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RODINGITIZATION OF DYKE ROCKS AND ENCLOSING SERPENTINITES IN THE JEFFREY MINE, QUEBEC APPALACHIANS

BY

Robert P. WARES [1] and Robert F. MARTIN [1]

ABSTRACT

Unusual rodingites have been found in the Jeffrey mine (Asbestos, Québec). In one felsic dyke, the repeated introduction of Ca has led to two generations of diopside-microcline assemblages. The fluid phase was modified by interaction with the dyke material so that it could efficiently replace serpentine in the wall rocks; the resulting rodingites are diopside-rich and contain relict chromite grains. Another body of rodingite attained an unusually calcic composition, reflected in its high wollastonite content; a third, originally a porphyritic basic rock, shows clear signs of metastability in the garnet assemblages of the most thoroughly transformed specimens. Rodingites can be expected to shed light on the sequential development of 1) serpentinization reactions in the enclosing rocks and 2) tectonic disruptions during emplacement of the ophiolite complex of southeastern Québec.

INTRODUCTION

The ophiolitic complex exposed in the Eastern Townships of southeastern Québec seems anomalous in the number of dykes and rootless blocks found in the tectonized peridotites and cumulate dunites. Three distinct episodes of dyke activity 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 after the serpentinization of the host rocks but before the formation of the economically important fibrous chrysotile. Dykes belonging to the third category also are subject to rodingitization, however. We provide here a summary of our detailed mineralogical and petrochemical investigation of three dykes and affected wallrocks from the Jeffrey mine, Asbestos, Québec (Fig. 1). One is interpreted to be a rodingitized granite dyke, the second is of indeterminate origin, whereas the third seems to have been a porphyritic basic rock. Wares

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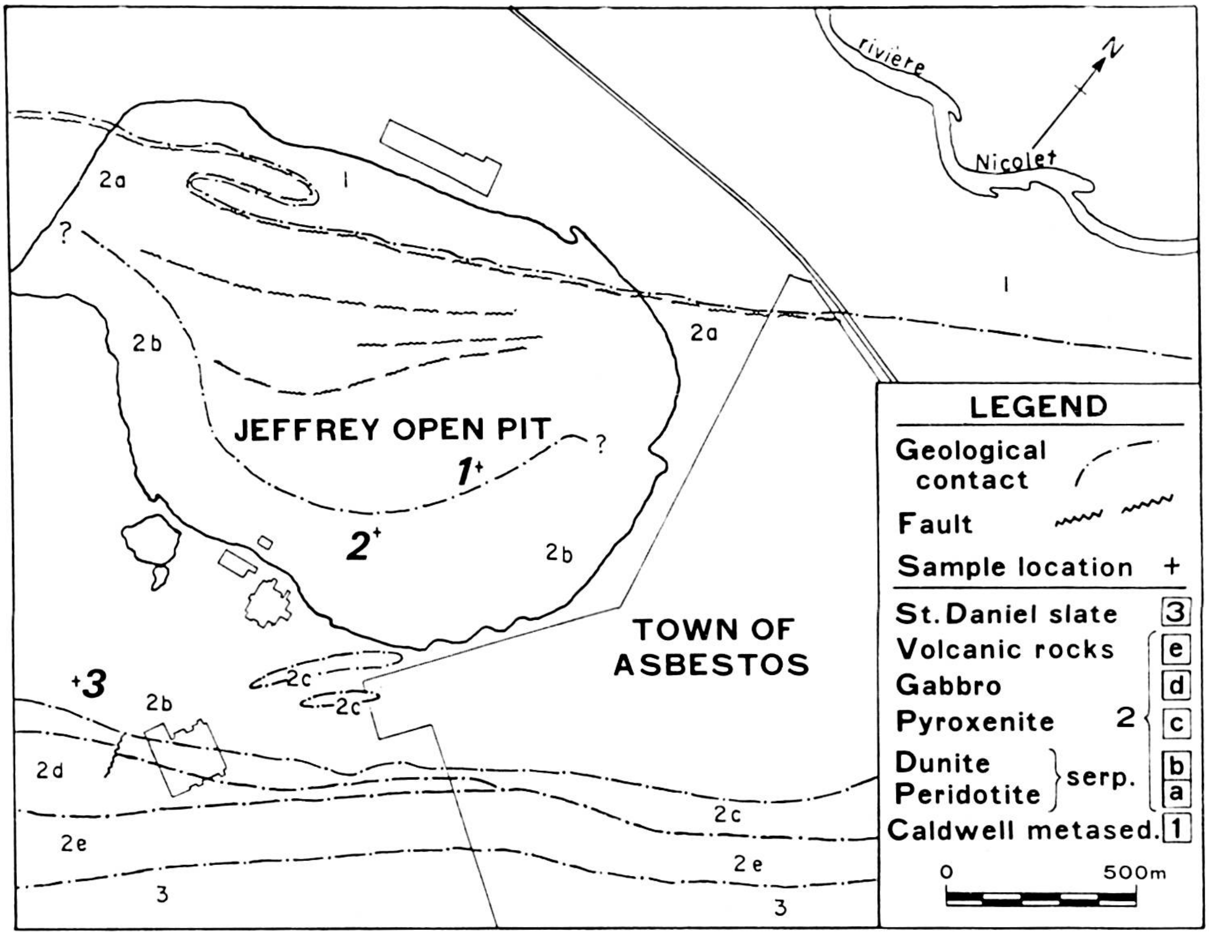

FIG. 1.—Geology of the Jeffrey mine area, adapted from a Canadian Johns Manville Co. map. Dyke 1 occurs in serpentinized harzburgite tectonite, whereas dykes 2 and 3 are emplaced in dunitic cumulates.

& Martin (1980) document the mineralogical and chemical changes in dyke 1, in which rodingitization reactions lead to unusual K-, Ca-rich assemblages. We present here a summary of our findings on dyke 1, and provide mineralogical and chemical data relevant to the evolution of dykes 2 and 3.

METHODS USED

Our investigation was designed to better characterize the rodingitic assemblages. De (1961, 1972) and Olsen (1961) had contributed to the question, but in many cases, their approach did not permit full identification of mineral assemblages in these fine-grained products of Ca metasomatism. We chose detailed powder X-ray-diffraction studies to determine the mineralogical assemblages, using a Guinier-Hägg focusing camera, Cu $K\alpha_1$ radiation, and a synthetic spinel internal standard (a 8.0833 Å at room temperature). Unit-cell refinements were performed wherever possible (program of Appleman & Evans 1973). This approach was supplemented by electron-microprobe analyses of individual mineral grains and by bulk-rock compositions obtained by X-ray fluorescence. Calcium analyses were checked by atomic absorption.

DYKE 1

Most of this prominent north-dipping E-W dyke, emplaced in serpentinized harzburgite in the eastern part of the pit (Fig. 1), has been removed by mining operations. Where sampled, it is conspicuously zoned across its 2 m width; we also had the benefit of a specimen (288c of R. Laurent) believed taken from the same dyke in a less rodingitized portion (F. Spertini, pers. comm. 1978).

Specimen 288c contains 30% (vol.) turbid microcline, 20% limpid microcline, 30% zoned plagioclase, and 20% clinopyroxene in fine-grained mats that mask the original grain boundaries and replace plagioclase cores. The presence of vugs in these mats suggests that quartz may have been removed by dissolution. The sodic plagioclase is albite which departs somewhat from the fully ordered form expected at low temperatures; the departure suggests an origin by albitization of plagioclase. The clinopyroxene is a salite of composition $En_{36}Fs_{14}Wo_{50}$ (determined by electron microprobe). The bulk composition resembles that of a syenite, but its low Al and high Ca + Mg suggest that the rock may represent a metasomatized granite, presumably a dyke rock belonging to the youngest of the three generations of dyke emplacement.

Millimetre-wide veinlets of less turbid orthoclase, well-ordered albite and bladed diopside crystals cut rock 288c. The coexisting feldspars are present in discrete grains, which suggests deposition at low temperatures. The absence of vugs indicates that quartz was not present in the veinlets and that this late-formed assemblage deposited from a fluid phase involved in rodingitization.

In the area sampled, dyke 1 is heavily rodingitized. Its brecciated pinkish core contains 35% clinopyroxene, 15% pink grossular and 50% white K-feldspar. The K-feldspar fragments are highly turbid low microcline; albite is absent. The clinopyroxene healing the fractures is close to end-member diopside, and the grossular seems hydroxyl-free. In this strongly metasomatized felsic dyke rock, K has been redistributed and Na has been removed. Turbidity in the feldspar reflects a dense network of fluid inclusions that result from volume shrinkage during dissolution and Si-Al ordering. Also healing the fractures are a new generation of clear low microcline.

Near the southern edge of the dyke, the rodingite is a light grey, fine grained mixture of clinopyroxene (70%, composition close to $En_{37}Fs_{17}Wo_{46}$ as inferred from the plots of Turnock *et al.* 1973), turbid intermediate microcline (25%, Ca and Ba relatively high, Na absent) and accessory prehnite. This rodingite is cut by diopside—intermediate microcline veinlets that presumably deposited directly from the fluid phase responsible for rodingitization.

A strikingly different rodingite is found towards the northern contact, near the hanging wall. The rock there consists dominantly of white diopside [$\sim$5 mol. % Hd component] in which are set black chromite specks that have an emerald green halo of chromium-bearing grossular and chromian phlogopite (Fig. 2). In contrast, the

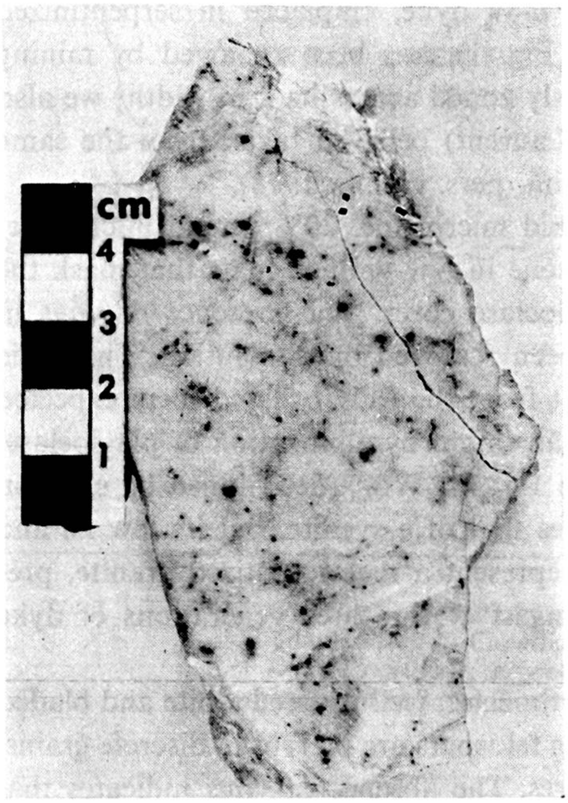

FIG. 2.—White rodingitized hanging-wall serpentinite showing the specks of relict chromite. Each speck has an emerald green halo of chromium-bearing grossular and chromian phlogopite.

grossular near the edge of the dyke is colorless and contains more hydroxyl, on the basis of cell dimensions. We interpret this rock as a metasomatized peridotite in which the surfaces of the chromite grains have been attacked by a K, Ca-rich fluid phase. Cavities in this rodingite contain finely acicular diopside crystals: the habit of the second-generation diopside indicates rapid crystallization under conditions of high supersaturation.

The edges of the dyke are marked by distinct selvages. The southern rim consists of a mixture of chlorite, stilpnomelane, actinolite, with accessory leucoxene and biotite. This rock is interpreted to have formed by local, early Mg metasomatism of the felsic dyke material. The northern edge shows a much less regular chlorite rim that has been extensively deformed and metasomatized; it is locally cut by grossular-diopside veinlets. Beyond this selvage, in the hanging wall, the serpentinite also shows signs of partial conversion to a diopside-rich assemblage over a distance of 0.5 m.

Chromite grains here do not seem to have been attacked, as the green halos are absent.

The compositional changes, revealed by X-ray-fluorescence analyses, are shown in Figure 3 in terms of an ACF triangular plot. One path illustrates the metasomatism

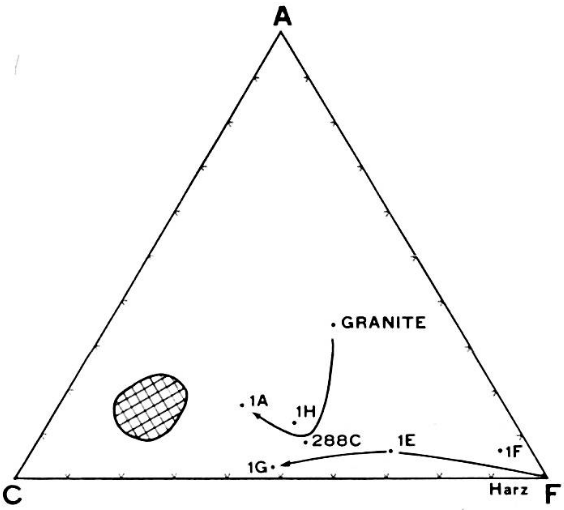

FIG. 3.—ACF triangular diagram showing the evolution of a felsic dyke rock and the hanging-wall serpentinite (labeled Harz) to wards the field of rodingite compositions (after Coleman 1977). The bulk composition of the protolith of dyke 1 is considered to have been close to that of the average calc-alkaline granite (labeled GRANITE).

of a felsic composition (from an average calc-alkaline granite to 288c to rodingites 1H (core) and 1A (southern edge). This curved path marks strong Mg-enrichment, owing to initial formation of clinopyroxene. Rodingite 1A falls short of the "rodingite field" of Coleman (1977) but the pattern of evolution is clearly in that direction. Rocks 1E (partly rodingitized hanging-wall) and 1G (green-speckled metasomatized serpentinized peridotite) follow a different trend; we contend that in this case, Mg was supplied *in situ* by serpentine, Ca was introduced in spite of having been released from peridotites elsewhere in the system, and Si was derived from the felsic dyke rock.

DYKE 2

The second dyke rock sampled in our study occurs approximately 400 m southwest of dyke 1, just south of the harzburgite-dunite contact (Fig. 1). It strikes in a southerly direction and is approximately 1 m wide. The rodingite is light grey to tan, massive, aphanitic and irregularly crosscut by white veinlets up to 2 m across. The fibrous mineral in these veinlets and in the massive rodingite is wollastonite (2Dl, Tables 1, 2). The rodingite also contains accessory slightly birefringent grossular (25% by volume) and fine grained diopside (10%). The cell edge of this grossular is 11.8575(9) Å (based on 15 indexed diffraction lines). Chloritic rims are absent along either side of the dyke. Instead, completely gradational contacts with the enclosing serpentinite are found; the light grey rodingite found in the 10-cm-wide transition zones contain black chromite specks, commonly with emerald green halos as seen

TABLE 1.—*Rock and mineral analyses, Dykes 2 and 3*

	1	2	3	4	5	6	7	8	9
SiO_2	51.24	55.81	53.02	53.37	30.73	44.58	44.30	47.99	40.71
Al_2O_3	0.00	5.04	3.08	0.00	16.82	10.53	8.88	4.76	12.80
FeO	0.06	0.81	1.85	2.92	12.53	9.28	7.21	4.96	6.64
MgO	0.07	0.27	7.82	18.69	27.86	19.40	19.64	12.51	8.07
CaO	48.14	37.65	34.22	24.94	0.29	11.72	15.31	28.52	30.53
Na_2O	0.00	0.15	0.28	0.00	0.00	0.00	0.18	0.00	0.00
K_2O	0.79	0.03	0.02	0.45	0.06	0.28	0.04	0.02	0.20
TiO_2	0.00	0.30	0.01	0.00	0.00	0.00	0.18	0.05	0.14
Cr_2O_3	0.17	—	—	0.07	0.25	0.80	—	—	—
MnO	0.00	—	—	0.18	0.29	0.31	—	—	—
P_2O_5	—	0.30	0.11	—	—	—	0.06	0.10	1.08
H_2O (total)	—	0.22	0.11	—	—	—	4.90	0.50	—
Total	100.47	100.58	100.52	100.62	88.83	96.90	100.70	99.41	100.17

Specimens: 1. wollastonite 2D1 from centre of dyke 2; average of 3 microprobe analyses. 2. rodingite 2D, centre of dyke 2; XRF analysis. 3. rodingite 2C, contact zone of dyke 2; XRF analysis. 4. fine grained diopside occupying metasomatized phenocrysts in rodingite 3C; average of 3 microprobe analyses. 5. chlorite in specimen 3C, from rims around pseudomorphs; average of 3 microprobe analyses. 6. amphibole after primary pyroxene in phenocrysts in specimen 3C; average of 2 microprobe analyses. 7. rodingite 3C, dyke 3; XRF analysis. 8. fracture-filling assemblage 3E, dyke 3; XRF analysis. 9. rodingite 227, dyke 3; XRF analysis, reported water-free.

TABLE 2.—*Cell dimensions of diopside and wollastonite in Dykes 2 and 3, Jeffrey mine*

	a	*b*	*c*	*α*	*β*	*γ*	*V*	*Δ2θ*	#
wollastonite 2D1	7.9211	7.3207	7.0641	90.045	95.228	103.338	396.82	0.008	36
	0.0005	0.0005	0.0005	0.006	0.006	0.006	0.03		
diopside 2C1	9.7652	8.9335	5.2506	90	105.715	90	440.93	0.021	25
	0.0025	0.0021	0.0012		0.020		0.13		
wollastonite 2C2	7.9237	7.3226	7.0666	90.108	95.290	103.354	397.12	0.013	22
	0.0018	0.0015	0.0011	0.023	0.017	0.021	0.13		
diopside 3A2	9.7693	8.9351	5.2547	90	105.806	90	441.34	0.026	14
	0.0065	0.0030	0.0017		0.061		0.33		
diopside 3D1	9.7570	8.9352	5.2538	90	105.752	90	440.83	0.015	23
	0.0016	0.0011	0.0010		0.019		0.09		

Units: *a*, *b* and *c* in Å, *V* in $Å^3$, α, β, γ and Δ2θ in degrees. # is the number of indexed X-ray reflections used in the cell refinement. Specimens: 2D1 sampled in centre of dyke 2, 2C1 and 2C2 sampled near the edge. 3A2 and 3D1 are the diopsides found in the metasomatized "phenocrysts" in dyke 3.

in dyke 1. The transition zones are characterized by iron-bearing diopside (50% by volume; Table 2, 2C1), wollastonite (40%; Table 2, 2C2), minor grossular [11.8700(11) Å based on 12 indexed lines, consistent with a slight enrichment in OH over the grossular in the centre of the dyke] and chromite. Diopside progressively becomes the predominant phase in the direction of the serpentinized dunite. The massive diopside then gives way to veinlets and porphyroblasts of diopside in serpentinite; grossular occurs only rarely as anhedral grains <0.5 mm across near the serpentinite.

The rodingites of dyke 2 are unusually calcic (2D, Fig. 4, Table 1), owing to the modal prominence of wollastonite. Unfortunately, the composition of the parent rock cannot be discerned on the basis of observed textures. The absence of microcline suggests that the dyke was not as "differentiated" as the first example in our study. The metasomatized serpentinite wallrocks (2C, Fig. 4, Table 1) seem more thoroughly rodingitized than analogous material in dyke 1, if the modal proportion of wollastonite and grossular to diopside is considered as a criterion.

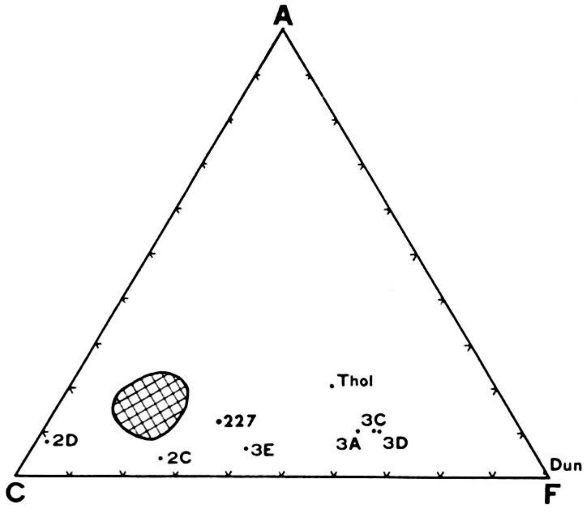

FIG. 4.—ACF triangular diagram showing the evolution of two dyke rocks (2 and 3) and adjacent metasomatized wall-rock serpentinite towards (and in one case, beyond) the compositional field of rodingites (after Coleman 1977). Rodingite 2C formed at the expense of the dunitic host rocks (labeled Dun). The rodingites of dyke 3 formed at the expense of a porphyritic basic rock whose composition is represented by an average tholeiitic basalt (Thol). The evolutionary trend culminates in rodingite 227, in which two distinct hydrogrossulars coexist.

DYKE 3

Dyke 3 is poorly exposed along a small road-cut near the mill (Fig. 1). Only one contact with serpentinized dunite can be seen; there is evidence of movement along this contact, such that this "dyke" may be a boudin. Internal deformation is not readily apparent, but numerous cream-white veins crosscut the rodingite in all directions.

Perhaps owing to lack of adequate exposure, textural and mineralogical features seem heterogeneously developed. The rock is generally light green, porphyritic, consisting of chlorite-rimmed "phenocrysts" up to 1 cm across. These contain fine grained diopside (anal. 4, Table 1) set in a matrix of diopside + chlorite + hydrogrossular (Fig. 5). In some specimens poor in hydrogarnet, relics of a calcic, aluminous amphibole are found (anal. 6, Table 1). This phase may represent an early product of replacement of a primary pyroxene phenocryst, a proposal based largely on the habit of the pseudomorph. The chlorite rims shown in Figure 5 (anal. 5, Table 1) presumably represent a by-product of the early metasomatism of the primary phenocrystic phase. Mere ghosts of these rimmed phenocrysts can be discerned in specimens of dyke 3 that have been thoroughly "garnetized". The garnet is hydrous, brownish, turbid and isotropic in thin section. Crystals are disseminated or form a network of veinlets where the process is incipient. An *a* cell edge of 11.9850(11) Å (based on 8 indexed diffraction lines) typifies the garnet in specimen 3C. In the chalky, more extensively garnetized specimens (*e.g.*, 227 provided by R. Laurent), coexisting garnets are recorded, even in very small samples of the fine grained matrix: 11.9169(10) and 11.9418(10) Å, based on 9 and 10 indexed lines, respectively. Random microprobe scans prove that these garnets contain only Ca and Al, such that the coexisting garnets must differ only in the extent of (H_4O_4)-for-(SiO_4) substitution. Disequilibrium crystallization at low temperatures probably accounts for the heterogeneity of the hydrogarnet in the most thoroughly metasomatized specimens. Fractures are lined

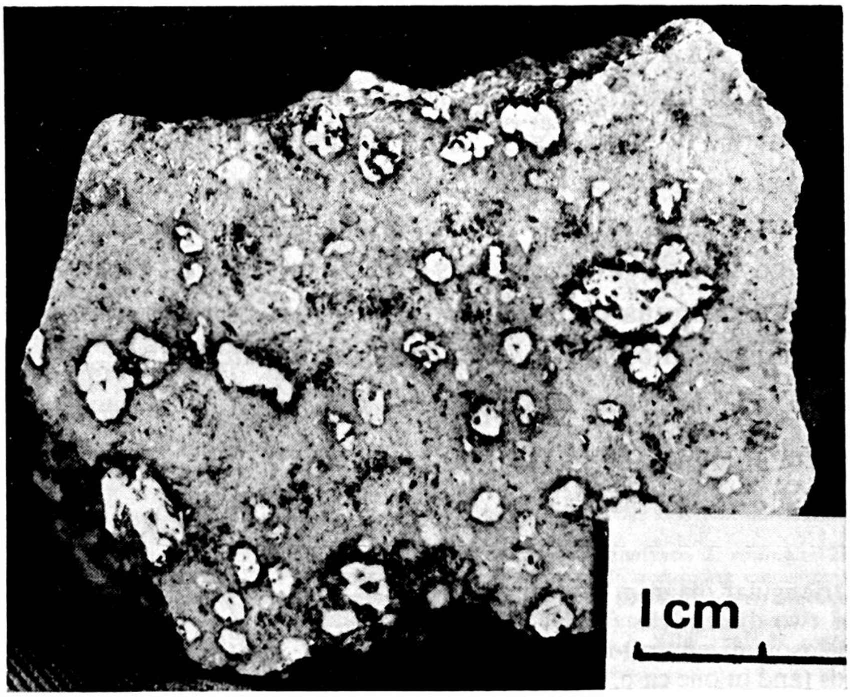

FIG. 5.—Chlorite-rimmed diopside pseudomorphs (after uralitized clinopyroxene) in chlorite-diopside groundmass (dyke 3, specimen 3B). More advanced rodingitization leads to compositions like 227 (Fig. 4), in which hydrogrossulars become dominant.

with an assemblage of diopside (70%), garnet (10%) and vesuvianite (20%) (rodingite 3E, Table 1). A clinopyroxene-phyric basalt may have been the original dyke rock.

The rocks in dyke 3 provide evidence of a changing pattern of metasomatism, in terms of an ACF plot (Fig. 4) and taking an average tholeiitic basalt composition as starting material. Early Mg enrichment (as in 3C) reflects the appearance of a magnesium-rich clinopyroxene. Massive replacement by hydrogrossular in more advanced stages of metasomatism (3E, 227) explains the shift in the direction of the rodingite field.

DISCUSSION

The brecciation observed in the rodingitized core of dyke 1 and the healing of these fractures by a second generation of diopside + microcline suggest that metasomatism occurred at least twice. The bulk composition of the dyke rock provided the source of potassium; calcium and magnesium were thus presumably released at least twice from the surrounding ultrabasic rocks undergoing serpentinization (*cf.*, Laurent & Hébert 1979). Perhaps because of the unusual composition of the fluid phase, even during the first episode of rodingitization, and as a function of the dip of dyke 1, the infiltrating fluid phase induced strong Ca-metasomatism above the basal contact and also affected the hanging-wall serpentinite. The high activities of Si and Ca required to lead to significant replacement of serpentine minerals by diopside above the dyke indicate that the fluid phase became modified by equilibration with the diopside-microcline assemblage in the felsic dyke rock.

Dyke 2 resembles dyke 1 in the importance of metasomatism of the surrounding serpentinites, a reflection of the local modification of the fluid phase so that it could dissolve serpentine. The absence of K-feldspar, however, suggests that dykes 1 and 2 probably do not belong to the same period of intrusive activity. The very strong calcium enrichment noted suggests that the fluids rose from the underlying harzburgite tectonite as it underwent serpentinization; the enclosing dunitic cumulates are not a likely source for the calcium. The apparent lack of brecciation in dyke 2 should not be considered as strong evidence that dyke emplacement postdated tectonic transport.

The original lithology of dyke 3 seems to have been basic; the dyke may thus be an example of the first generation of intrusive activity recognized by Laurent & Hébert (1979). Dyke 3 does show evidence of tectonic transport and of rodingitization that is both pre- and post-tectonic. As with dyke 1, therefore, the earliest episode of Ca metasomatism probably accompanied pervasive serpentinization on the sea floor. The economic deposits of the Eastern Townships are attributed to a second episode of serpentinization in which the chrysotile fibres healed fractures in the deformed ophiolitic rocks after their tectonic emplacement. It is interesting to note that rodingites, in their mineralogical diversity, may hold a clear record of the tectonic events that have shaped the evolution of the ophiolitic complex, which culminated in economic chrysotile mineralization.

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