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Resorbed forsterite in the carbonatite from the Cretaceous Sung Valley Complex, Meghalaya, NE India – Implications for crystal-melt interaction from textural studies

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ABSTRACT

Through this paper, we present the significance of textural studies and discuss on the petrogenetic implications of resorbed forsterite from the Sung valley carbonatite, Meghalaya, NE India. Petrographic studies revealed the presence of resorbed olivine, exhibiting conspicuous reaction rim with the surrounding carbonate in the Sung carbonatite. Studies reveal the presence of calcite as dominant mineral phase, with subordinate apatite and accessory magnetite, ilmenite and perovskite. Olivine is noticed as a conspicuous silicate phase in the carbonatite. EPMA studies indicated high Mg nature of the olivine i.e. $Fo_{97.3}$. The SiO_2 content in the forsterite olivine range from 40.95 to 41.60% and MgO content from 54.43 to 56.31%. In the Fe_2 / (Fe_2+Mg) / $(Mg/(Fe_2+Mg)$ mineral chemistry plot, the resorbed olivine from the Sung valley carbonatite falls close to the vicinity of the forsterite end member. We present the succinct details on petrographic and mineral chemistry and discuss on the petrogenetic significance of the forsterite olivine in the Sung carbonatite. Presence of Mg rich foresterite exhibiting spectacular resorbed texture in the carbonatite of Sung Valley Complex indicate early crystallization of olivine and subsequent crystal-melt interaction between the early formed silicate and carbonate melt.

Key words: Forsterite, carbonatite, Sung valley, Meghalaya.

INTRODUCTION

The Sung valley ultramafic-alkaline-carbonatite complex (SACC) occurs as an intrusive suite within the Shillong Group metasediments around Sung area in parts of East Khasi Hills and Jaintia Hills of Meghalaya (Yusuf and Saraswat, 1977; Chattopadhyay, 1979; Chattopadhyay and Hashmi, 1983; Krishnamurthy, 1985; Srivastava and Sinha, 2004; Srivastava et al., 2005; Melluso et al., 2010; Ranjith and Sadiq, 2013). The NNW-SSE trending oval shaped SACC has a partial ring structure with a central serpentinite surrounded by pyroxenite (Figure 1). It is about 4 km in width and extends over a stretch of 7.2 km in NNW-SSE direction from Umkehn nala in north to Byrthar in south. Presences of carbonatites, ultramafic and alkaline rocks were established in Sung Valley Complex during mapping (Gogoi, 1973; Chattopadhyay, 1979). The first major account of Sung valley carbonatite was given by Yusuf and Saraswat (1977). The dominant rock type of the complex includes (i) peridotite, (ii) serpentinite, (iii) pyroxenite, (iv) uncomphagrite (v) alkaline rocks, (vi) biotite – alkali feldspar, and (vii) carbonatite (Figure 1). Apatite-magnetite rock is also present in significant amount in southern part of SACC. Krishnamurthy (1985) carried out petrological studies of Sung valley carbonatites. Viladkar et al., (1994) carried out the mineralogical and geochemical studies of Sung carbonatite complex. A narrow zone of fenite and a brecciated zone of mixed fenite and quartzite have developed at places particularly along the border (Chakraborty and Thapliyal, 2000). In one of the earlier works on geochronology, a $^{206}Pb/^{204}Pb–^{207}Pb/^{204}Pb$ age of 134 ± 20 Ma with a model μ_1 of 8.19 ± 0.02 has been obtained for the carbonatite from Sung Valley, Meghalaya, placing their time of emplacement very close to the time assigned for the break-up of Gondwana (Veena et al., 1998). Rb–Sr isochron of the Sung Valley carbonatites, pyroxenite and a phlogopite from a carbonatite yielded an age of 106±11 Ma (Jyotiranjan Ray et al., 2000). An age of 115.1 ± 5.1 Ma was reported by U–Pb dating of perovskite from the ijolite of Sung Valley (Srivastava et al., 2005). However, a precise $^{40}Ar-^{39}Ar$ age of 107.2 ± 0.8 Ma was reported for the Sung Valley carbonatite alkaline complex (Ray and Pandey, 2001). In a significant contribution, the mineral compositions from the Ultramafic and alkaline rocks and carbonatite from the Sung Complex have been studied by Melluso et al., (2010). Recently, eleven carbonatites were delineated during mapping by GSI (Ranjith and Sadiq, 2013), while Sadiq et al., (2014), reported uraninite, xenotime and REE bearing minerals in Sung carbonatite.

Significance of Magnesium Rich Olivine

Forsterite is a Mg rich end-member of the olivine isomorphous solid solution series involving forsterite

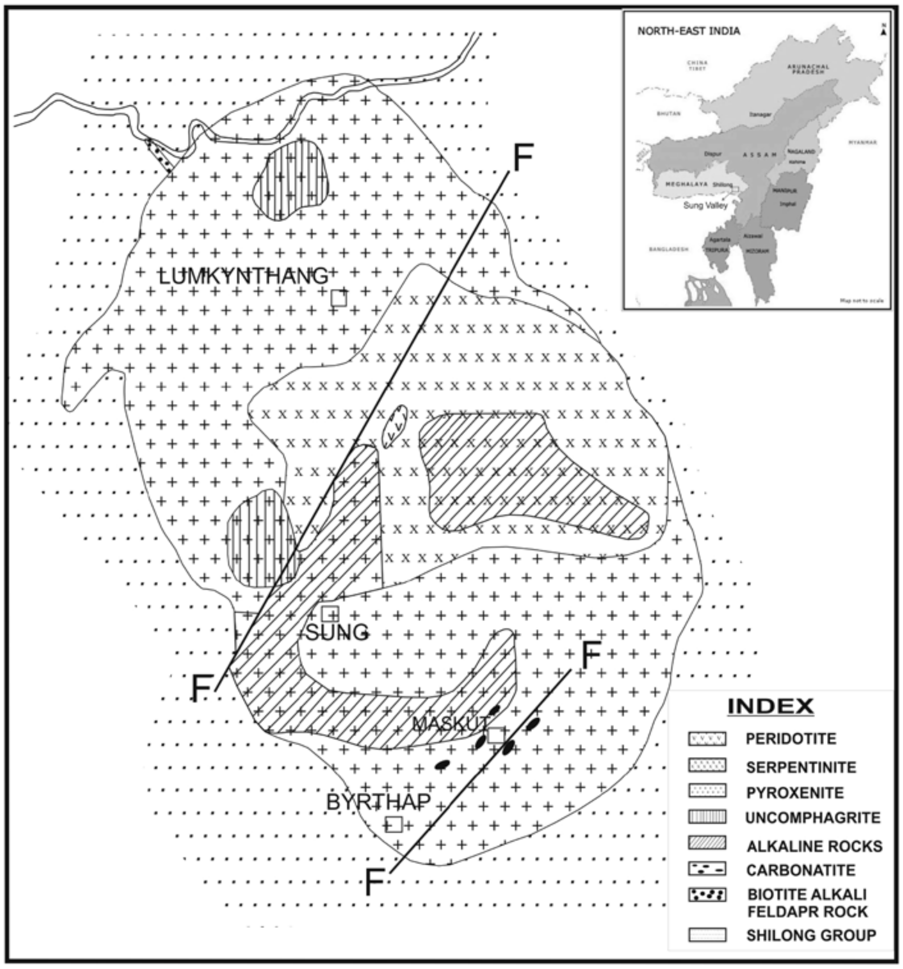

Figure 1. Geological Map of Sung Valley Alkaline-Ultramafic Complex, Meghalaya. (Modified after Chattopadyay and Hashimi, G.S.I. 1984). Inset: Location of Sung Complex in Meghalaya, NE India.

(Mg_2SiO_4) and fayalite [(Fe_2SiO_4), (Deer et al., 1992)]. Forsterite olivine can occur in high Mg ultramafic rocks, kimberlites, lamproites and carbonatites; mantle derived rocks of igneous origin. Among these, carbonatites are rare carbonate rich magmatic rocks; generally confined to the intracontinental rift association. High pressure experimental studies involving (i) olivine-basalt system and (ii) olivine carbonatite system in conditions corresponding to upper mantle, indicated that 'Mg-carbonatite melt has higher conductivity than basaltic melt' (Yoshina et al., 2010). Irrespective of immiscible or residual origin, the carbonatitic melts are rich in alkalis and evolve to alkali-rich compositions (Lee and Wyllie, 1997). This observation is supported by the abundance of Na–K–Ca and Na–Mg carbonate daughter minerals in the inclusions within the forsterite olivine from Kovdor carbonatites (Vekslar et al., 1998). Forsterite can also occur during the process of silicification involving contact thermal metamorphism of Mg rich sediments like dolomite (eg. Ferry et al., 2011). In one of the most significant contributions, presence of forsterite olivine (Fo_{83}) has been observed in interplanetary dust particle (Scott Messenger et al., 2005). Hence, the genesis of the Mg rich olivine in rocks and particles of terrestrial and extra-terrestrial origin indicate a specific petrogenetic process. The present study provides detailed petrographic and mineral chemistry studies of the high Mg forsterite olivine from the Sung valley carbonatite and highlights the textural significance of the resorbed forsterite.

Field Disposition

The oval shaped SACC of Meghalaya plateau in NE India has an areal extent of 26 sq. km (Chattopadhyay and Hashmi, 1983; Ranjith and Sadiq, 2013). The carbonatite occurs as plugs within a highly weathered terrain of mainly pyroxenite and alkaline country rocks around Maskut area, in the southern part of the Cretaceous Sung Complex. Carbonatite, carbonate-apatite rich rocks and magnetite apatite rocks are located in the vicinity of a NE-SW trending fault (Figure 1, Chattopadhyay and Hashmi, 1984).

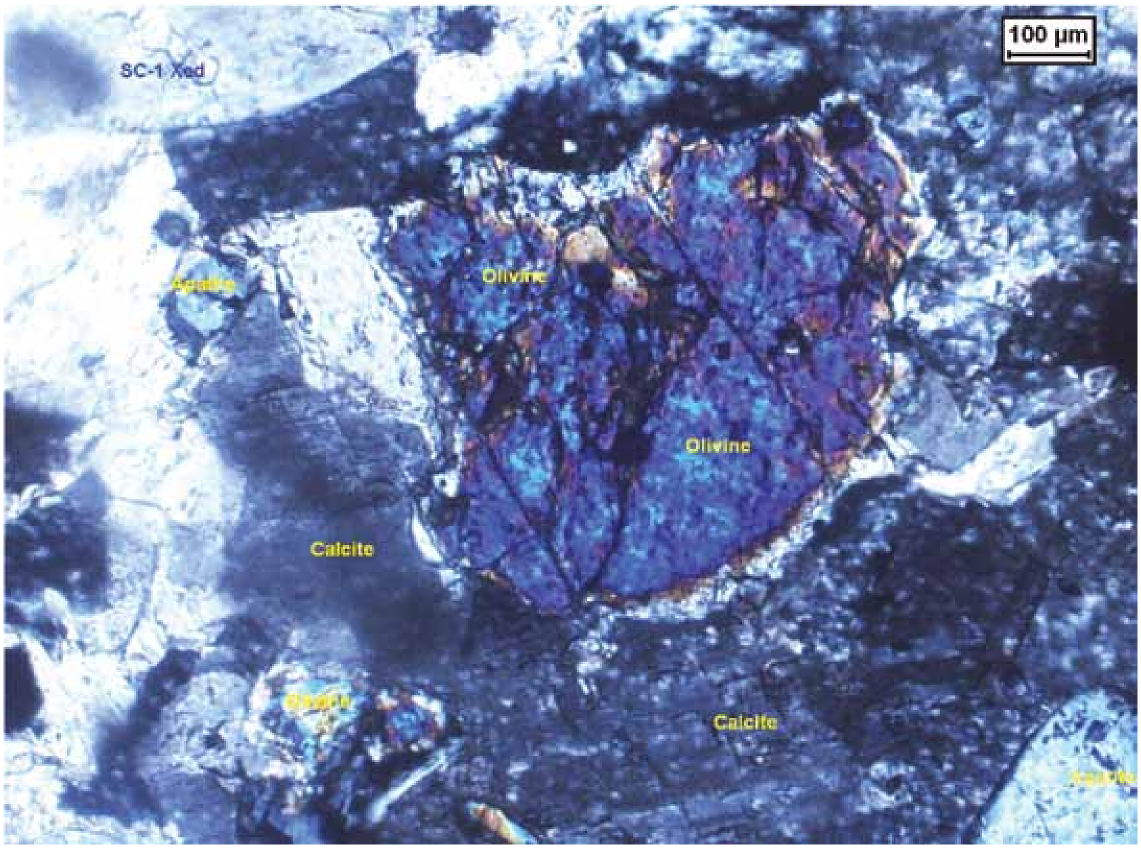

Figure 2. Photomicrograph under crossed Nichols showing the resorbed nature of the olivine at the interface of forsterite and carbonate in Sung valley carbonatite. Note the reaction rim all around the olivine.

Ijolitic rocks occur as small lenses along with carbonate-apatite rich lenses and apatite-magnetite rocks that analyses phosphate content upto 31.36% P_2O_5 was analysed in the around Maskut area (Chattopadhyay and Hashmi, 1983). The carbonatite of the Sung Complex occurs in the form of isolated oval shaped bodies, minor dykes and veins that vary in length from 20 to 125 m with a maximum width of 40 m (Ranjith and Sadiq, 2013; Sadiq et al., 2014).

Petrography and Mineral Chemistry

Petrographic studies of the carbonatite rock from SACC indicate that the rock is coarse grained with crystalline texture and essentially constituting coarse grained crystals of calcite. The size of the calcite crystals ranges from ~ 4 to 5.2 mm. Euhedral to subhedral apatite is conspicuous and is more or less uniformly distributed throughout the carbonatite. Opaque oxides are represented by magnetite and ilmenite, while the conspicuous silicate phase is olivine. In the carbonatites, the non-carbonate component is apatite, olivine, or magnetite (Chakhmouradian et al., 2016). Pervoskite occurs as minute euhedral grains ranging in size from 0.05 to 0.1 mm. Metamict grains after pyrochlore are also noticed in the carbonatite.

Electron Probe Micro Analyses (EPMA) was carried out at Central Petrological Laboratory, GSI, Kolkata by CAMECA Sx 100. Analyses conditions: Accelerating voltage: 15 kV, current: 12 nA. Beam size: 1 μ. All natural standards have been used except for Mn and Ti for which synthetic standards have been used.

Modal abundance of the carbonate minerals in the carbonatite ranges between 65 to 80%. Most of the carbonate grains show rhombohedral cleavage and twinning characteristic of calcite. Consertal relationship in the form of embayed contact is often noticed along the grain boundaries of the carbonate grains. Olivine is noticed as euhedral to subhedral inclusions (0.05 mm size) within the calcite and often a sharp reaction rim is noticed along the interface of olivine and carbonate (Figure 2). Occurrence of pyrochlore associated with calcite and apatite is reported along with bastnasite and other REE minerals recently (Sadiq et al., 2014).

Mineral chemistry studies indicated that the SiO_2 content in the forsterite olivine range from 40.95 to 41.60%, MgO content vary from 54.43 to 56.31%, MnO content of 0.24 to 0.40%, FeO^T content of 1.51 to 2.75 % and Cr_2O_3 content upto 0.05%. CaO is negligible; upto 0.09% EPMA analyses of the forsterite olivine are furnished in Table-1. The Mg # varies for the olivine analyses

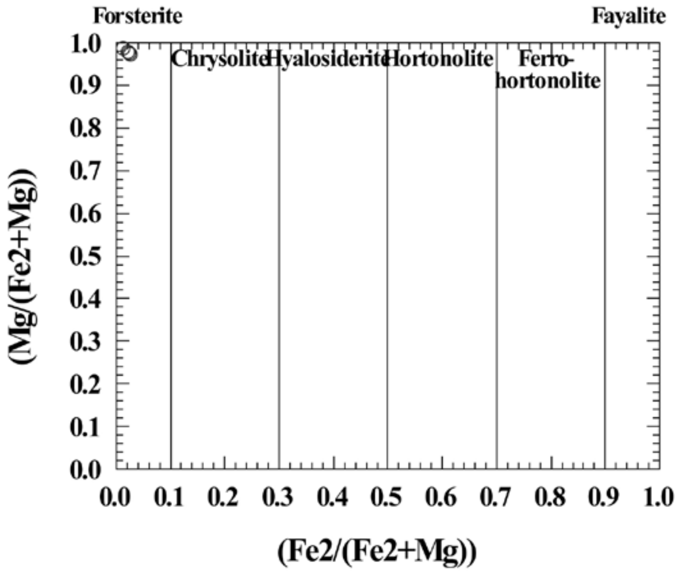

Figure 3. Fe_2/ (Fe_2+Mg)/(Mg/(Fe_2+Mg) plot showing the position of Forsterite from the carbonatite of Sung valley, Meghalaya, NE India.

Table 1. Mineral chemistry of olivine (shown in Figure 2) from the carbonatite of Sung Valley Alkaline-Ultramafic- Carbonatite Complex, Meghalaya.

Oxide	**SA-1/1**	**SA-1/2**	**SA-1/3**	**SA-1/4**	**SA-1/5**	**SA-1/6**
SiO_2	40.95	41.31	41.09	41.60	41.42	41.00
Al_2O_3	0.00	0.05	0.00	0.02	0.00	0.03
TiO_2	0.03	0.00	0.00	0.00	0.03	0.00
MnO	0.39	0.33	0.40	0.24	0.30	0.36
MgO	55.52	55.59	56.31	54.43	55.51	55.92
FeO^T	2.60	2.54	1.51	2.75	2.54	2.41
Na_2O	0.10	0.06	0.06	0.08	0.05	0.06
K_2O	0.02	0.02	0.04	0.01	0.02	0.01
CaO	0.05	0.09	0.00	0.07	0.05	0.02
Cr_2O_3	0.04	0.00	0.05	0.00	0.02	0.00
P_2O_5	0.10	0.00	0.36	0.00	0.00	0.28
BaO	0.00	0.00	0.00	0.00	0.13	0.00
Total	99.79	100.00	99.82	99.19	100.10	100.10
Mg #	95.52	95.63	97.38	95.19	95.62	95.86
Cation						
Si	0.977	0.983	0.975	0.996	0.985	0.973
Al	0.000	0.000	0.000	0.001	0.000	0.001
Ti	0.000	0.000	0.000	0.000	0.001	0.000
Mn	0.008	0.008	0.008	0.005	0.007	0.007
Mg	1.975	1.971	1.991	1.943	1.968	1.979
Fe	0.052	0.051	0.030	0.055	0.050	0.048
Na	0.005	0.003	0.003	0.004	0.002	0.006
K	0.001	0.001	0.001	0.000	0.001	0.001
Ca	0.001	0.000	0.000	0.002	0.001	0.000
Cr	0.001	0.001	0.001	0.000	0.000	0.000
P	0.002	0.001	0.007	0.000	0.000	0.006
Ba	0.000	0.000	0.000	0.000	0.001	0.000
Mineral	Forsterite	Forsterite	Forsterite	Forsterite	Forsterite	Forsterite

indicated in Table-1 is > 95; ranging from 95.19 to 97.38. In Fe_2/ (Fe_2+Mg)/(Mg/(Fe_2+Mg) plot the olivine falls close to forsterite end member (Figure 3). Based on the average of the six point analyses (Table-1), the calculated structural formula for the olivine is $(Mg_{1.97}\ Fe_{0.047}\ Mn_{0.007}\ Ca_{0.0006})_{2.0}\ (Si_{0.98}\ Al_{0.00})_{0.98}\ O_4$. End member in terms of Forsterite and Fayalite are $Fo_{97.3}$ and $Fe_{2.3}$ respectively; indicating the presence of a very high Mg olivine as a silicate phase in Sung carbonatite.

DISCUSSION

Several occurrences of forsterite in carbonatites have been reported in the world (eg Veksler et al., 1998; Woolley, 2001; Lee et al., 2005). Experimental studies demonstrated that carbonatitic melts percolate in olivine (Hammouda and Laporte, 2011). It is observed that in the reactions involving percolation of carbonate melt in olivine are accompanied by the reprecipitation of the forsterite in the carbonatite reservoir. Melluso et al., (2010) identified the presence of olivine during the mineral composition study of the Sung Valley carbonatite. The threshold abundance of the carbonate minerals in the mantle derived magmatic carbonatites is 50% (Le Maitre 2002). However, by mode the carbonate can exceed 90% in some of the cumulus carbonatites (e.g., Xu et al., 2007). Modal abundance of the carbonate minerals in the carbonatite ranges between 65 to 80%. Forsterite-bearing calcite carbonatite is also reported from the Kovdor complex of Kola Peninsula (Veksler et al., 1998). Co_2 enriched volatile magmas may result due to the phenomenon of crystallization and fractionation of early high-magnesium minerals (Panina and Motorina, 2008). One of the possibilities of the generation of carbonatite melts can be due to fractional crystallisation of CO_2-rich alkaline silicate magma. Experimental studies demonstrated that liquid immiscibility does occur between the silicates and carbonate melts (Hamilton and Ian 979). Sen, (1999), observed that Mg rich peridotite and pyroxenite of SACC were initially fractionated from the parental melilitic magma; resulting in enrichment of calcium and generation of carbonatite melt by the process of liquid immiscibility. However, Melluso et al., (2010), observed that the genesis of the Sung valley carbonatites (with very high Mg minerals), is not related to the mafic and felsic rocks in the Complex. Melluso et al., (2010), further indicated that the rocks of Sung complex evolved independently in batches from a primitive magma. The present study highlights the presence of high Mg olivine as a conspicuous silicate phase in the Sung valley carbonatite from Maskut area. Olivine is noticed as euhedral to subhedral grains (0.05 mm size) within the calcite and often a sharp reaction rim is noticed along the interface of olivine and carbonate (Figure 2). Mineral chemistry by EPMA indicates high MgO (54.43 to 55.92%) and low Cr_2O_3 content (upto 0.05) in the resorbed forsterite from the Sung carbonatite.

CONCLUSION

Presence of olivine exhibiting resorbed texture in the carbonatite of Sung Valley Complex indicates early crystallization of olivine (Figure 2). The high Mg nature of the olivine (average composition of $Fo_{97.3}$ based on EPMA analyses of the resorbed olivine) and its conspicuous reaction rim with the surrounding carbonate is a significant petrographic textural feature, indicating crystal-melt interaction between an early formed silicate and carbonate melt in the mantle originated Sung carbonatite. We observe that further analyses, involving mineral inclusion studies of the olivine from Sung carbonatite will help to understand the evolution of carbonatite melts of the SACC.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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