromite grains now show green halos of chromian grossular and phlogopite. Local Mg and K metasomatism, responsible for dark chlorite–biotite selvages, may have occurred between the two periods of rodingitization. The events in this relatively young dyke presumably reflect the two stages of serpentinization recognized in the host peridotite, one before and one after obduction of the ophiolitic complex.

Keywords: rodingite, Jeffrey mine, Québec, granite dyke, serpentinized peridotite, K, Ca metasomatism.

SOMMAIRE

L'étude minéralogique et pétrologique d'un dyke felsique rodingitisé de la mine Jeffrey (Asbestos, Québec) laisse entrevoir une évolution métasomatique longue et compliquée. Un stade de métasomatisme sodique du plagioclase magmatique a précédé le premier épisode de rodingitisation et la mobilisation du K qui formèrent des assemblages insolites riches en clinopyroxène + microcline. Une deuxième rodingitisation, qui a suivi la mise en place du complexe ophiolitique, a aussi affecté la serpentinite encaissante à l'éponte supérieure, transformant celle-ci en clinopyroxénite dans laquelle on observe des reliques de chromite à auréoles vertes de grossulaire et phlogopite chromifères. Un métasomatisme local à Mg et K entre les deux épisodes de rodingitisation expliquerait la formation de lisières foncées aux cristaux de chlorite-biotite. L'histoire de ce dyke relativement récent reflète probablement les deux stades de serpentinisation qui ont affecté la péridotite encaissante, l'une avant, l'autre après la mise en place par obduction du complexe ophiolitique.

(Traduit par la Rédaction)

Mots-clés: rodingite, mine Jeffrey, Québec, filon granitique, peridotite serpentinisée, métasomatisme K, Ca.

INTRODUCTION

The ophiolitic suite exposed in the Eastern Townships of southeastern Québec has undergone a complicated sequence of events since its emplacement on the Cambrian sea floor. These events are recorded not only in the harzburgite tectonite, dunite cumulates, basic rocks and overlying sedimentary units (Laurent 1975a, b, Laurent & Hébert 1979), but also in the associated dyke rocks. As these dykes are not all contemporaneous, they hold much promise for unraveling the sequence of magmatism, deformation and metasomatism in the suite as a whole.

Coleman (1977) and Evans (1977) provided concise reviews of the characteristics of rodingites. They are invariably Ca-rich metasomatic rocks, closely related spatially and temporally with processes of serpentinization. In broad terms, the elements that are not accepted by the crystal structures of serpentine and associated low-grade metamorphic minerals in the ultrabasic portions of the ophiolitic complexes concentrate in a high-pH aqueous fluid that readily interacts with and metasomatizes dyke rocks or nearby country rocks. Coleman (1977) noted that a removal of silica is universally observed, and that in the few cases studied of rodingitization of granitic rocks, alkali feldspars are commonly present in the calc–silicate assemblages.

This paper constitutes the first in-depth study of rodingitized dyke material from the Québec Appalachians. The dyke occurs in the Jeffrey mine, the asbestos mining operation of the Canadian Johns-Manville Co. at Asbestos, Québec. Dyke location and general geology of the open-pit area are illustrated in Figure 1. Previous work on rodingites in the Eastern Townships includes Graham's (1917) brief report of "lime-rich assemblages" in the serpentinites of the Black Lake–Thetford Mines area and the surveys of Olsen (1961) and De (1961, 1972).

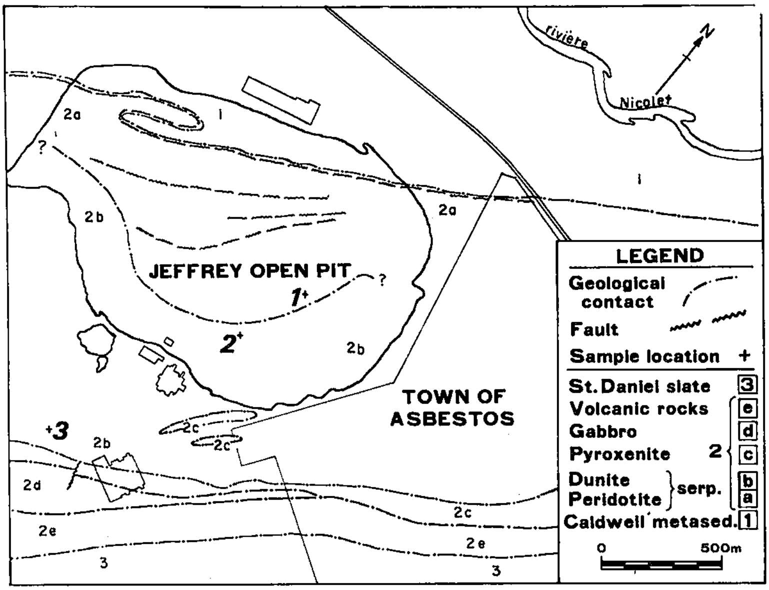


FIG. 1. Geology of the Jeffrey mine area, adapted from a Canadian Johns-Manville Co. map. Specimen locations 2 and 3 indicate other dykes currently under investigation.

Riordon (1975) also commented on the common occurrence of rodingites in the asbestos-producing serpentinites of southeastern Québec.

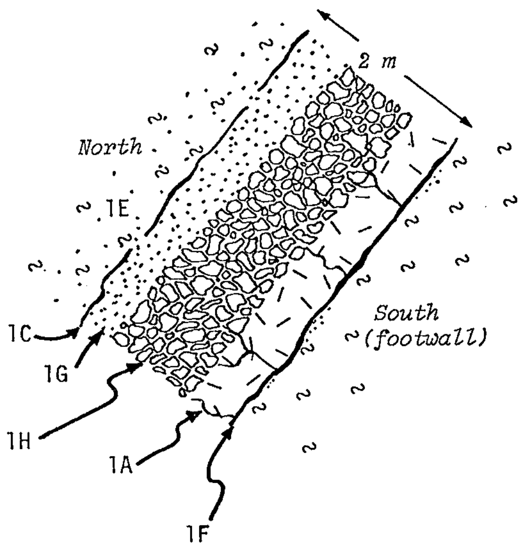


FIG. 2. Schematic diagram of rodingitized dyke and host rock. 1E: partly rodingitized serpentinite (hanging wall). 1C: brown, sporadic chloritic selvage. 1G: completely rodingitized serpentinite (clinopyroxenite). 1H: brecciated feldspathic "core". 1A: diopside–K-feldspar–prehnite assemblage (southern edge). 1F: well-developed, green chloritic selvage.

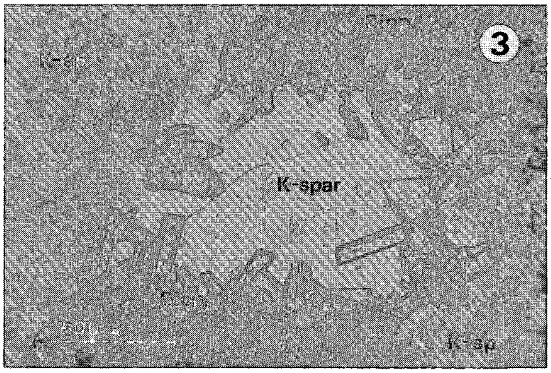
FIELD RELATIONSHIPS

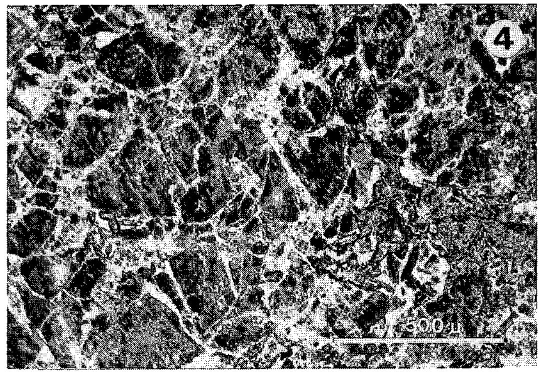
Located in the eastern part of the pit (Fig. 1), the dyke strikes roughly E–W and dips approximately 50°N. It is 2 m wide and exposed for at least 10 m along strike; mining operations have removed other exposures of this prominent dyke (F. Spertini, pers. comm. 1978). It is conspicuously zoned (Fig. 2): the pinkish, featureless core (1 m wide) grades into a 0.5 m wide light grey zone towards the southern contact, which is marked by a conspicuous, dark green chlorite-rich selvage 1–5 cm wide. The footwall is massive, dark green and apparently unaffected by the dyke except for small, isolated, pale green blotches along the selvage. Towards the northern contact, the core gives way to a dense, aphanitic, white to light green zone 0.5 m wide that is mottled with black to emerald-green specks. The northern contact is gradational, heterogeneous, and characterized by a sporadic brown, foliated selvage up to 5 cm wide; the hanging-wall serpentinite is pale to dark green and cross-cut for at least 0.5 m beyond the selvage by irregular, diffuse white veinlets.

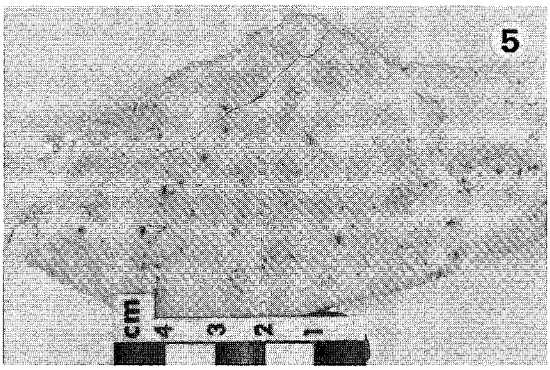
PETROLOGY AND MINERALOGY

The protolith

A specimen of the dyke rock collected earlier







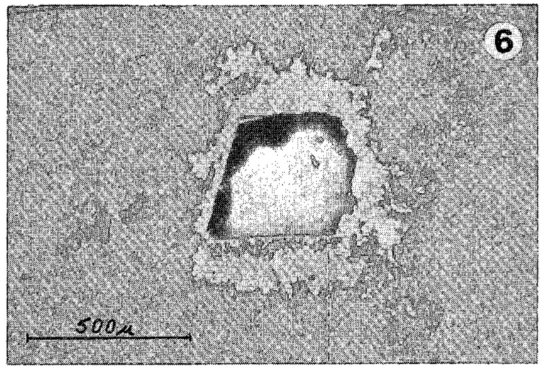


FIG. 3. Euhedral diopside crystals projecting into second-generation, limpid microcline. Specimen 288c, plane-polarized light.

FIG. 4. Brecciated microcline-rich rodingite. Clasts consist of relatively well-ordered, turbid microcline, whereas intermediate microcline + diopside heal the fractures. Specimen 1H, plane-polarized light.

FIG. 5. Macroscopic appearance of rodingite from northern edge. The mottling is due to chromite grains and associated halos of chromian grossularite and phlogopite.

FIG. 6. Phlogopite halo around euhedral chromite grain in diopside groundmass. Specimen 1G, plane-polarized light.

by R. Laurent (his 288c) provides the best example of the original lithology. That part of the dyke has since been removed during mining operations. In 288c, primary igneous textures are still visible; the rock is light grey, medium grained and equigranular, consisting of 30 (vol.) % turbid microcline, 20% secondary, limpid microcline, 30% zoned plagioclase and 20% irregular, fine-grained (< 0.2 mm) mats of clinopyroxene. These clinopyroxene clusters mask original K-feldspar–plagioclase grain boundaries and replace plagioclase cores. The limpid, apparently nonperthitic microcline fills "vugs" lined with diopside prisms in the intergranular clinopyroxene mats (Fig. 3). The felsic rock is cut by millimetre-wide veinlets consisting of (1) blades of feldspar and of diopside that nucleated on both walls and (2) rare, complexly zoned zoisite.

TABLE 1. BULK COMPOSITIONS OF RODINGITIZED FELSIC DYKE AND WALLROCK

	288c	1H	1A	1F	1G	1E	Harz.
SiO_2	61.61	56.84	53.66	39.89	53.60	51.77	41.55
Al_2O_3	14.22	12.51	13.18	13.06	1.68	5.43	0.31
FeO*	2.25	2.42	3.58	6.59	2.55	4.04	7.21
MgO	5.14	9.70	6.32	25.48	15.37	21.55	40.29
CaO*	7.44	13.65	17.43	2.72	25.57	13.15	0.34
Na_2O	3.74	0.26	0.11	0.08	0.54	0.18	0.06
K_2O	5.10	4.56	3.78	7.43	0.09	0.13	0.05
TiO_2	0.23	0.11	0.49	0.31	0.01	0.01	-
MnO	-	-	-	-	-	-	0.12
P_2O_5	0.11	0.11	0.11	0.21	0.09	0.06	-
H_2O (tot.)	-	0.20	1.59	4.82	0.18	4.36	9.48
total	99.84	100.36	100.25	100.59	99.68	100.68	99.31

288c: mildly rodingitized and Na-metasomatized felsic dyke rock. 1H: rodingitized felsic dyke rock in brecciated core zone. 1A: rodingitized felsic dyke rock at south edge of dyke. 1F: chloritic selvage (blackwall) at southern contact. 1G: rodingitized serpentinite (white rodingite, green halos around chromite grains. 1E: partly rodingitized serpentinite in hanging wall. * Total iron expressed as FeO. CaO values represent an average of XRF and AA determinations (XRF only for 288c and 1H). Harz.: 70% serpentinized harzburgite (Laurent 1975b).

The bulk composition resembles that of a syenite (Table 1). However, the relatively high Ca and Mg and somewhat low Al contents for

TABLE 2. CELL DIMENSIONS AND DERIVED COMPOSITIONAL AND STRUCTURAL PARAMETERS OF THE ALKALI FELDSPARS IN THE RODINGITIZED FELSIC DYKE, JEFFREY MINE

	a	b	c	α	β	γ	V	$\Delta 2\theta$	#	α^*	β^*	γ^*
288c	8.1331	12.7934	7.1539	94.089	116.619	87.774	663.75	0.012	20	86.541	63.464	90.443
(rock)	0.0014	0.0029	0.0011	0.034	0.014	0.023	0.15			0.029	0.014	0.014
288c	8.6062	12.9894	7.1990	90	115.905	90	723.91	0.026	20	90	64.095	90
(veinlet)	0.0033	0.0047	0.0026		0.041		0.36				0.041	
	8.1391	12.7859	7.1561	94.227	116.612	87.769	663.99	0.014	29	86.389	63.473	90.380
	0.0010	0.0023	0.0011	0.021	0.013	0.012	0.14			0.022	0.013	0.014
1H1	8.5893	12.9648	7.2171	90.595	115.955	87.814	722.08	0.015	54	90.402	64.049	92.142
(core)	0.0012	0.0014	0.0009	0.014	0.010	0.013	0.11			0.013	0.010	0.011
1A5	8.5854	12.9646	7.2168	90.964	116.032	88.025	721.35	0.018	10	89.891	63.984	91.727
(S. rim)	0.0053	0.0048	0.0021	0.153	0.055	0.053	0.60			0.157	0.055	0.063
1A2	8.5901	12.9695	7.2153	90.671	115.995	88.066	722.12	0.011	19	90.196	64.013	91.824
(veinlet)	0.0017	0.0016	0.0012	0.027	0.013	0.026	0.16			0.023	0.013	0.021

	N_{Or}	Δbc	$\Delta\alpha^*\gamma^*$	t_1O	Δ	ψ
288c	-0.023	0.936	0.958	0.947		1.051
(rock)		0.009	0.008			
288c	1.032	0.780		0.390		
(veinlet)		0.021				
	-0.020	0.966	0.961	0.963		1.123
		0.008	0.007			
1H1	0.975	0.964	0.944	0.954	0.920	
(core)		0.007	0.006			
1A5	0.953	0.962	0.855	0.909	0.560	
(S. rim)		0.019	0.019			
1A2	0.976	0.940	0.836	0.888	0.722	
(veinlet)		0.009	0.011			

Units: a, b, c and $\Delta 2\theta$ in Å, V in Å^3, α, β, γ, α^*, β^* and γ^* in degrees. # is the number of indexed lines used in the cell refinement. Composition N_{Or} is calculated from unit-cell volume, formulation of Stewart & Wright (1974); Δbc (= $t_1O + t_1m$) is obtained by the program of Blasi (1977), as is $\Delta\alpha^*\gamma^*$ (= $t_1O - t_1m$). The obliquity of a triclinic K-feldspar Δ is 12.5 ($d_{131} - d_{1\bar{3}1}$); in a plagioclase, ψ is the angular separation $2\theta_{131} - 2\theta_{1\bar{3}1}$, in degrees. Specimens are identified in the text.

a syenite suggest that 288c has been modified metasomatically. In particular, the presence of "vugs" in interstitial mats of fine-grained clinopyroxene and the universal observation of important desilication (Coleman 1977) suggest that quartz grains may have been removed by dissolution. The rock thus may have been granitic; granites constitute one of the three common rock types encountered in dykes in the Eastern Townships ophiolitic complex (see below).

TABLE 3. CELL DIMENSIONS OF THE CLINOPYROXENES IN THE RODINGITIZED FELSIC DYKE, JEFFREY MINE

	a	b	c	β	$a\sin\beta$	V	$\Delta 2\theta$	#
288c	9.7544	8.9665	5.2534	105.872	9.383	441.96	0.012	14
	0.0031	0.0017	0.0012	0.049		0.30		
1H4	9.7519	8.9286	5.2541	105.800	9.383	440.20	0.019	26
	0.0018	0.0020	0.0010	0.017		0.11		
1A5	9.7693	8.9517	5.2541	105.630	9.408	442.48	0.007	13
	0.0015	0.0017	0.0004	0.015		0.09		
1A2	9.7568	8.9262	5.2567	105.726	9.392	440.68	0.029	9
	0.0139	0.0078	0.0019	0.105		0.84		
1G1	9.7590	8.9329	5.2536	105.774	9.392	440.74	0.012	25
	0.0014	0.0013	0.0005	0.011		0.07		
1C4	9.7558	8.9318	5.2647	105.866	9.384	441.27	0.021	11
	0.0036	0.0040	0.0031	0.045		0.22		
1E1	9.7509	8.9271	5.2500	105.787	9.383	439.76	0.020	26
	0.0029	0.0018	0.0010	0.021		0.12		

Units: a, b, c, $a\sin\beta$ in Å, V in Å^3, β and $\Delta 2\theta$ in degrees. # is the number of indexed X-ray reflections used in the cell refinement. Specimens: 288c lightly metasomatized felsic dyke rock, 1H4 heavily rodingitized felsic dyke rock in the core of the dyke, 1A5 light grey rodingite towards the southern contact, 1A2 cross-cutting veinlet in specimen 1A, 1G1 white rodingite towards the northern contact, 1C4 brown selvage on the north side, 1E1 serpentinite beyond northern selvage.

Adjacent to a K-feldspar–diopside veinlet, 288c consists mainly of albite + augite. The albite is close to the end-member composition, but it is slightly disordered, as it plots away from the curve for Si,Al-ordered plagioclases in the β^*–γ^* diagram (Smith 1974). Cell dimensions [b, c, α^*, γ^*; 288c (rock), Table 2] can be used to calculate a value of t_1O, the proportion of Al in the T_1O position: 0.95 (1.00 for fully ordered albite). Martin (1973) has shown that such departures from complete Si, Al order are characteristic of albites that form by Na metasomatism of Ca-bearing plagioclases. The coexisting clinopyroxene (288c, Tables 3, 4) is a salite of composition $En_{36}Fs_{14}Wo_{50}$.

The cross-cutting veinlets contain orthoclase and albite in discrete grains; albite exceeds K-feldspar in volume. The orthoclase contains 0.79 Al distributed over the two T_1 positions. The a cell edge, which is very sensitive to composition, is unusually large [288c (veinlet), Table 2], suggesting the presence of significant Ba or Rb in the structure. Interestingly, the albite in the veinlet plots close to ordered $NaAlSi_3O_8$, suggesting that it did not form by replacement of oligoclase or andesine, as did the albite in the adjacent rock. The absence of "vugs" or tufts of fine-grained clinopyroxene in the veinlet suggests that quartz never was present, and that the mineral assemblage was deposited from the same hydrothermal fluid (*i.e.*, undersaturated with respect to quartz) believed to have caused rodingitization of the felsic dyke rock. Deposition occurred at subsolvus temperatures, as the two feldspars nucleated and grew separately. Although the veinlet minerals have re-equilibrated compositionally down to low temperatures, the K-feldspar is still monoclinic to X-rays.

Core of the rodingitized dyke rock

The pinkish core of the rodingite dyke (1H, Fig. 2) consists of 35 (vol.) % colorless clinopyroxene, 15% pink grossular and 50% orange-fluorescent white K-feldspar. In thin section, the rock appears thoroughly brecciated; the angular fragments, generally 2 mm but up to 1 cm across, consist of very turbid K-feldspar clasts. These are cemented by fracture-filling minerals (Fig. 4), chiefly disseminated euhedral to subhedral diopside prisms up to 0.5 mm long and K-feldspar that is markedly less turbid than in the fragments. Grossular occurs in clusters of anhedral, weakly birefringent crystals each up to 2 mm across; they contain diopside inclusions.

The turbid K-feldspar (Fig. 4) consists of nonperthitic low microcline (Table 2) characterized by a degree of Si,Al order close to the arbitrary limiting value chosen for intermediate microcline. Its t_1O (0.95) and its obliquity (0.92) fall significantly short of the values typical of well-ordered microcline. Albite is notably absent, and the microcline contains only 2.5 mol. % $NaAlSi_3O_8$ in solution. The coexisting clinopyroxene (1H4, Table 3) consists of diopside very close to end-member composition. The cell edge of the garnet, 11.8412(10) Å (refined using 15 indexed lines), suggests grossular (*i.e.*, devoid of hydroxyl). The fracture-healing clinopyroxene and K-feldspar were sampled in veinlets in the light grey rodingite that forms the southern edge (see below).

We interpret the absence of albite, the much better degree of Si,Al order of the K-feldspar and the intense turbidity of the microcline as reflections of thorough redistribution of potassium. This evidently followed the trend of Na metasomatism recorded in 288c; the apparent Si,Al disorder in the resulting microcline may be inherited from the partly disordered albites that formed during Na metasomatism of the felsic dyke rock, or may reflect Ca and Ba in the microcline structure (see below). The intense turbidity is due to fluid inclusions and voids that result mainly from dissolution of the microcline during K redistribution. Perhaps they also result from shrinkage during Si,Al ordering of a disordered K-feldspar that may have preceded the microcline during the early stages of disturbance. The limpid microcline (see below) that heals fractures (Fig. 4) presumably nucleated and grew as microcline after brecciation of the turbid assemblage.

The composition of the core (1H, Table 1) is characterized by high Ca, Mg, Al and K, as could be expected from the mineral assemblage present. Compared with the composition of 288c, Na has almost disappeared, Si and K have been depleted, and Ca has been added.

Light grey zone towards the southern contact

The light grey rodingite that forms the southern edge of the dyke (1A, Fig. 2) contains a fine-grained (< 0.5 mm) mixture of 70% clinopyroxene, 25% turbid K-feldspar and accessory prehnite in pink to brown anhedral crystals. The rock is cross-cut by dark green veinlets of clinopyroxene rimmed by coarser (~ 1 mm), less turbid microcline. Contact of this zone with the core is gradational: the clinopyroxene becomes more abundant and finer grained, and the brecciated feldspar gives way to the finer grained, disseminated variety.

The clinopyroxene that forms the bulk of this rock (1A5, Table 3) has cell dimensions that suggest $En_{37}Fs_{17}Wo_{46}$ (Turnock *et al.* 1973). The coexisting K-feldspar is intermediate microcline, distinctly less well ordered than the turbid microcline in the core zone: its t_1O and Δ are 0.90 and 0.56 (Table 2). A better cell refinement was obtained on the K-feldspar in the cross-cutting veinlet (1A2, Table 2); its t_1O and Δ values, 0.88 and 0.72, again indicate intermediate microcline. On the basis of cell volume, it apparently contains ~ 2 mol. % dissolved $NaAlSi_3O_8$ and is free of coexisting albite. However, it is Ca that is causing a decrease in cell volume: an electron-microprobe analysis indi-

TABLE 4. ELECTRON-MICROPROBE ANALYSES OF MINERAL PHASES IN RODINGITE

	1	2	3	4	5
SiO_2	53.02	63.15	41.99	42.24	1.34
Al_2O_3	0.99	18.24	16.50	15.35	11.20
FeO	8.44	0	8.77	5.49	20.73
MgO	12.15	0	16.37	21.73	10.86
CaO	23.96	0.54	0.20	0.52	0.14
Na_2O	-	0.04	0	0	0
K_2O	-	17.11	10.18	9.45	0
TiO_2	0.11	0	0.15	0	0.76
Cr_2O_3	0.13	0	1.34	0.20	55.04
MnO	1.05	0	0.40	0.03	0.27
Total	99.85	99.04	95.88	95.01	100.34

1. clinopyroxene in rodingite 288c, av. of 3 analyses: $En_{36}Fs_{14}Wo_{50}$.
2. microcline, south edge of dyke, unit 1A (also contains barium).
3. phlogopite adjacent to chromite grain, north-edge rodingite (1G).
4. phlogopite 1 mm farther from chromite grain. Reported H_2O-free.
5. chromite grain in north-edge rodingite, unit 1G.

cates 0.04% Na_2O, 0.54% CaO (Table 4) and comparable quantities of barium. This amount of calcium is close to the upper limit reported for microclines (Smith 1974). Both Ca and Ba account for part (but probably not all) of the departure from an ordered Si,Al distribution. Coexisting with this relatively calcic microcline in the veinlet is relatively pure diopside (Table 3).

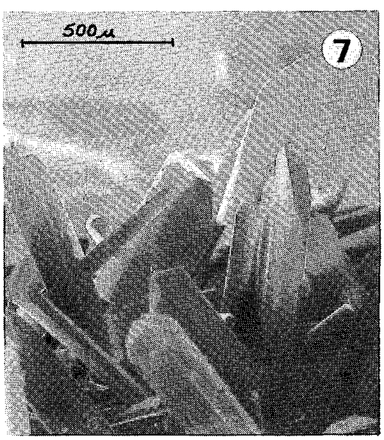
The bulk composition of the rodingite along the southern edge (1A, Table 1) is similar to that in the core; the lower K, Mg and higher Ca, Fe, Ti contents reflect (1) the modal proportion of microcline to salite, (2) the composition of the metasomatic clinopyroxene and (3) the presence of prehnite. The trends developed from 288c to 1H are sustained in 1A.

White rodingite towards the northern contact

The white rodingite developed in the direction of the northern contact (1G, Fig. 2) consists almost entirely of a dense, porcellaneous mass of wispy, prismatic clinopyroxene crystals up to 0.1 mm long. These are randomly oriented, aligned in swirls or, more rarely, in radiating clusters up to 3 mm across. Accessory black specks in the white rock (Fig. 5) are chromite grains; these euhedral to subhedral fractured crystals, up to 2 mm across, commonly have an emerald-green halo of chromium-bearing grossular and chromian phlogopite (Fig. 6). The most intense green coloration occurs immediately adjacent to or in fractures in crystals of chromite.

The main mineral in this white rodingite is a diopside whose cell dimensions suggest $\sim$ 5 mol. % Hd component (1G1, Table 3). An average of several microprobe analyses shows $<$ 2% FeO. The chromite grains are compositionally homogeneous (Table 4). The chromium was released by chemical corrosion along the planar faces and migrated very short distances: microprobe analyses of phlogopite indicate approximately 1.4% Cr_2O_3 at a distance of 0.1 mm from the grain boundary and 0.20% at a distance of 1 mm from the chromite (Table 4). The greenest garnet found in the rock is not uvarovite (a = 12.00 Å: Deer *et al.* 1966), as its cell edge (based on 16 indexed lines) is 11.8489(9) Å. Very little Cr thus is needed to impart a deep green color to grossular. Colorless phlogopite and grossular [a 11.8490(6) Å based on 15 indexed lines] occur away from the chromite specks. A different colorless Ca, Al-rich garnet [a 11.8926(18) Å, based on 7 indexed reflections] occurs in this rock near the contact with the brown selvage. Note that the cell edge exceeds that found in grossular. From the curve of Yoder (1950), this colorless garnet would appear to be hydroxyl-bearing and intermediate between grossular and hibschite. The occurrence of grossular and OH-bearing grossular in adjacent specimens may be a sign of metastability.

The contact between the white rodingite and the pink core is marked by the disappearance of microcline. Green, pink and cinnamon-brown grossulars occur near this contact; the euhedral and transparent crystals up to 1 mm across line



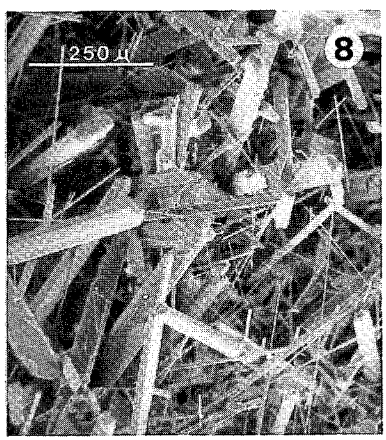


FIG. 7. Bladed diopside crystals from fracture in rodingite from northern edge. Specimen 1G.

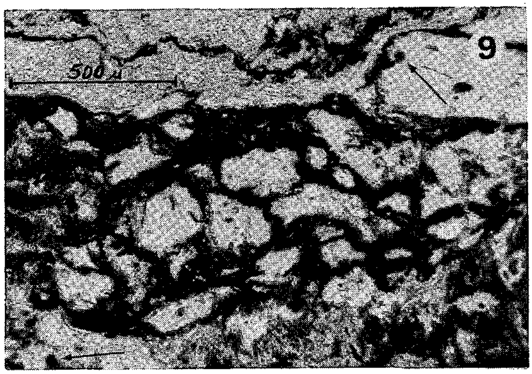
FIG. 8. Acicular diopside crystals from vug in rodingite from northern edge. Specimen 1G. A few of these crystals are hollow.

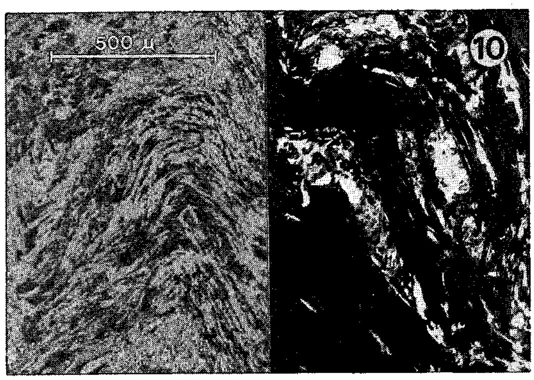
small cavities. Some exhibit a green core and cinnamon-brown margins, suggesting that they overgrew a chromite nucleus. Fractures in the diopside-rich rodingite also are lined with colorless to green grossular dodecahedra up to 1 mm across, as well as yellow-green euhedral blades of diopside up to 4 mm long (Fig. 7). Cavities are filled with extremely fine, acicular, colorless diopside crystals that form loose, porous masses (Fig. 8). These hair-like crystals also are euhedral and, in rare instances, apparently hollow. Such peculiar habits presumably reflect rapid crystallization from supersaturated solutions in the cavities, as is documented for apatite by Argiolas & Baumer (1978).

The bulk composition of the white rodingite (1G, Table 1) is atypically low in Al and high in Si, Mg. The rock, which could be called a metasomatic clinopyroxenite, clearly was a peridotite, in view of the relict chromite specks; the original host rock along the northern contact of the felsic dyke was evidently thoroughly rodingitized.

The southern chlorite-rich rim

The southern rim (1F, Fig. 2) constitutes a blackwall of 40% chlorite (< 5 mm across; variety pennine), 40% green stilpnomelane and 10% disseminated acicular actinolite (< 0.2 mm long). These minerals occur within a mesh-like structure of opaque leucoxene and biotite (Fig. 9). Rare zircon grains ~ 0.2 mm across form pleochroic halos in the mica and chlorite. The stilpnomelane defines the foliation parallel to the dyke wall. The bulk composition of the rim (1F) is listed in Table 1.





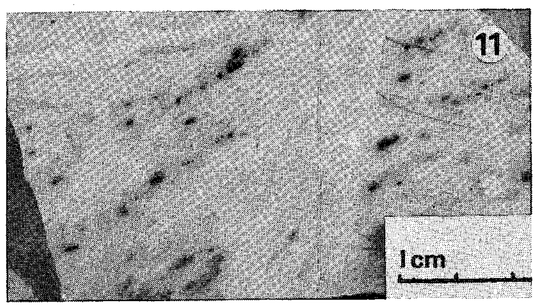


FIG. 9. Chlorite–stilpnomelane–actinolite assemblage in mesh texture of leucoxene and biotite. Arrows point to zircon-induced pleochroic halos in stilpnomelane. Specimen 1F, plane-polarized light.

FIG. 10. Folded clinochlore–diopside–garnet assemblage from northern selvage. Specimen 1C, plane-polarized light (left), crossed polars (right).

FIG. 11. Macroscopic appearance of partly rodingitized serpentinite. Specimen 1E.

The brown selvage on the north side and the adjacent hanging wall

Where present, this selvage (1C, Fig. 2) consists mainly of irregularly foliated, kinked and crenulated brown clinochlore (Fig. 10). Individual flakes attain 0.2 mm across, the axial surfaces of the microfolds are generally perpendicular to the dyke wall. Also locally important are fine-grained diopside (1C4, Table 3), interstitial (~ 15%) or in narrow veinlets, disseminated grossular [*a* 11.8585(6) Å, based on 10 indexed reflections] and minor brown mica. At the selvage–serpentinite contact, a dark green layer (~ 5 mm thick) of clinochlore invariably occurs.

The serpentinite beyond the brown selvage (1E, Fig. 2) has been metasomatized for at least 0.5 m. The diffuse veinlets that cross-cut the serpentinite (Fig. 11) contain fine grained prismatic diopside and traces of clinochlore. The cell dimensions of the pyroxene (1E1, Table 3) are consistent with nearly end-member diopside. In contrast to the adjacent speckled white rodingite, the chromite here is barely affected, but the textures of the two rocks are similar (Figs.

5, 11). The bulk composition (1E, Table 1) shows that Ca and Si have been introduced, whereas H_2O and Mg are lower than expected in a serpentinized harzburgite.

Bulk-Composition Changes During Rodingitization

The bulk compositions in Table 1 are plotted on an ACF diagram (Fig. 12) to show the effects of progressive rodingitization of two very different rock types. One path is curved from an average calc-alkaline granite composition through 288c to rodingites 1H and 1A. The curved path marks a strong, early magnesium-enrichment trend in 288c, due to initial crystallization of a salitic clinopyroxene as the only calc-silicate phase. Sample 1A is the most rodingitized rock; although it is alkali-rich and does not fit within the "rodingite field" delineated by Coleman (1977), the trend towards that field is nevertheless obvious.

Rodingites 1E and 1G were formed at the expense of serpentinite. The main elements added here are Ca and Si; the magnesium required to form diopside was derived from the breakdown of serpentinite. The felsic dyke undoubtedly provided the Si.

The fluids responsible for the observed rodingitization were strongly alkaline, presumably Ca-, Al-, OH-bearing (Barnes & O'Neil 1969).

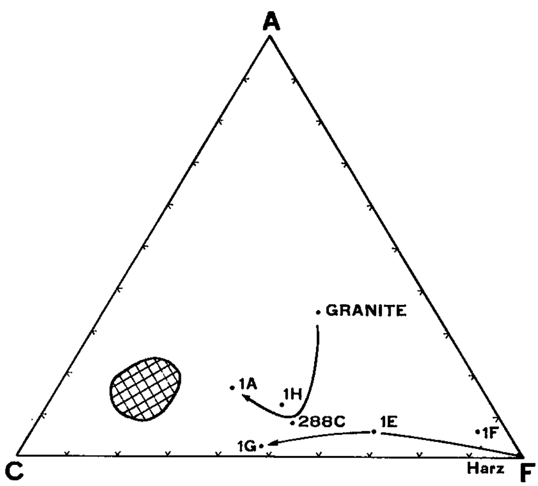


Fig. 12. ACF plot of dyke rocks showing metasomatic trends. Both granite and serpentinite converge toward the "rodingite field" delineated by Coleman (1977).

The K-feldspar in the calc-silicate assemblage clearly is in its field of stability, and is devoid of sericitic alteration. The inability of the K-feldspar to order completely in the presence of such an alkaline fluid phase (Martin 1973) must reflect in part the short-lived nature of the metasomatic events, in part the presence of divalent cations in the structure. In spite of this, the fluids must have been particularly supersaturated with respect to diopside, presumably in view of a high local activity of Si (relative to the serpentinite mass as a whole), to effect important metasomatic transformation of the hanging-wall serpentinite during the episodes of rodingitization. The high activity of Si in the fluid phase may also account for the predominance of grossular (over hydrogrossular) in these rodingites. This aspect clearly merits further study, especially since rodingitized basic dykes in the Jeffrey mine do contain hydrogrossular (Wares & Martin, unpubl. data on dyke 3, Fig. 1).

Discussion

Three distinct groups of intrusive rocks emplaced in the ultrabasic part of the ophiolitic complex have been recognized (Laurent & Hébert 1979): (1) thoroughly rodingitized gabbroic dykes, (2) deformed, partly rodingitized hornblende diorite and (3) late, relatively undeformed dykes of granite, emplaced once the peridotites had been serpentinized but before the formation of chrysotile fibres. The rodingitized felsic dyke described here probably belongs to the youngest group, emplaced in partly serpentinized rock but itself not foliated. The brecciated aspect of the core zone of the dyke and the presence of fracture-healing veinlets containing rodingitic mineral assemblages show that deformation occurred after dyke emplacement and after initial rodingitization. Renewed serpentinization of the broken-up harzburgite tectonite after obduction onto the continental margin may be responsible for renewed rodingitization of the dyke rock (especially along the south edge) and of the adjacent hanging wall. The timing of the second generation of rodingitization may thus correspond to the second episode of serpentinization in the fractured host rock and to deposition of the asbestos veins. Laurent (1975b) has shown that movement accompanied asbestos mineralization in some vein systems, with the orientation of the growing fibres controlled by the direction of minimum shear stress.

The first metasomatic event that occurred after emplacement involved mild Na metasomatism. This may indicate that the event occurred on the sea floor, during the cooling of the dyke rock. More information must be obtained on this stage of dyke evolution to ascertain the environment of early metasomatism. There then followed a reversal in the pattern of metasomatism, in which Ca and minor Ba were introduced at the expense of Na, and K was redistributed. There is evidence for the initial crystallization of a monoclinic K-feldspar, which then suffered brecciation. The brecciated, turbid feldspar is low microcline, in which the slight apparent departure from fully ordered low microcline may largely be due to compositional factors (*e.g.*, Ca, Ba in the structure). Where rodingitization is more advanced, as along the southern edge, the microcline falls far short of the fully ordered configuration, having crystallized during the second period of rodingitization. The data acquired on the pyroxenes suggest that the metasomatic salite containing significant quantities of Fe gives way to almost pure diopside in the more advanced stages of rodingitization.

Most cases of rodingitization described in the literature involve the Ca metasomatism of basic rock types. The southeastern Québec ophiolites seem anomalous in the importance of granite dykes and plugs that were presumably emplaced during an episode of calc-alkaline magmatism, when the ophiolite sequence had become involved in subduction-related events. The resulting rodingites are unusual in that they show the close association of Ca, Mg and K in low-temperature metasomatic assemblages. The source of calcium required for rodingitization is usually attributed to the surrounding serpentinized harzburgite and cumulate dunite, in view of the inability of the serpentine structure to accept this element. The dyke rocks constitute an environment of high Si activity that is favorable to the formation of calc-silicate assemblages.

This occurrence of rodingite is unusual in another respect: it seems to be the first documented case of completely rodingitized serpentinite. At first glance, it may seem contradictory to propose rodingitization of a rock that is the *raison d'être* of the rodingitic suite. The only way to explain this odd occurrence in the hanging wall of the granite dyke is to propose (1) rodingitization by fluids of unusually high Si activity in which serpentinite was unstable and (2) renewed Ca metasomatism after the first episode, presumably as a result of more complete serpentinization in nearby peridotites. That rodingitization is not symmetrically developed suggests that the fluids infiltrated unidirectionally, upward through the dyke. This would account for (1) the much more diffuse upper (northern) margin (Fig. 2), (2) the precipitation of phlogopite in the serpentinized hanging-wall peridotite, (3) local enrichment of the fluid in K and Si by interaction with the felsic dyke rock and (4) more thorough rodingitization of the southern (lower) edge.

The green chloritic selvage on the south side probably represents early, localized Mg metasomatism of the dyke rock rather than metasomatized serpentinite; this would explain the occurrence of zircon crystals in the selvage. Such a thin chloritic blackwall commonly develops around bodies of foreign material intruded or tectonically incorporated into the serpentinized parts of ophiolitic complexes (Vuagnat 1953). This blackwall probably formed soon after the first period of serpentinization and rodingitization; we consider that it had an equivalent along the northern contact: the sporadically developed, contorted brown selvage found beyond the green-speckled, white rodingitized serpentinite. This hypothesis implies that much rodingitization of serpentinite did occur during the first episode. The northern selvage was later highly modified by oxidation, dissolution and metasomatism during the second episode of rodingitization. The brecciated core zone would have provided the avenue for efficient infiltration of K-, Ca-bearing alkaline fluids that continued the metasomatic transformation of the hanging wall well beyond the original blackwall rim.

Our study shows that a dyke, probably belonging to the youngest generation of minor intrusions in the area, locally has been thoroughly metasomatized by infiltration in at least two stages, and that the resulting rodingite is anomalously K-rich. Thus, not only the older dykes of gabbro and diorite show two distinct episodes of rodingitization (*cf.*, Laurent & Hébert 1979). Rodingites should not be so narrowly defined as to exclude such alkali-rich compositional variants. More investigations of this type will be needed to categorize the rodingites, to establish criteria diagnostic of specific parent-rock lithologies, to evaluate the temperature and pressure of the metasomatic events, and to study the link between localized low-temperature Na, Ca and Mg metasomatic events and widespread K metasomatism that led to the formation of reddish-brown biotite in the older intrusive rocks (Olsen 1961, De 1972).

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References

Argiolas, R. & Baumer, A. (1978): Synthèse de chlorapatite par voie hydrothermale: étude de l'influence de la sursaturation sur l'évolution des faciès des cristaux. *Can. Mineral.* **16**, 285-290.

Barnes, I. & O'Neil, J.R. (1969): The relationship between fluids in some fresh alpine-type ultramafics and possible modern serpentinization, western United States. *Geol. Soc. Amer. Bull.* **80**, 1947-1960.

Blasi, A. (1977): Calculation of *T*-site occupancies in alkali feldspar from refined lattice constants. *Mineral. Mag.* **41**, 525-526.

Coleman, R.G. (1977): *Ophiolites: Ancient Oceanic Lithosphere?* Springer-Verlag, New York.

De, A. (1961): *Petrology of Dikes Emplaced in the Ultramafic Rocks of Southeastern Quebec.* Ph.D. thesis, Princeton Univ., Princeton, N.J.

——— (1972): Petrology of dikes emplaced in the ultramafic rocks of southeastern Quebec and origin of the rodingite. *Geol. Soc. Amer. Mem.* **132**, 489-501.

Deer, W.A., Howie, R.A. & Zussman, J. (1966): *Introduction to the Rock-forming Minerals.* Longmans, London.

Evans, B.W. (1977): Metamorphism of alpine peridotite and serpentinite. *Ann. Rev. Earth Planet. Sci.* **5**, 397-447.

Graham, R.P.D. (1917): Origin of massive serpentine and chrysotile asbestos, Black Lake–Thetford area, Quebec. *Econ. Geol.* **12**, 154-202.

Laurent, R. (1975a): Occurrence and origin of the ophiolites of southern Quebec, northern Appalachians. *Can. J. Earth Sci.* **12**, 443-455.

——— (1975b): Petrology of the alpine-type serpentinites of Asbestos and Thetford Mines, Quebec. *Schweiz. Mineral. Petrog. Mitt.* **55**, 431-455.

——— & Hébert, Y. (1979): Paragenesis of serpentine assemblages in harzburgite tectonite and dunite cumulate from the Québec Appalachians. *Can. Mineral.* **17**, 857-869.

Martin, R.F. (1973): Controls of ordering and subsolidus phase relations in the alkali feldspars. *In* The Feldspars (W.S. MacKenzie & J. Zussman, eds.), Manchester University Press, Manchester, England.

Olsen, E.J. (1961): High temperature acid rocks associated with serpentinite in Eastern Quebec. *Amer. J. Sci.* **259**, 329-347.

Riordon, P.H. (1975): Geology of the asbestos deposits of southeastern Québec. *Ministère des Richesses Naturelles du Québec, Services des Gîtes Minéraux, Etude Spéciale* **18**.

Smith, J.V. (1974): *Feldspar Minerals. 2. Chemical and Textural Properties.* Springer-Verlag, New York.

Stewart, D.B. & Wright, T.L. (1974): Al/Si order and symmetry of natural alkali feldspars, and the relationship of strained cell parameters to bulk composition. *Soc. franç. Minéral. Crist. Bull.* **97**, 356-377.

Turnock, A.C., Lindsley, D.H. & Grover, J.E. (1973): Synthesis and unit cell parameters of Ca–Mg–Fe pyroxenes. *Amer. Mineral.* **58**, 50-59.

Vuagnat, M. (1953): Sur un phénomène de métasomatisme dans les roches vertes du Montgenèvre (Hautes-Alpes). *Soc. franç. Minéral. Crist. Bull.* **76**, 438-450.

Yoder, H.S., Jr. (1950): Stability relations of grossularite. *J. Geol.* **58**, 221-253.

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