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Chromite composition as evidence of metamorphism in komatiites, greenstone belt, Mozambique

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Archaean komatiites of the greenstone belt in Manica area, western Mozambique contains accessory amount of disseminated chromite grains. The komatiite rocks comprise peridotitic and basaltic komtiite. These komatiites are affected by regional metamorphism as all of the studied area. It is observed that only chromian spinel is preserved as the primary mineral and that all the other primary minerals in the komatiite samples are completely altered. The present work gives first time data on the effect of metamorphism on texture and composition of chromite enclosed in komatiite, Manica area, Mozambique. The primary chromian spinel has high $Cr^{\#}$ (Cr/(Cr+Al) atomic ratio; approximate value = 0.9, which is comparable with $Cr^{\#}$ value of chromian spinel in the worldwide komatiites. The chromian spinel have low Al and Mg value (up to 0.26 and 0.21 respectively, low $Mg^{\#}$ and high $Cr^{\#}$ and $Fe^{\#}$ values. Most of the studied spinel grains rimmed by ferritchromite which is transformed outwards to magnetite. Textural features and mineral chemistry of chromian spinel enclosed in these komatiites indicate postmagmatic alteration and metamorphism in greenchist to amphibolite transition facies. The metamorphism also involves reequilibration of the chromian spinel cores with the surrounding silicate assemblage.

Key words: Chromite, microprobe analyses, komatiite, Mozambique.

INTRODUCTION

Chromite in komatiites at low metamorphic grades can be useful indicator of crystallization environment, as described by Barnes (1998). The modification of chromite due to metamorphism is the subject of this paper. Metamorphic modification in the literature in the context mainly of ophiolitic or alpine ultramafic complex (Evans and Frost, 1975; Hoffman and Walker, 1978; Kimball, 1990; Burkhard, 1993; Marina and Judith, 2010; Stephen et al., 2012) and a few studies of komatiitic rocks (Bliss and Maclean, 1975; Donaldson, 1983; Gole and Hill, 1990) and in a detailed study of the Pechenga intrusions (Abzalov, 1998). These studies indicate that chromite core composition become progressively modified during prograde metamorphism as a result of exchange of compounds with surrounding silicate minerals (Abzalov, 1998). The present paper examines the nature and magnitude of these effects in komatiites from Archaean greenstone belt in Mozambique.

GEOLOGY

The Archaean rocks in Mozambique occur as small outcrops in the marginal region of the Zimbabwean

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craton, along the Zimbabwean border (Manica Provinces). According to Salman and Abdula (1995), the Archaean Mozambique structures include two major units: (1) Granite-gneiss complex in the Manica region and (2) Manica group structure (greenstone, banded iron formation of Macequece and M'Beza / Vengo formations. The Manica group is a structure unit of the Zimbabwe Craton. The geological map and the location of the studied area are indicated in Figure 1. A first genetic interpretation of the Manica greenstone belt was postulated by D' orey (1979) which considers the greenstone belt represents a formerly stretched basin filled by volcanosedimentary deposits 10 to 15 km in thickness.

KOMATIITE PETROGRAPHY

Microscopic investigation indicate that the studied komatiites underwent regional metamorphism under green schist – amphibolite transition condition as most of the primary magmatic minerals were fully replaced by secondary assemblages of actinolite – tremolite, actinolitic hornblende, serpentine, chlorite, epidote, chromite and magnetite. The studied thin sections contain relics of primary magmatic textures. All the studied samples are characterized by the common and distinctive spinifex texture, which consists of long acicular pseudomorphs of alteration minerals after olivine (Figure 2) which gives the rock a bladed appearance. Relics of primary acicular olivine have sometimes survived alteration showing elongated or platy habit.

METHODOLOGY

Mineral analyses were carried out at the Center for Co-operative research of Kanazawa University, Japan, using a JOEL JXA – 8800 electron probe microanalyzer. The analytical conditions were a 25 kv accelerating voltage, 20 nA probe current and 3 µm probe diameter. The raw data were corrected using an on – line ZAF program, the ferrous iron of spinel were calculated assuming spinel stoichiometry. The $Cr^{\#}$ is Cr/(Cr + Al) atomic ratio, the $Mg^{\#}$ is Mg/(Mg+Fe) atomic ratio for spinel.

Mineral chemistry

Selected microprobe analyses are listed in Table 1. In Figures 2 and 3 the magnetite outer rim is low in Al, Mg and Mn and rich in iron but the inner rim is Cr-rich and iron and magnesium- poor spinel. Chromian spinel shows variable ranges of Cr_2O_3 contents in the studied samples from 4.11 to 23.64% due to differences in degree of metamorphism. TiO_2 content of spinel is very low, < 0.2 wt%. The majority of the studied spinel have very low MgO contents (0.02 to 0.21 wt%) and low Mg / (Mg + Fe^2) values ranging from 0.01 to 0.21. These low $Mg^{\#}$ values reflect equilibrium temperature of metamorphism around 500°C resulted from a sequence of exchange of Mg^{2+} and Fe^{2+} between chromite and coexisting silicates, particularly olivine and chlorite. Al and Fe^3 contents in spinel fall within the typical range for lower amphibolite facies.

Intensity of spinel alteration increase outward from the center of spinel grains which transformed to Cr – bearing magnetite and then completely transformed to magnetite (Figures 2 and 3). The spinel is depleted in Al_2O_3 < 0.3 wt% and this spinel plots along the Cr – Fe^{3+} join of Cr – Al – Fe^3. It plots at the top right corner of the Cr/(Cr+Al) Vs (Fe^{3+} / (Fe^{3+}+Al+Cr), (Figure 4) and at the top left corner of the [Cr/(Cr+Al) Vs. [Mg/(Mg+Fe), (Figure 5). Magnetite and spinel tend to loose Al, relative to Cr during metamorphism and reaction with coexisting silicates through metamorphic fluids to form chlorite and or amphibole and the resulting spinel plots along the Cr – Fe^{3+} Join of the Cr – Al – Fe^{3+} diagrams. Textures in Figure 2 indicate metamorphic origin for the spinel and magnetite which is supported by their low Al and high ferric and ferrous contents. Barnes (2000) suggested that the maximum Cr content in the magnetite rim is controlled by equilibrium with spinel cores across the miscibility gab between spinel and magnetite which widens rapidly below 600°C.

DISCUSSION

The studied komatiitic flows of Manica area, Mozambique are located near the Zimbabwean border and considered as a part of Zimbabwean craton (Afonso, 1995). These komatiitic massive rocks have small outcrops in remnant areas and were emplaced in a succession of volcanosedimentary rocks composed of sandstone, greywacke, conglomerate, banded iron formation with layers of lavas and conglomerate. Previous geological studies indicate that the volcaniclastic rocks are common in Manica greenstone belt. Therefore the studied komatiite may have erupted in shallow water under hydrostatic pressures low enough to permit phreatomagmatic eruption. Barnes and Often (1990) reported similar komatiites emplaced in greenstone belt rich in volcaniclastic rocks at Karasjok, Finland. These features provide evidence that the komatiitic units under investigation were emplaced in or on a series of sediments close to or on the sea floor. The Mineral chemistry and textures of chromite of the studied area provide a picture of the chemical modification of chromite during lower greenschist alteration and subsequent amphibolite facies metamorphism.

Anomalously low Al and highly variable Fe^{3+} contents are observed in most of the studied samples, where the metamorphic effect are somewhat higher and metamorphic olivine is widespread (Fischer, 1979; McQueen, 1981). In some samples chromite underwent particular advanced replacement by magnetite, and these grains are commonly mantled by chlorite. This effect is restricted to a relatively small proportion of grains at each sample. The extent of reaction may be a function of fluid rock ratios and the extent to which the exchange and replacement reactions are driven by fluid influx (Barnes, 1998).

Arai (1992) reported that TiO_2 content of spinel in magmas varies depending on the tectonic setting of magma generation: it is relatively low for arc magma, intermediate for MORB and high for intraplate magma. So, the depleted komatiite with high $Cr^{\#}$, low TiO_2 spinel

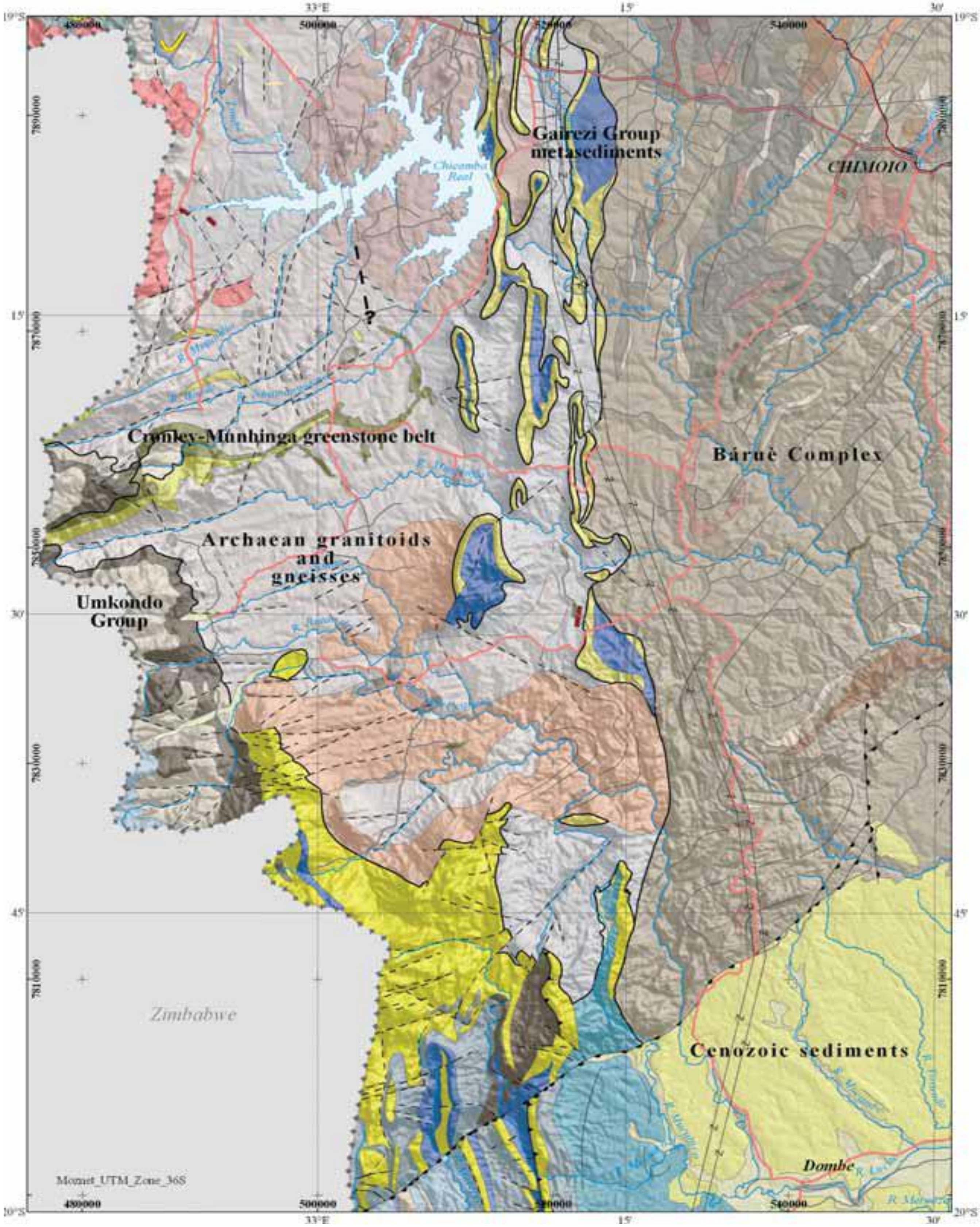

Figure 1. Geology of the studied area.

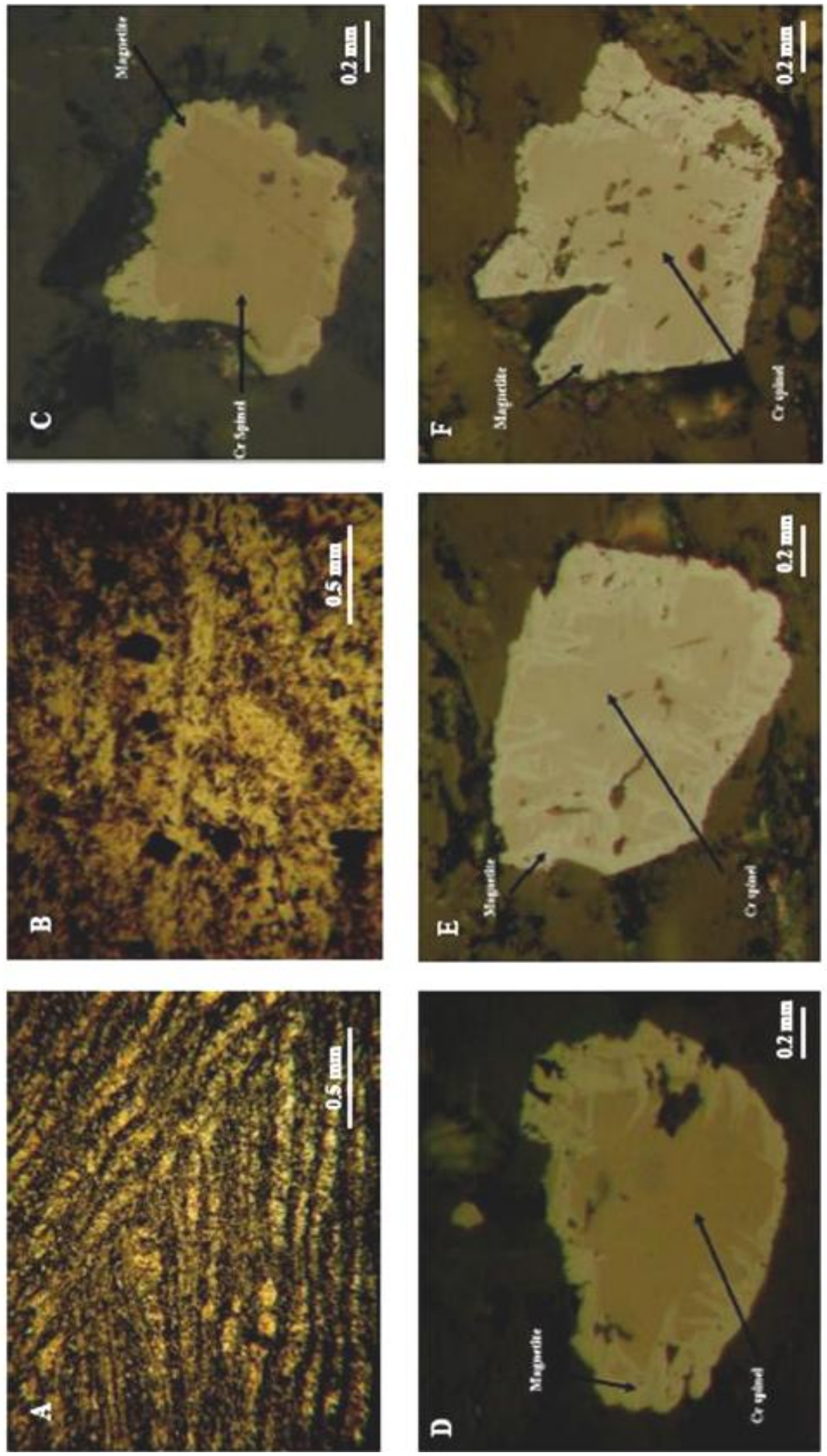

Figure 2. Photomicrograph of spinifex texture consisting of long acicular pseudomorphs of alteration minerals after olivine, crossed polar (A) and back–scattered electron micrographs of chromites and composite chromite–chromian magnetite grains, illustrating progressive replacement of chromite by magnetite during progressive metamorphism. (B) Pristine euhedral igneous magnesiochromite, no magnetite. (C) Incipient development of outer crystal faces on magnetite rim, and sharp, lobate internal phase boundaries against chromite. (D), (E) and (F) Advanced replacement of chromite by zoned chromian magnetite. Inner boundary is a sharp phase boundary.

Table 1. Electron microprobe analyses of chromium spinel and altered olivine in the studied komatiite.

M	Chromite		Ferritchromite		Magnetite		Altered olivine	
	1	2	3	4	5	6	7	8
SiO_2	0.03	0.05	0.23	0.16	2.16	1.95	55.89	47.02
TiO_2	0.21	0.08	0.19	0.24	0.13	0.16	0.06	0.08
Al_2O_3	6.70	7.02	0.36	0.47	0.02	0.05	0.98	0.06
Cr_2O_3	53.00	52.01	32.27	31.98	4.76	4.38	0.01	0.02
FeO	9.10	7.91	24.13	25.91	30.42	29.85	4.15	2.81
Fe_2O_3	22.55	23.59	38.18	37.85	63.71	62.12	2.57	1.02
MnO	0.74	00.14	00.81	0.76	0.07	0.08	0.33	0.18
MgO	8.10	9.12	2.89	3.01	1.92	1.85	21.37	38.01
CaO	0.04	0.03	0.01	0.02	0.04	0.02	13.44	9.56
Na_2O	0.01	0.02	0.03	0.01	0.01	0.02	0.00	0.01
K_2O	0.02	0.01	0.01	0.02	0.01	0.01	0.32	0.27
NiO_2	0.05	0.04	0.10	0.07	0.18	0.19	0.04	0.01
Total	99.85	100.02	99.12	100.49	99.43	100.63	99.15	99.04

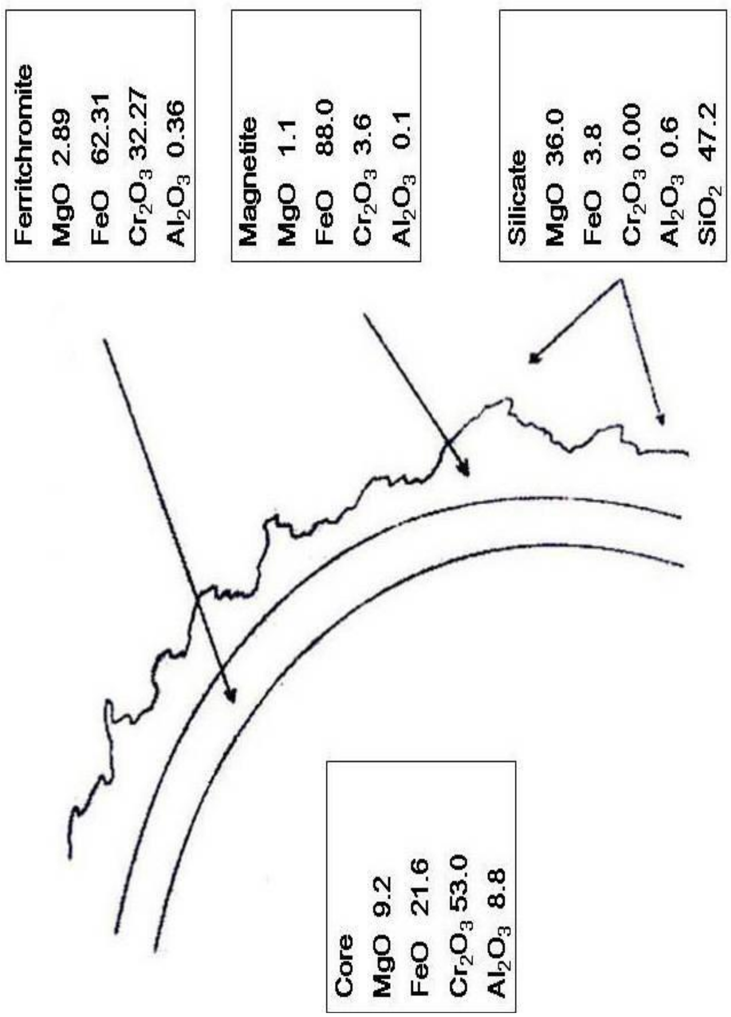

Figure 3. Typical quantitative electron microprobe analysis of a disseminated chromite grain is shown in Figure 2.

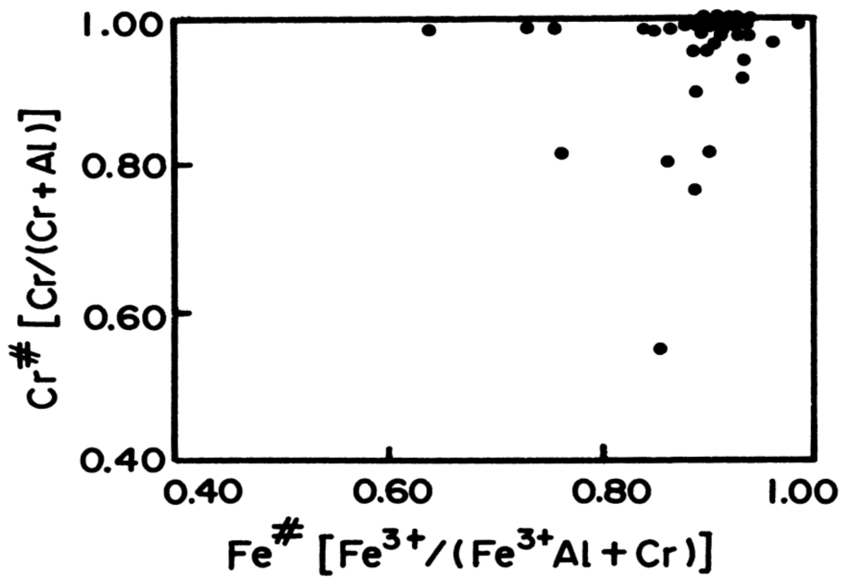

Figure 4. Variation of $Cr^{\#}$ (Cr / (Cr + Al) atomic 'ratios) versus $Mg^{\#}$ (Mg / (Mg^{+} Fe^{2+}) atomic ratios) of the analyzed spinel grains of the studied komatiite samples.

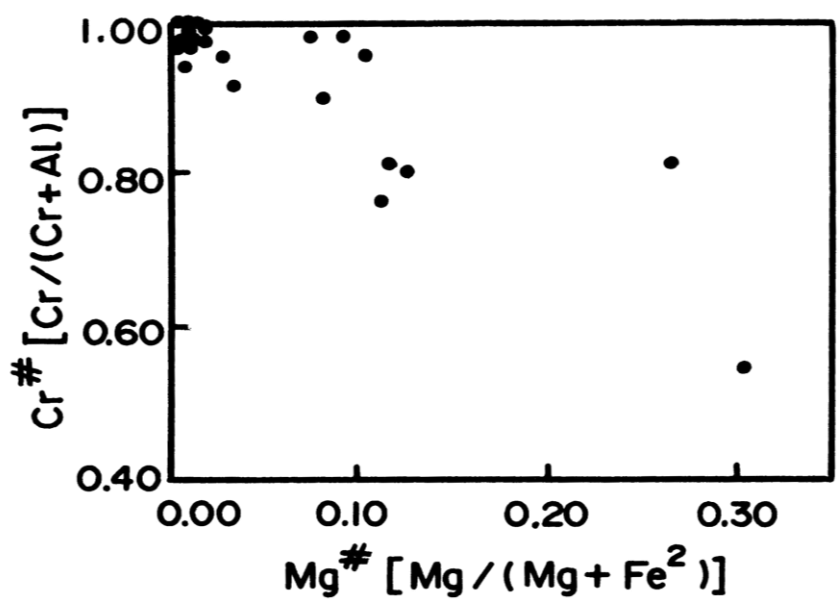

Figure 5. Variation of Cr* (Cr / (Cr + Al) atomic ratios) versus $Fe^{\#}$ (Fe^{3+} / (Fe^{3+} Al + Cr) atomic ratios) of the analyzed spinel grains of the studied komatiite samples.

from Manica area, Mozambique suggests an origin from the mantle wedge or sub – arc mantle.

Conclusions

(1) Petrological and geochemical studies of Manica komatiite indicated that they comprise peridotitic and basaltic komatites and are characterized by spinifex textured olivine.

(2) Textural features and mineral chemistry of chromian spinel enclosed in these komatiite indicate postmagmatic alteration and metamorphism in the green schist to amphibolite transition.

(3) Metamorphism also involves reequilibration of the chromian spinel cores with the surrounding silicate assemblage.
(4) The studied komatiites formed by partial melting of a depleted mantle under hydrous condition in subduction (arc) environment, confirming the existence of wet mantle in the Archaean era.
(5) The evidences that these komatiites are formed from wet mantle are as follows:

(i) The association of the komatiite with falsies and occurrence of volcanic tuffs and breccia indicating that those magmas contained volatiles (Schaeffer and Morton ,1991).
(ii) The presence of a distinctive spinifex texture consisting of long acicular phenocrysts of bladed olivine (or pseudo morphs of alteration mineral after olivine). Grove et al. (1997) proposed that elevated water content in komatiitic magmas would lead to the rapid growth of large crystals, and accompanying degassing of hydrous komatiites would generate a strongly super cooled liquid.
(iii) The formation of ferritchromite rind around chromite cores as a result of aqueous mobilization of Cr during serpentinization.

(6) Although recent data imply that many komatiites are derived from a dry mantle source, there are still some rocks that could be subduction-related such as komatiite from greenstone belt in South Africa, and the komatiite of Mozambique in the present study.

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