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METAMORPHIC OLIVINE IN PERIDOTITIC KOMATIITE FLOWS, LAC GUYER, QUÉBEC

KAREN STAMATELOPOULOU-SEYMOUR AND DONALD M. FRANCIS

Department of Geological Sciences, McGill University, 3450 University Street, Montreal, Quebec H3A 2A7

Abstract

Fresh olivine occurs throughout both massive and spinifex-textured peridotitic komatiite flows (now in the amphibolite facies) of the Lac Guyer Archean greenstone belt, James Bay, Quebec. This olivine encloses tremolite pseudomorphs of primary olivine and pyroxene skeletal crystals and contains secondary serpentine veinlets, two features that require it to be of metamorphic origin. It is also characterized by an unusually low forsterite content (Fo_{80-65}), which reflects the low bulk Mg/(Mg+ΣFe) of the flows. This fresh olivine, unlike the metamorphic olivine reported in alpine peridotites, is in fact less Mg-rich than the expected primary olivine. Its distribution within individual flow units, however, reflects a chemical polarity developed by magmatic fractionation. Towards the base of the spinifex-textured flows, the metamorphic olivine becomes increasingly abundant and more idioblastic, but decreases in crystal size. The prominence of such olivine on weathered surfaces and its distribution pattern may constiute valuable field criteria for the recognition of komatiite flows in highly deformed and metamorphosed terrains.

Keywords: metamorphic olivine, peridotitic komatiite flows, Archean, Lac Guyer greenstone belt, Quèbec, amphibolite facies.

Sommaire

On trouve de l'olivine saine dans toutes les coulées de komatiite péridotitique à facies amphibolite, qu'elles soient massives ou à texture spinifex, de la ceinture de roches vertes archéennes du lac Guyer, baie de James (Québec). Cette olivine renferme des inclusions de trémolite pseudomorphes de cristaux squelettiques d'olivine et de pyroxène primaires, ainsi que des veinules de serpentine secondaire; ces deux observations exigent qu'elle soit d'origine métamorphique. Sa teneur en Mg est anormalement basse (Fo_{80-65}), en accord avec le faible rapport Mg/(Mg+ΣFe) trouvé pour ces coulées. Cette olivine saine, contrairement à l'olivine métamorphique des péridotites alpines, est en fait moins magnésienne que l'olivine primaire à laquelle on s'attendrait. Sa distribution à l'intérieur d'une coulée reflète toutefois une polarité chimique qui résulte d'un fractionnement magmatique. En direction de la base des coulées à texture spifinex, les cristaux d'olivine métamorphique deviennent plus abondants et plus idioblastes, mais aussi plus petits. La visibilité de pareille olivine sur des surfaces d'altération et son type de distribution pourraient constituer des critères utiles pour l'identification, sur le terrain, de coulées komatiitiques dans les séries de roches métamorphiques fortement déformées.

(Traduit par la Rédaction)

Mots-clés: olivine métamorphique, coulées de komatiite péridotitique, Archéen, ceinture de roches vertes du lac Guyer, Québec, facies amphibolite.

Introduction

Olivine is a stable mineral in metamorphic assemblages in serpentinized ultramafic rocks of suitable composition (high MgO, low CaO) from 400 to 1000°C (Evans 1977). There is, as a result, possible ambiguity as to whether olivine in a metamorphosed peridotite represents a magmatic relic or a prograde metamorphic mineral. This problem is complicated by the fact that metamorphic olivine may assume a variety of habits, in many cases difficult to distinguish from those of magmatic olivine. For example, olivines in regionally metamorphosed terrains or in contact metamorphic aureoles, or those grown in the presence of a fluid, have been reported to exhibit elongate or bladed habits similar to the quench textures observed in ultramafic lavas or sills (Evans & Trommsdorff 1974, Collerson *et al.* 1976, Hietanen 1977, Snoke & Calk 1978). Because of this problem, the relatively higher forsterite content of metamorphic olivine in serpentinized alpine peridotites, compared with relict primary olivine (Arai 1975), has been used as a criterion for the recognition of a metamorphic origin (Hietanen 1977, Snoke & Calk 1978). The application of this criterion to olivine megacrysts in more iron-rich komatiitic volcanic rocks, however, leads to conclusions at odds with textural evidence (Oliver & Ward 1971, Oliver *et al.* 1972).

In our study of peridotitic komatiites from central Québec we have also found that metamorphic olivines exhibit forsterite contents that are not only low with respect to those of alpine peridotites but even lower than those estimated for the primary olivine in the flows. These olivines are not only chemically but also texturally distinctive. Variation in the size, habit and distribution of this olivine within individual cooling units reflects primary magmatic fractionation.

Volcanic Stratigraphy

The Lac Guyer greenstone belt of the James Bay region of Québec (lat. 53°30'N, long. 75°10'W) comprises two sequences of metamorphosed and deformed Archean volcanic rocks. The rocks of the lower sequence, predominantly basaltic, are separated from the overlying volcanic sequence by an iron formation. The basal portion of the second sequence is dominated by felsic tuffs with lesser amounts of associated felsic flows. These are overlain in turn by mafic tuffs and flows and then by a suite of komatiitic volcanic rocks ranging upward in composition from peridotitic komatiite to basalt. Ultramafic sedimentary units, presumably derived from the komatiites (Stamatelopoulou-Seymour & Francis, in prep.), occur near the top of the succession, underlain by pillowed pyroxenitic komatiite and overlain by pillowed komatiitic basalt. Both ultramafic and gabbroic sills cut the two volcanic sequences of the belt.

The Lac Guyer volcanic rocks exhibit mineral assemblages characteristic of the amphibolite facies. Fresh olivine is observed in all rocks (regardless of origin) containing more than 23 wt. % MgO (volatile-free). Attention in this paper is restricted, however, to the occurrence of olivine in the peridotitic flows.

Petrography of Peridotitic Flows

The peridotitic komatiite flows at Lac Guyer are similar to those documented in other Archean greenstone terrains (Viljoen & Viljoen 1969, Nesbitt 1971, Pyke *et al.* 1973); they are characterized by high MgO, low alkalis, and TiO_2 contents below 0.9 wt. % (Table 1). They occur as light grey-green, thin flows with brecciated flow tops and well-developed polygonal jointing. Both massive and spinifex-textured flows are present. The massive flows are fine grained, homogeneous throughout, and characterized by delicate dendritic tremolite pseudomorphs.

TABLE 1. COMPOSITION* OF THE PERIDOTITIC KOMATIITE FLOWS FROM LAC GUYER

SiO_2	46.98
TiO_2	0.38
Al_2O_3	6.42
Fe_2O_3**	12.59
MgO	27.20
CaO	6.04
Na_2O	0.33
K_2O	0.02
P_2O_5	0.04
Mg/(Mg+ΣFe)	0.81

*Weighted average (8 analyses) expressed in wt.%.

**Total Fe as Fe_2O_3. Samples have been analyzed by X-ray fluorescence using a PW 1220 semiautomatic unit. Precision for Fe, Ti, K, Ca is ±1%, for Si, Al ±2% and for Mg, Na, P ±5%. All data were corrected for mass absorption effects and normalized volatile-free to 100%.

The spinifex-textured flows exhibit an internal stratigraphy identical to that established by Pyke *et al.* (1973) at Munro Township, Ontario. The spinifex-textured zone is highly variable in thickness in any single flow, and may extend locally across the entire cooling unit. Although the rock is completely recrystallized, pseudomorphs after olivine spinifex, tremolite pseudomorphs after skeletal chain and hopper olivine, and pyroxene spherulites generally preserve the primary volcanic textures. The pseudomorphs are set in a groundmass of fine acicular tremolite with very fine serpentine and chlorite, minor magnesium carbonate ± talc. The groundmass tremolite is similar in chemistry to the larger tremolite pseudomorphs and commonly occurs as delicate dendrites, probably as pseudomorphs of devitrified glass. Magnetite, pyrrhotite, pentlandite and chalcopyrite occur as accessory phases in the groundmass.

The cumulate zones of these flows consist of 50 vol. % equant pseudomorphs of chlorite after primary olivine and closely resemble the cumulate zones described in other spinifex-textured flows (Pyke *et al.* 1973, Nesbitt 1971).

Occurrence and Distribution of Olivine

Fresh olivine crystals occur throughout the peridotitic komatiite flows. They are chemically unzoned, with relatively constant Fo contents, between 60–65 mol. % (Table 2). Throughout the massive flows and in the noncumulate portions of the spinifex-textured flows, the dominant habit of this olivine is large (4–10 mm), roundish porphyroblasts with lobate to cuspate margins (Fig. 1). These crystals poikiloblastically enclose the tremolite pseudomorphs of skeletal chain and hopper olivine and pyroxene (Figs. 2, 3) and areas of groundmass. Locally the olivine metacrysts contain dendritic and spherulitic tremolite and, in the spinifex zones, pseudomorphs after randomly oriented olivine blades. Spinifex-textured zones tend to contain less metamorphic olivine.

Metamorphic olivine is most abundant in the cumulate portions of spinifex-bearing flows, reflecting their high content of normative olivine (Table 3). The grain size of olivine decreases (0.2–0.9 mm) and its habit becomes increasingly subidioblastic to skeletal-like downward, in part controlled by the pseudomorphs of chlorite after cumulate magmatic olivine (Fig. 4). In addition, olivine crystals have grown locally in serpentine-bearing veinlets that crosscut the groundmass.

The olivine porphyroblasts are partly replaced by iddingsite, clinohumite, serpentine and opaque phases. Commonly, the alteration consists of a corona of iddingsite separating an olivine core from a rim of clinohumite, serpentine and magnetite. These layers are resistant to weathering and, together with the red-brown weathering olivine cores, give the host rock a characteristic spotted appearance in outcrop (Fig. 5).

TABLE 2. COMPOSITIONS OF METAMORPHIC OLIVINE AND TREMOLITE

	OLIVINE		TREMOLITE
	LG 45*	LG 132**	LG 45*
SiO_2	35.97	35.21	55.89
TiO_2	0.02	-	0.06
Al_2O_3	0.00	-	0.98
FeO	31.20	35.20	6.13
MnO	0.75	-	0.33
MgO	31.13	29.05	21.37
CaO	0.01	0.18	13.44
Na_2O	-	-	0.00
K_2O	-	-	0.32
	99.08	99.64	98.52
	Cation Proportions		
O	4	4	23
Si	0.992	0.982	7.769
Al	0.000	-	0.161
Ti	0.000	-	0.007
Fe	0.719	0.821	0.712
Mg	1.279	1.208	4.427
Mn	0.017	-	0.039
Ca	0.000	0.005	2.002
Na	-	-	0.000
K	-	-	0.056
TOTAL	3.007	3.016	15.173
$\frac{Mg}{Mg+Fe+Mn}$	0.63	0.60	0.85

*LG 45: Average of 4 grain analyses.
**LG 132: Average of 3 grain analyses.

Mineral compositions have been determined by an ACTON-CAMECA electron microprobe equipped with a TRACOR NORTHERN energy-dispersive unit, using the BENCE-ALBEE correction procedure (after Albee & Ray 1970).

Discussion

The poikiloblastic habit, enclosure of pseudomorphs of primary phases and occurrence in cross-cutting veinlets unequivocally indicate that the olivine of the Lac Guyer komatiites has a postmagmatic, metamorphic origin. The forsterite content of this olivine (Fo_{60-65}), however, is significantly lower than that of metamorphic olivine reported in alpine peridotite (Fo_{89-97}: Arai 1975, Hietanen 1977, Snoke & Calk 1978). The criterion of high forsterite content as an indicator of metamorphic origin is clearly inappropriate for olivine in the Lac Guyer komatiites and in similar porphyroblasts reported by Oliver

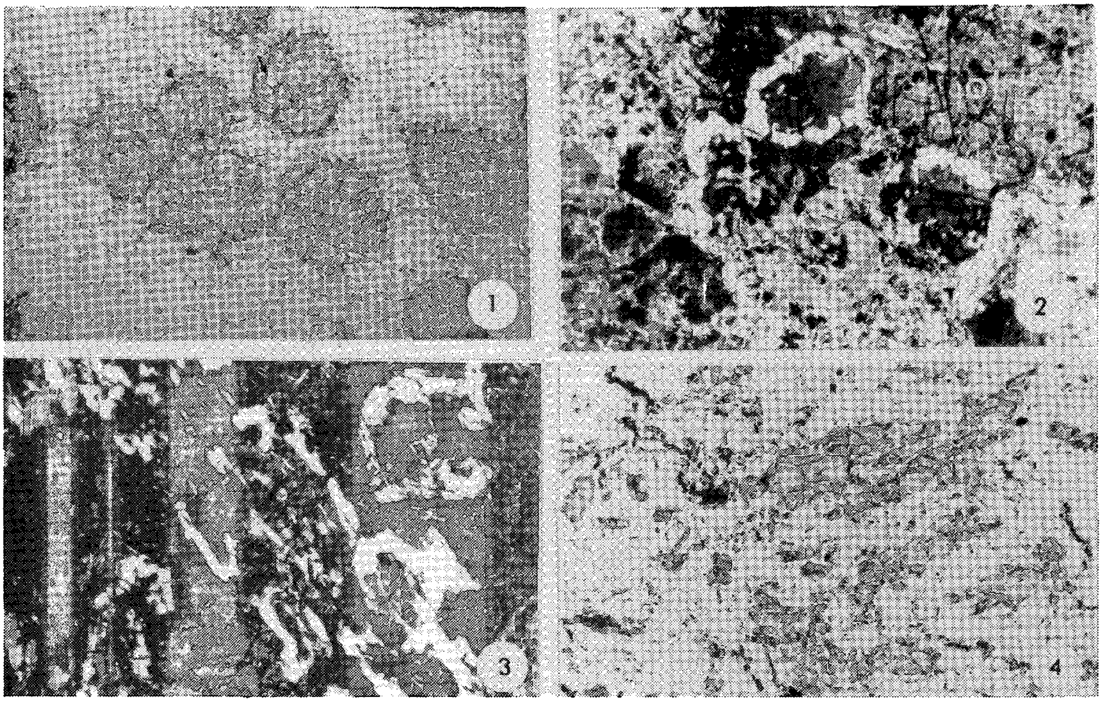

FIG. 1. Olivine porphyroblasts in a massive peridotitic komatiite flow, showing the characteristic roundish habit and lobate to cuspate margins. These olivine crystals poikiloblastically enclose tremolite pseudomorphs after primary hopper crystals (arrow). Width of field is 35 mm.

FIG. 2. An enlargement of Figure 1, showing tremolite pseudomorphs after primary hopper olivine enclosed in fresh olivine (ol). Width of field is 3 mm.

FIG. 3. Tremolite pseudomorph of primary olivine chains, entirely enclosed in olivine porphyroblast at extinction. Width of field is 3 mm.

FIG. 4. Small, subidioblastic olivine grains (0.4–0.8 mm) in the cumulate portion of a spinifex-textured flow. Width of field is 3 mm.

TABLE 3. DISTRIBUTION OF METAMORPHIC OLIVINE IN FLOWS

	Bulk Mg/(Mg+ΣFe)	Normative Olivine (wt.%)	Modal Olivine (vol.%)	Olivine Grain Size (mm)
Spinifex-Textured Flow				
(LG 454)				
Spinifex Zone	0.76	28.5	20	6
Cumulate Zone	0.80	42.7	75	0.4
Massive Flow				
(LG 315)	0.80	36.7	30	7

et al. (1972) from Western Australia. It is apparent that the low forsterite content of the Lac Guyer olivines reflects the low Mg/(Mg+ΣFe) ratio of the host volcanic rocks (Table 3) compared with that in alpine peridotites (Green 1964). In general, metamorphic olivine in komatiite flows seems to be less magnesian than primary magmatic olivine in the same rocks. Primary olivine is not observed in Lac Guyer flows, but application of the distribution coefficient of Roeder & Emslie (1970)

$$\frac{Fe_{ol}}{Mg_{ol}} \cdot \frac{Mg_{lq}}{Fe_{lq}} = 0.30 \pm 0.03$$

to the estimated liquid compositions of the Lac Guyer peridotitic komatiites (Table 3) suggests that such olivine would have had forsterite contents in the range $Fo_{89.9-93.2}$. This is in accord with primary olivine compositions analyzed in spinifex zones of Munro peridotitic komatiite flows (Pyke *et al.* 1973, Arndt *et al.* 1977).

The Lac Guyer peridotitic komatiite flows

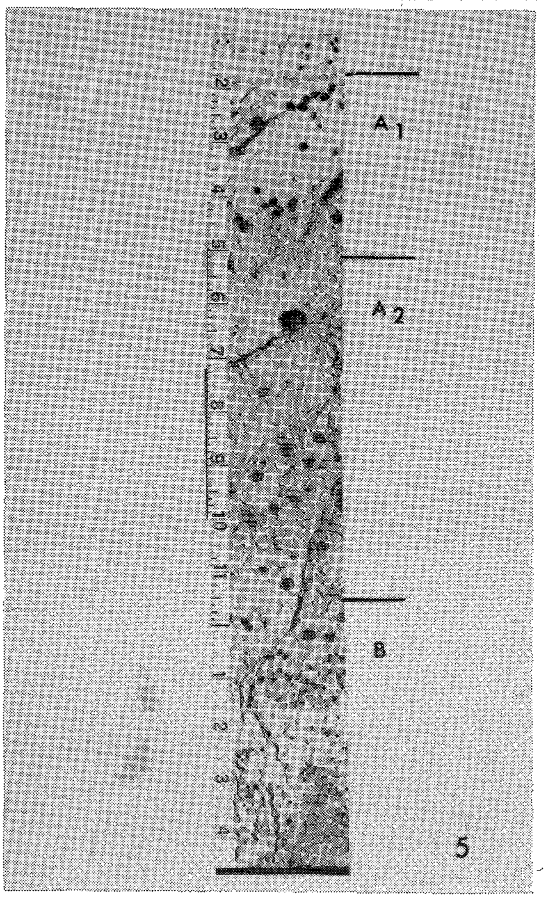

FIG. 5. Metamorphic olivine distribution and size variation in a thin, spinifex-textured peridotitic komatiite flow at Lac Guyer. Number 2 of the measuring tape is next to the upper chilled margin. The lower chilled margin of the flow lies just outside the lower margin of the section. A_1: flow top, A_2: spinifex zone, B: cumulate zone.

have been metamorphosed in the amphibolite facies. Their equilibrium mineral assemblage, consisting of olivine–tremolite–serpentine–chlorite ± talc, is compatible with the presence of staurolite in the associated sedimentary rocks at Lac Guyer. The absence of anthophyllite suggests temperatures less than 680°C at $P(H_2O)$ = P(total) = 2 kbar (Greenwood 1963). The field of stability of olivine is probably set at low temperatures by the reaction serpentine + diopside = forsterite + tremolite + vapor (~ 480°C at 2 kbar: Evans & Trommsdorff 1970). The pressure of metamorphism is not known for the Lac Guyer rocks, but these temperature estimates are relatively insensitive to pressure.

In view of the influence of the bulk chemistry on metamorphic olivine composition, textural relationships appear to be the only reliable criteria for identifying the metamorphic origin of olivine in peridotites. The resistance to weathering and roundish habit of metamorphic olivine at Lac Guyer may prove to be a valuable field guide to the identification of komatiitic lavas in metamorphosed greenstone terrains. The preferential development of metamorphic olivine in the cumulate portions of such lavas, as well as its intraflow size and habit variations, may be used to recognize primary flow stratigraphy.

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