Tremolite-Olivine-Phlogopite-bearing Ultramafic Enclaves in the Archaean Migmatite Gneiss near Naregal, Gadag District, Karnataka

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Abstract: The polyphase migmatite gneiss exposed in the vicinity of Naregal contains unusual ultramafic enclaves with the modal composition of 50% tremolite, 21% olivine, 16% phlogopite, 10% Cr-magnetite (with 5 6 wt% Cr_2O_3) and 2% anthophyllite Geochemically the enclaves resemble 'Barberton komatiite' in respect of high MgO, Ni, Cr and Low Al_2O_3 and TiO_2 and one of 'Wajrakarur kimberlite' plug rocks with reference to high K_2O, Rb Zr and Ba The finding suggests the possible existence of pristine crust in the northern part of the Western Dharwar Craton

Keywords Ultramafic enclaves Polyphase gneiss, Fresh olivine, Phlogopite, Pristine crust, Naregal Karnataka

Introduction

The paper reports the occurrence of ultramafic enclaves within the migmatitic gneiss exposed near the town of Naregal (Lat N15°33 855', Long E75°47 527') in Gadag district Considering their location in the very northern low-grade block of Western Dharwar Craton and the unusually well preserved mineralogy and geochemistry, the enclaves have been examined in detail and the results are reported here

Occurrences of ultramafic enclaves in granitic gneisses have been reported from various locations of the India shield However, the authors have not come across any report of ultramafic enclaves, comparable in mineralogy and geochemistry to the one described here, specially from the northern part of Western Dharwar Craton

Field Occurrence

The ultramafic rock described here occurs as rounded enclaves, each (enclave) measuring less than about a meter in diameter More than half a dozen-isolated enclaves of the rock are exposed in a quarry located about 2 km west of Naregal town They are found enclosed in about 3-4 m wide and 15 m long zone in migmatitic gneiss They do not show intrusive or xenolith-like features Pegmatite veins are not uncommon close to the borders of enclaves (Fig 1), but seldom those permeate the enclaves Some of the enclaves are traversed by thin fractures (2-3 cm) filled by cross fibers of asbestiform amphibole The enclaves show sharp contacts with the host rock We also do not see these attached and grading into the numerous mafic (amphibolite) pods/lenses/patches of the migmatite A rare meta-sedimentary granulite enclave (around 2 m x 0 5 m) containing 46% clinopyroxene (salite with 13 % $MnSiO_3$), 23% quartz, 14% garnet (with 45% spess and 35% alm) and 7% magnetite, occurs in the near vicinity

Nomenclature Our scanning of available literature, specially on Dharwar craton, has not revealed the reported occurrence of an ultramafic enclave with a modal mineral composition comparable to that of Naregal Mineralogically it is broadly comparable to 'hornblende mica peridotite' and 'sapelite' (phlogopite-hornblende-peridotite) On the basis of modal mineral composition, we propose to name the Naregal ultramafic enclave rock as 'olivine-phlogopite-tremolitite' (*see* also Wyllie, 1967, pp 1 to 3)

Petrography

The enclave ultramafite is medium grained, dull grey to dark green colored with coarse prisms of tremolite displaying luster mottling In thin section, the rock shows approximate mineral lineation (Fig 2) The abundant *tremolite* forms large prisms which may show multiple twinning and enclose

Fig.1. Field photograph showing the rare ultramafic enclaves in the Hatalgeri-Naregal migmatite gneiss. Note the dismembered occurrence, sharp contacts and massive appearance of the enclaves (U) and also the abundant mafic enclaves (grey) and profuse permeations of granitic neosomes. Quarry behind Erappajjana temple, about 2 km SW of Naregal town.

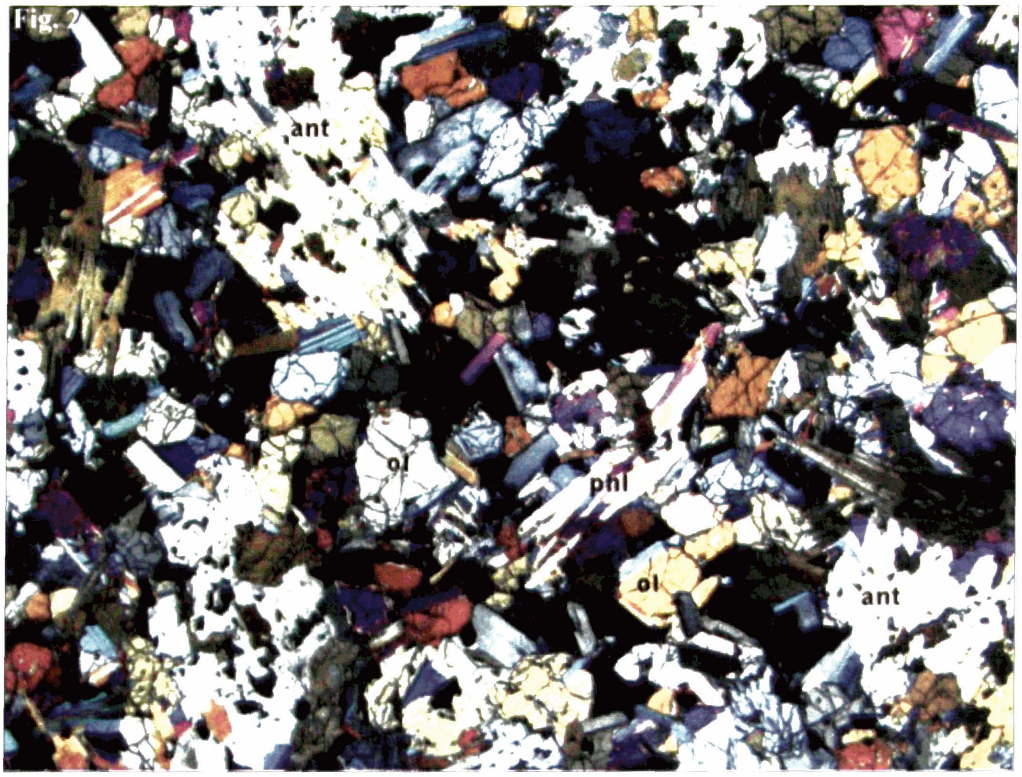

Fig.2. Photomicrograph of the Naregal ultramafite enclave showing the typical minerals *amphibole* (*tremolite* forming large prismatic plates, displaying typical multiple twinning) *olivine* (ol) (forming typical rounded granular aggregates), *phlogopite* (phl) (mostly enclosed in tremolite), *Fe-Cr oxide* (black) and *anthophyllite* (ant) (small sporadic patches in tremolite). Crossed Nicols. Photo width covers 10 mm of the slide.

poikilitically all the other minerals *Olivine* occurs as aggregates of subhedral to rounded grains, which show very little evidence of serpentinization but look clouded with fine dusty blackish iron oxide dissemination Light brown colored and moderately pleochroic *mica* occurs in shapeless patches enclosed within tremolite, but, shows no obvious replacement relation towards the host mineral Euhedral to anhedral *Fe-Cr ore* grains occur sieving the amphibole Very light purple colored and weakly pleochroic *anthophyllite* occurs in sporadic anhedral patches within tremolite Mica and less commonly amphiboles are affected by chloritization specially along the grain boundaries

Mineralogy

Modal analysis has indicated that the rock is composed of 50% amphiboles, 21% olivine, 16% phlogopite, 10% Fe-Cr oxide and 2% anthophyllite Electron probe microanalysis of the individual minerals (see Table 1 for analytical data) obtained at the Institute of Electron Optics, University of Oulu, Finland, using JEOL Superprobe JXA-8200 has revealed the following

Olivine is fosteritic (Fo_{81}) and has significantly high Ni (0 4% NIO) ***Magnetite*** is markedly chromiferrous (Cr_2O_3 5 6%) and perceptibly high in Ni (0 6% NiO) *Mica* is ***phlogopite*** with high Mg Fe ratio (9 9), Cr_2O_3 (0 35%) and NiO (0 23%) The abundant *amphibole* is calcic and magnesian corresponding to ***tremolite*** with 91 4 mol % Mg-component and typically low Al content of 0 08 to 0 25 atoms per formula unit As compared to tremolite, ***anthophyllite*** in association analyses contrastingly low CaO, much more depleted in Al_2O_3 and alkalies, and consistently high in MgO, FeO and MnO

Geochemistry

Chemical analysis of one of the representative samples of the ultramafic enclave rock performed at the Institute of Electron Optics, University of Oulu, Finland, using Siemens XRF (Model SRS-303) is given in Table 2 A perusal of the

Table 1 Microprobe analyses of minerals in the Naregal ultramafic enclave

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Olivine		Cr Mg*	Phlogopite			Tremolite			Anthophyllite			
SiO_2	39 35	39 69	0 00	41 94	41 13	41 62	57 06	56 89	55 32	57 44	57 38	56 83	57 32
TiO_2	0 00	0 01	0 28	0 42	0 55	0 64	0 10	0 07	0 11	0 00	0 01	0 07	0 00
Al_2O_3	0 01	0 00	0 00	11 97	12 69	12 62	0 56	0 71	1 53	0 09	0 11	0 05	0 05
V_2O_3	0 01	0 02	0 17	0 00	0 00	0 01	0 02	0 00	0 00	0 00	0 00	0 05	0 03
Cr_2O_3	0 01	0 02	5 58	0 21	0 48	0 35	0 03	0 07	0 10	0 04	0 03	0 01	0 10
Fe_2O_3			59 65										
FeO	17 58	17 27	29 17	4 28	4 55	4 45	3 41	3 58	4 01	10 85	10 65	10 85	10 87
MgO	42 92	42 25	0 15	24 79	24 43	24 68	23 06	22 59	22 12	26 99	26 56	26 56	27 01
MnO	0 40	0 43	0 09	0 08	0 04	0 02	0 19	0 12	0 16	0 54	0 61	0 80	0 59
NiO	0 36	0 42	0 55	0 18	0 26	0 24	0 13	0 10	0 13	0 14	0 08	0 15	0 16
ZnO	0 05	0 00	0 00	0 03	0 05	0 06	0 00	0 00	0 00	0 00	0 00	0 03	0 05
CaO	0 00	0 00	0 00	0 02	0 10	0 01	12 02	12 41	12 22	0 73	0 73	0 66	0 70
Na_2O	0 03	0 04	0 01	0 15	0 19	0 18	0 18	0 24	0 34	0 01	0 02	0 00	0 05
K_2O	0 01	0 02	0 00	10 00	10 16	10 12	0 03	0 05	0 10	0 01	0 00	0 00	0 00
Total	**100 7**	**100 2**	**95 65**	**94 07**	**94 63**	**95 00**	**96 79**	**96 83**	**96 14**	**96 84**	**96 18**	**96 06**	**96 92**
Si	0 996	1 008	0 000	6 032	5 901	5 937	7 923	7 906	7 774	7 983	7 970	8 005	7 964
Ti	0 000	0 000	0 010	0 043	0 061	0 069	0 009	0 009	0 009	0 000	0 000	0 000	0 000
Al	0 000	0 000	0 000	2 022	2 139	2 125	0 083	0 117	0 253	0 017	0 017	0 017	0 017
V	0 000	0 000	0 010	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000
Cr	0 000	0 000	0 180	0 017	0 052	0 034	0 000	0 000	0 017	0 000	0 000	0 000	0 000
Fe^3			1 800										
Fe^{2+}	0 372	0 365	0 980	0 518	0 544	0 531	0 392	0 417	0 473	1 261	1 259	1 242	1 259
Mg	1 619	1 598	0 010	5 314	5 228	5 243	4 770	4 675	4 634	5 546	5 585	5 530	5 587
Mn	0 009	0 009	0 002	0 009	0 009	0 000	0 025	0 017	0 017	0 076	0 067	0 076	0 067
Ni	0 008	0 009	0 000	0 017	0 026	0 026	0 017	0 008	0 017	0 008	0 017	0 008	0 007
Zn	0 002	0 000	0 020	0 000	0 009	0 009	0 000	0 000	0 000	0 000	0 000	0 000	0 000
Ca	0 000	0 000	0 000	0 000	0 017	0 000	1 785	1 845	1 840	0 101	0 108	0 109	0 100
Na	0 000	0 004	0 000	0 034	0 052	0 052	0 050	0 066	0 084	0 000	0 000	0 000	0 016
K	0 000	0 000	0 000	1 832	1 864	1 834	0 000	0 000	0 016	0 000	0 000	0 000	0 000
Mg/Fe	4 352	4 378		10 259	9 610	9 874	12 168	11 211	9 797	4 436	4 452	4 394	4 438

Chromiferrous magnetite [1] Calculated

Table 2. Comparison of chemical analysis of Naregal ultramafic enclave with Barberton komatiite and Wajrakarur kimberlite

Sl. No	Major elements 1	2	3	Trace elements	1	2	3
SiO_2	43.26	42.1	39.56	V	63	48	
TiO_2	0.41	0.33	1.36	Cr	2593	2737	1163
Al_2O_3	3.52	2.73	3.59	Ni	2126	1535	1651
Fe_2O_3	16.51	10.83	9.88	Cu	56	42	
MnO	0.35	0.17	0.14	Zn	128	92	
MgO	29.03	30.54	31.71	Ga	6	4	
CaO	2.84	4.26	6.12	Rb	73	2	
Na_2O	0.13	0.15	0	Sr	10	15	
K_2O	1.88	0.03	1.25	Y	8	4	
P_2O_5	0.07	0.04	0.44	Zr	47	31	
F	0.04			Nb	3		
LOI	1.21		5.62	Cs	12		
CaO/Al_2O_3	0.81	1.56	1.7	Ba	134	33	152
Al_2O_3/TiO_2	8.58	8.27	2.64	Hf	3		
Mg#	60.27	70.87	73.47	Pb	3		
				MO	3		
				Th	4		
				U	4		
				Cl	156		
				Sc	9		
				As	3		
				Ho	3		
				La	11		60
				Ce	37		125
				Pr	11		
				Nd	15		47
				Gd	5		4
				Dy	7		
				Er	2		

1 - GD-59: Naregal ultramafic enclave
2 - Average of 24 peridotite komatiite samples from Barberton (Glikson, 1983)
3 - Average chemical analysis of WA-4 Wajrakarur (kimberlite) pipe, Anantapur district, Andhra Pradesh (Burhanuddin, 1993)

data presented reveals low Al_2O_3, TiO_2, CaO, Na_2O, V, Sr and high MgO, K_2O, Cr, Ni, Rb, Ba and Cl of the rock. While its chemistry is comparable to average *peridotite komatiite* from Barberton (Glikson 1983) (Table 2, no.2) with similarly high MgO, Ni, Cr and low Al_2O_3 and TiO_2, in respect of high K_2O, Rb, Zr, Ba and Cl, it shows semblance to one of the *(kimberlite) pipe rocks* reported from Wajrakarur (Burhanuddin 1993) (Table 2, no.3). However, CaO/Al_2O_3 viz. 0.8 of Naregal ultramafite is significantly lower than both komatiite and kimberlite. While the primitive mantle normalized pattern obtained for several of the LIL elements of Naregal ultramafite is comparable to that of average peridotitic komatiite from Barberton (Fig. 3), the distinctly

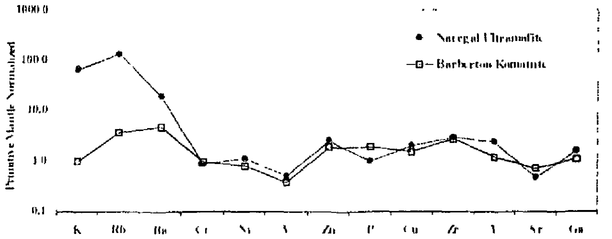

Fig.3. Comparison of primitive mantle normalized patterns of a Barberton komatiite and Naregal ultramafite in respect of selected trace elements. Note significant enrichment of K, Rb and Ba, in the Naregal ultramafite, otherwise closely similar patterns of the two.

high K, Rb and Ba values suggest approximate semblance of the former to kimberlite. Strictly it is neither the same as Barberton peridotite komatiite nor Wajrakarur kimberlite. It is a type in itself both mineralogically and geochemically and the authors have not come across any reported examples, especially from Karnataka craton, exactly matching Naregal ultramafite.

Discussion and Conclusions

Mafic-ultramafic enclaves are not unusual in the migmatite gneisses of southern Peninsular India. Some authors have interpreted, specially the ultramafic enclaves as representing relics of the oldest recognizable Sargur Supracrustal Group (Swami Nath and Ramakrishnan, *1981*; Radhakrishna and Vaidyanadhan, 1997; Srikantia and Bose, 1985). The Naregal ultramafic enclave rock described here has the following features, which need to be taken into account whilst commenting on its petrogenesis.

1. Location in the northern block of Western Dharwar Craton with an overall low-grade metamorphic impress.
2. Occurrence engulfed in a polyphase migmatite gneiss.
3. Lack of evidence of assimilation despite being dismembered and permeated by pegmatite veins along the borders.
4. Massive fabric, preservation of almost fresh Mg-rich olivine and absence of pyroxenes.
5. Occurrence of hydrous minerals, tremolite and phlogopite as major minerals.

As compared to abundant associated mafic rock (viz. amphibolite), which shows marked stretching, preferred orientation involvement in assimilation with the granitic neosomes (*see* Fig.1), the ultramafic enclave rock with its massive and compact fabric shows only physical dismemberment. Mineral assemblage/compositions and whole rock geochemistry are indicative of formation of the Naregal enclaves from ultramafic magma derived from a mantle source. From the absence of direct evidence of assimilation of potassic crustal rocks during the upward passage of ultramafic magma it is presumed that the potassium needed for phlogopite formation was present in the ultramafic magma itself. While low silica activity in the system favoured preservation of fresh olivine, high water pressure possibly facilitated formation of abundant hydrous mineral phases of the rock (*see* Evans 1982). We propose preemplacement crystallization of olivine in the magma chamber and formation of amphiboles and mica upon emplacement of ultramafic magma to crustal levels. Equilibrium association of fresh olivine with abundant amphiboles with no obvious replacement relationship between the minerals is still an enigmatic feature. Further it is inferred that the ultramafic enclave and the associated abundant mafic (amphibolite) and rare metasedimentary lenses noted are all portions of relics of pristine crust that existed when the monzogranite-tonalite palaeosome of migmatitic gneiss invaded about 3.3 Ga ago (this is the model Sm-Nd age obtained by us for the palaeosome of host migmatite gneiss). It is also surmised, considering specially the mineralogy of ultramafic and metasedimentary enclaves that the Naregal block has perhaps exposed deep crustal section. Evidence of major faulting picked up in the area (*see* Chadwick et al. 2000) probably also suggests that we have at Naregal an uplifted block of deep crust. As already mentioned, the northern block of WDC otherwise typically exposes upper crustal section.

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