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SHORT COMMUNICATION

Fe-rich Olivines from the Ferrosyenites of Sivamalai, Tamil Nadu, India

The electron microprobe analysis of olivines from the ferrosyenites of Sivamalai shows that they are extremely rich in iron with $Fa_{96.4}$-$Fa_{93.9}$. The restricted range of Fe^{2+}:Mg:Mn values and high Fe^{2+}/Mg ratios amongst the analysed samples suggest that parental liquids underwent high degree of fractionation. Association of fayalitic olivine, orthopyroxene, inverted pigeonite and quartz in the ferrosyenites of Sivamalai strongly suggests their tholeiitic nature.

Introduction: Fayalite-bearing assemblages represent highly evolved magmas associated with anorthositic, gabbroic and alkaline instrusions, and anorogenic granites and rhyolites (Frost *et al.* 1988). The fayalite-bearing ferrosyenites of Sivamalai in Tamil Nadu, S. India, are spatially associated with the celebrated alkaline intrusion comprising of nepheline syenites, syenites and quartz syenites (Subramaniam, 1949; Bose, 1971; Bhaskar Rao, 1982).

The ferrosyenites of Sivamalai are coarse to medium grained massive rocks with a greasy charnockitic appearance. They exhibit hypidiomorphic texture (Fig.1) and are composed chiefly of orthoclase perthite (75-95% by vol.), plagioclase (1-10%), olivine (3-5%), clinopyroxene (2-10%) orthopyroxene (tr.), fossil pigeonite (tr.), amphibole (tr.), biotite (tr.) and quartz (tr.); accessories include opaques (Fe-Ti oxides) and apatite. The purpose of this note is to present electron microprobe analysis of the olivines more iron-rich than the reported compositions from Sivamalai (Bose, 1971; Bhaskar Rao, 1982; Rao *et al.* 1994) and discuss a few relevant petrogenetic aspects of the ferrosyenites.

The Composition of Olivine: The olivine occurs as equidimensional, anhedral, skeletal or spongy grains. This non-pleochroic pale brown mineral is fractured with frequently included Fe-Ti oxides (Fig.1) and apatite. (Fig.2). No compositional zoning in olivines is observed. The mineral shows a tendency to occur in synneusis of clinopyroxene, quartz and ilmeno-magnetite with invariable sharp grain-contacts. Rarely orthopyroxene (eulite-ferrosilite) rims around olivine which suggests that the latter bears a reaction relation with the liquid to give rise the former (Leelanandam, 1993).

The EPMA analysis of the olivine were carried out at NGRI, Hyderabad on a cameca (Camebax Microprobe) equipped with PDP 11/03 computer. Operating conditions of the instrument included a 15kV accelerating potential and a 15mA beam current. Two or three spots were analysed on cores and rims of 2 or 3 grains in each thin section for a total of 4 to 9 analyses per sample. Mineral compositions listed in Table I are averages of these multiple analyses.

There is no inter- or intra-element granular compositional variation in the olivines which were analysed. The Sivamalai olivines are extremely iron-rich with $Fa_{93.9}$ to $Fa_{96.4}$ (Table I). There is no enrichment of CaO suggesting their plutonic environment. However,

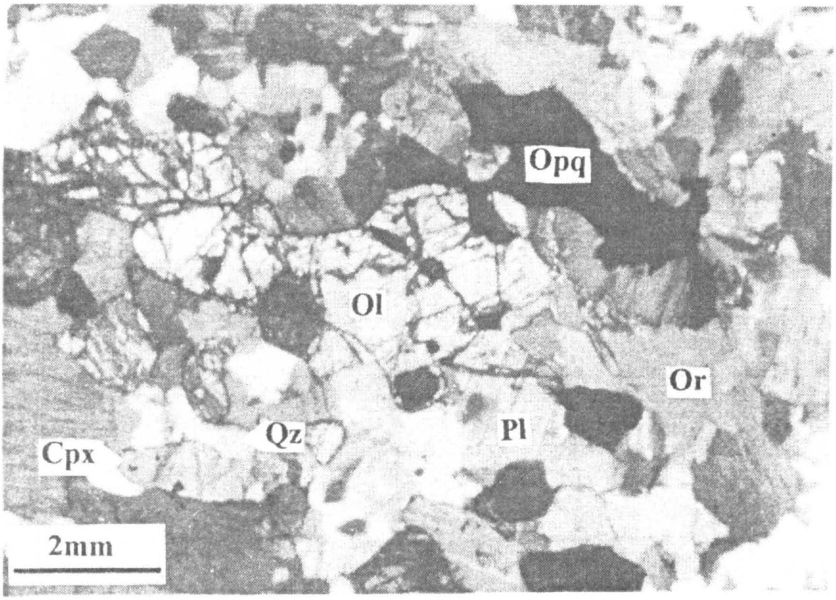

Fig.1. Photomicrograph of the ferrosyenite of Sivamalai showing hypidiomorphic texture. Olivine has inclusions of opaque oxides (Crossed polars).

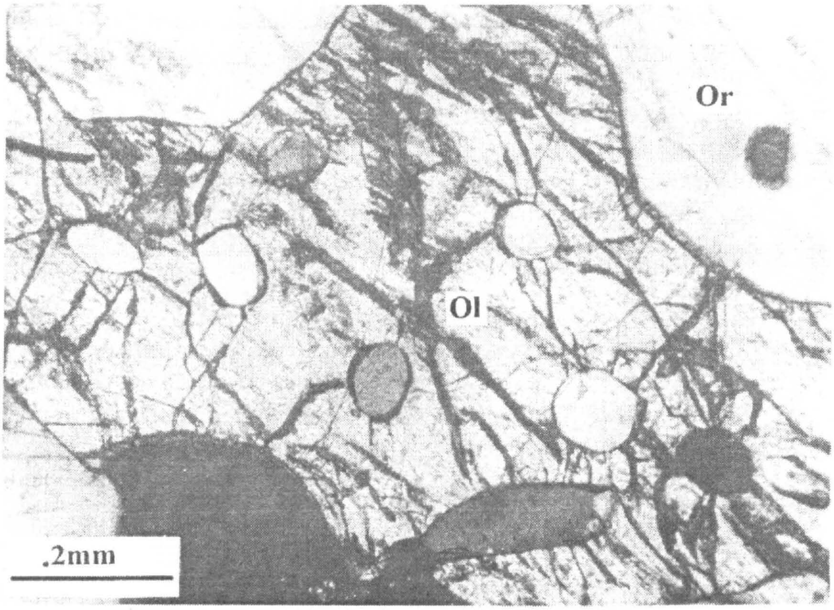

Fig.2. Photomicrograph of the olivine from the ferrosyenite of Sivamalai. Note subrounded inclusions of apatite and cracks filled with opaque oxides (Crossed polars).

MnO (1.88 to 2.34 wt%) is considerable and is more than MgO in three out of four analysed fayalites. Mn has chemical affinity for Fe and higher amounts of Mn are expected in Fe-rich olivines (*see* Deer *et al.* 1967, p.13). There is no gradual increase in Fe with increase in Mn as the ratio Fe/(Fe+Mn) is nearly constant ~0.7. The restricted range of atomic ratios from $Fe^{+2}_{91.0}$ $Mg_{6.1}$ $Mn_{2.9}$ to $Fe^{2+}_{93.7}$ $Mg_{3.6}$ $Mn_{2.7}$ (Table I) and high Fe^{2+}/Mg ratios suggest that the liquids parental to ferrosyenites underwent high degree of fractionation prior to their derivation (Upton *et al.* 1990). Minute sub-microscopic plates of exsolved ferric and chromic oxide are the likely source of the small amount of Cr found in one of the olivine grains analysed (SM35a).

Table I. Electron microprobe analyses of olivines from the ferrosyenites of Sivamalai, Tamil Nadu.

Sample No.	SY35a	SM15	SM34	SY37
SiO_2	30.64	28.61	28.15	30.78
TiO_2	0.01	0.04	0.04	0.03
Al_2O_3	0.15	0.03	0.00	0.00
FeO^t	65.33	68.18	66.87	64.67
MnO	1.88	2.34	2.17	2.04
MgO	1.40	1.52	1.71	2.43
CaO	0.13	0.10	0.06	0.01
Na_2O	0.07	0.02	0.04	0.00
K_2O	0.05	0.04	0.02	0.05
Cr_2O_3	0.15	0.06	0.04	0.00
Total	99.81	100.94	99.10	100.01
Number of ions on the basis of 4 oxygens				
Si	1.019	0.963	0.964	1.017
Ti	0.000	0.001	0.001	0.001
Al	0.006	0.001	0.000	0.000
Fe^{2+}	1.817	1.919	1.915	1.787
Mn	0.053	0.066	0.063	0.057
Mg	0.070	0.076	0.087	0.120
Ca	0.005	0.004	0.002	0.000
Na	0.004	0.001	0.002	0.000
K	0.002	0.002	0.001	0.002
Cr	0.004	0.002	0.001	0.000
Atomic ratios				
Fe^{2+}	93.66	93.11	92.74	90.99
Mn	2.73	3.20	3.05	2.90
Mg	3.61	3.69	4.21	6.11
Fe^{2+}/Mg	25.94	25.23	22.03	14.89
Fa*	96.39	96.31	95.79	93.89

*Fa= 100 (Fe^{2+}+Mn)/(Fe^{2+}+Mn+Mg)

Discussion: The association of fayalitic olivine with orthopyroxene, inverted pigeonite and quartz in the ferrosyenites of Sivamalai suggests tholeiitic nature of the rocks. The iron-enrichment with concomitant magnesium-impoverishment in the olivines suggests the highly evolved and fractionated nature of the ferrosyenitic magma and increasing activity of silica ($^aSiO_2$). Similar sympathetic Fe-enrichment occurs in the co-existing orthopyroxenes and clinopyroxenes (Table II). The extremely high Fe-enrichment necessarily requires unusually high-pressure crystallization since the composition of orthopyroxene in equilibrium with olivine plus quartz at a given temperature is a function of pressure.

Table-II. Compositions of coexisting ferromagnesian minerals from the ferrosyenites of Sivamalai.

		SY35a	SM15	SM34	SY37*
Olivine	Fa	96.39	96.31	95.79	93.89
	Fo	3.61	3.69	4.21	6.11
Orthopyroxene	Fs	78.00	97.00	92.00	75.00
	En	22.00	3.00	8.00	25.00
Clinopyroxene	Fs	45.65	49.12	50.46	41.92
	En	11.61	7.57	8.14	15.44
	Wo	42.74	43.31	41.40	42.64

* from Leelanandam, (1993).

In silicate systems with high $Fe^{2+}/(Fe^{2+}+Mg)$ ratios, (fayalite+quartz) crystallizes in place of ferrosilite. In the presence of fayalite, the stability of the associated Fe-Ti oxides is a function of both silica activity and oxygen fugacity and is governed by the following equilibrium abbreviated as QUIIF (Frost *et al.* 1988).

$$\underset{\text{(Quartz)}}{SiO_2} + \underset{\text{(Ulvöspinel)}}{2Fe_2TiO_4} = \underset{\text{(Ilmenite)}}{2Fe_2TiO_3} + \underset{\text{(Fayalite)}}{Fe_2SiO_4}$$

Low Ti content in the liquid and low oxygen fugacity inhibit crystallization of significant amounts of ilmenite and magnetite respectively, and therefore tend to favour the crystallization of fayalite (Stephenson and Hensel, 1978). The presence of nearly pure fayalites in the Sivamalai ferrosyenites suggests that the ambient oxygen fugacity was at or below the FMQ buffer. The relative stabilities of fayalitic olivine+ quartz and ferrosilite-rich orthopyroxene have been experimentally determined by Bohlen *et al.* (1980a; 1980b) and Bohlen and Boettcher (1981) and the results suggested that for each mol% $MgSiO_3$ the stability of orthopyroxene extends by 0.34 kb relative to $FeSiO_3$ and each mol% $MnSiO_3$ extends orthopyroxene stability by 0.12 kb. The presence of orthopyroxene rim around olivine of Sivamalai testifies to the role played by Mg, Fe and Mn during the crystal-liquid reaction.

The Sivamalai ferrosyenites containing the assemblage olivine +quartz+orthopyroxene+augite+fossil pigeonite+ two Fe-Ti oxides are useful to obtain the intensive variables such as T,P, fO_2 and $^aSiO_2$ (Frost *et al.* 1988). The fayalite-orthopyroxene-quartz-bearing assemblages from many localities throughout the world yielded very high pressures corresponding to ~70 km depth suggesting prevalence of thick continental crust during the mid- to late-Proterozoic. However, Lindsley *et al.* (1964) suggested that fayalite+quartz react to produce ferrositite above 18 kb at 1150°C and the ferrosilite breaks down to fayalite+quartz below 14 kb at 1000°C. Preliminary P-T estimates (Leelanandam, 1993) yielded reequilibrium temperatures in the range of 660-800°C and pressures from 6.2 to 7.6 kb for a majority of the south Indian ferrosyenites including the Sivamalai rocks.

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