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PETROTECTONICS OF OLIVINE DOLERITE INTRUDING ALMORA NAPPE, KUMAUN LESSER HIMALAYA

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Abstract

Fresh mafic rocks are markedly rare in the Lesser Himalayan nappes. In the Almora Nappe of Kumaun Lesser Himalaya the olivine dolerite reported some 60 years back from Ranikhet continued to be the lone intrusive of its kind into the prograde metamorphic sequence reaching K-feldspar – sillimanite grade metamorphism till about ten years back when another similar dyke was reported from Khunt area in the Almora Nappe. The occurrence of unmetamorphosed dykes intruding these metamoprphics comprising Almora Nappe raises issues of particular relevance from a tectonic perspective in the Himalaya. Preservation of the original mineralogy and texture of these dykes within the metamorphics evidences absence of any appreciable post intrusive thermal perturbation in the Almora Nappe. This inference would necessitate an extensional episode that opened fractures tapping the mantle to bring basic magma to much shallower levels -- a largely unlikely possibility during the compression that led to the collisional tectonics leading to Himalayan Mountains.

Key words : Kumaun Himalaya, collisional tectonics, extensional tectonics, metamorphism, mafic, dyke.

Introduction

The Himalayan mountain chain formed due to continent – continent collision and the Higher Himalayan Metamorphic Belt (HHMB) has been tectonically transported some 100km southwards over the Main Central Thrust (MCT) during the Tertiary Himalayan Orogeny. The erosion assisted by tectonic uplift has been responsible for the present disposition of nappes and klippes all over the Lesser Himalayan autochthon (Gansser, 1964; Valdiya, 1980). One such southward transported rock package, viz. the Almora Nappe carries at least two mafic dykes, intruding the Lesser Himalayan metamorphics. The metamorphics show multiple deformation (Gairola and Joshi, 1978) and polyphase metamorphism (Joshi et al, 1994; Joshi and Tiwari, 2004, 2007, 2009), which is well preserved in the central parts of the Almora Nappe that escaped shearing (Joshi, 1990). The mafic dykes are also known to be intrusive into the various units of the underlying autochthon / paraautochthon (Valdiya, 1980).

These relatively unaltered mafic dykes intruding the Lesser Himalayan Almora Nappe are of particular interest. The olivine dolerite dyke reported by Sharma (1962) in Ranikhet and the unaltered mafic dyke near Khunt (west of Almora town, first reported by Joshi in 2006 in a project proposal submitted to the DST, New Delhi), both of which intrude the Lesser Himalayan metamorphics (LHM) of Almora Nappe, are of special importance because they intrude the Tertiary (?) metamorphics and are still unaltered. Location of the area comprising part of the Almora Nappe is shown in Fig. 1.

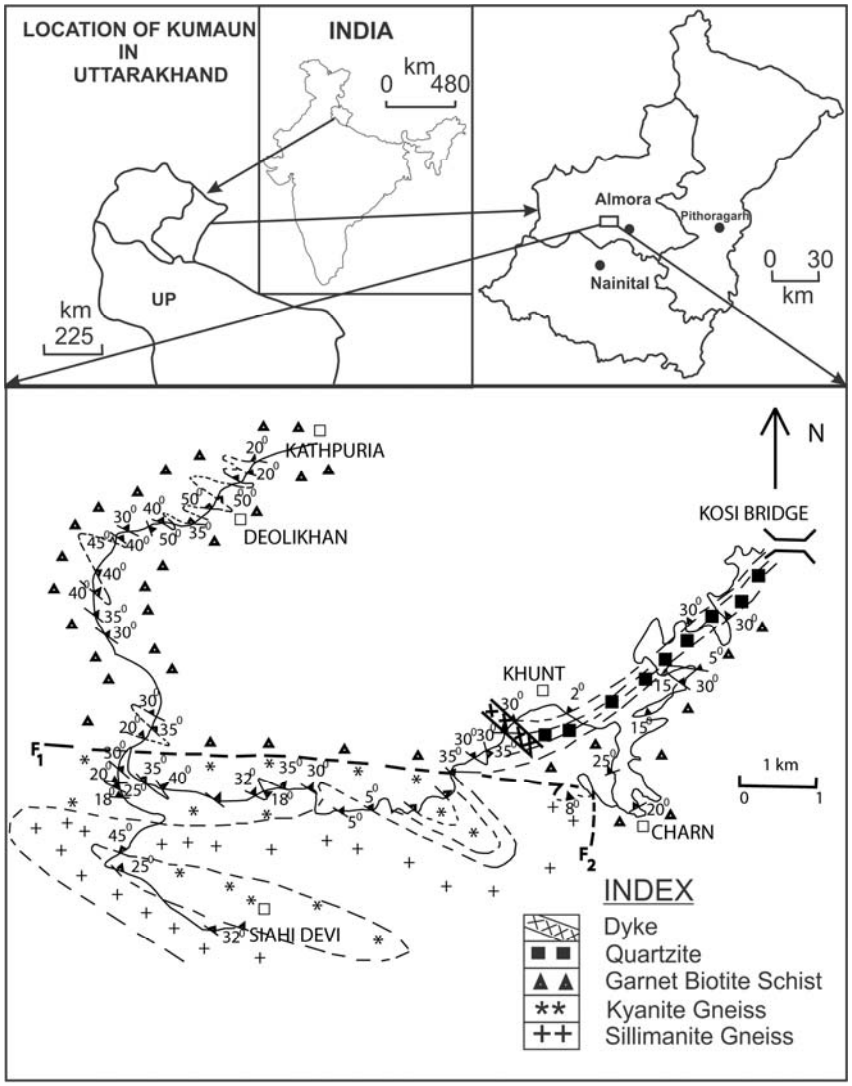

Fig.1 Geological map of the area showing the rock types, structural details and the dolerite dyke.

The host metamorphics have undergone regional metamorphism up to the upper amphibolites facies conditions, reaching temperatures in excess of 700^0C and pressure around 8 kbar (Joshi and Tiwari, 2004; 2005, Joshi et al, 2013). Interestingly these studies suggest that the central parts of Almora Nappe comprising these metamorphics are largely unaffected by Tertiary metamorphism and likely carry the vestiges of a Pre-Himalayan metamorphism preserved in the central parts of the nappe (Joshi et al., 1994, Joshi and Tiwari, 2004).

There are also older amphibolite dykes and sills which intrude the regional metamorphic sequence of Almora Group of rocks and the field relationships suggest that they have been metamorphosed during the regional metamorphism of the Almora Group of rocks.

Mafic rocks also intrude the Ramgarh Group of rocks (Singh, 1990) of the Kumaun Himalaya. Relatively unaltered mafic dykes are also recorded from the underlying low grade metasedimentaries from many areas including Nainital, Bhimtal, Ladhiya valley and Ratighat (Sinha, 1976 in Valdiya, 1980, Valdiya, 1980 and Valdiya-personal communication). Many basic rocks are emplaced in the rock units underlying the MCT in the north, particularly in the Bhatwari Formation (Valdiya, 1980).

Most of these unaltered mafic dykes are of doleritic or gabbroic composition. A detailed study of dykes intruding the Almora Nappe, particularly the olivine – bearing mafic and other dolerite dykes along with the unaltered dykes intruding the autochthon / paraautochthon are of special interest for providing time and tectonic constrains for better understanding of this part of Himalaya.

The olivine bearing mafic dykes raise and are capable of answering many significant questions about the changes in tectonic setting during the evolution of the rocks comprising this part of the Himalaya. Occurrence of fresh olivine dolerite dykes in a Lesser Himalayan nappe is particularly intriguing as to (1) how the dykes could be intruded in a compressional regime a collisional mountain belt is supposed to be? or (2) whether they could be survivors from an old extensional episode?

Petrography

These melanocratic, unusually fresh, fine to coarse grained olivine dolerite dykes characterized by ophitic to subophitic texture are defined by association of lath-shaped euhedral to subhedral laths of plagioclase with surrounding or interstitial large anhedral crystals of pyroxene. Plagioclase and clinopyroxene comprise most of the thin sections while olivine is the next most abundant mineral in the core of the dyke. Modal percentage of hornblende and biotite increases as the margins of the dyke are approached. Important accessory minerals are iron and titanium oxides, apatite and sphene.

Plagioclase

Unusually light yellowish brown in colour, the plagioclase laths commonly

form an irregular mesh but are at times grouped radially. Although rare plagioclase laths exceed 5mm in length but 1mm laths is the rule. Plagioclase shows lamellar, pericline and polysynthetic twinning. The central unaltered parts of the dyke are characterized by plagioclase and 'clinopyroxene + olivine' occupying roughly equal modal proportions. Towards the margin of the dyke, particularly close to the contact with the country rocks, the modal proportion of hornblende and biotite increases at the expense of clinopyroxene and olivine suggesting ingress of water and concomitant mineralogical reactions. The plagioclases are markedly unstrained in the core of the dyke and there is very limited strain effect close to the contact apparently associated with the deformation during the intrusion itself. On the basis of chemical analysis on EPMA the plagioclase comprises 54% anorthite, 45% albite and 0.9% orthoclase.

Pyroxenes

Both the orthropyroxene and the clinopyroxene occurring as medium to coarse grained subhedral and anhedral grains have been identified under the microscope. Clinopyroxenes characterized by bright second order interference colours and inclined extinction dominate the assemblage while the orthopyroxenes showing first order grey and yellow colours with straight extinction comprise the subordinate modal amounts. Both the pyroxenes show two sets of perfect cleavage at 93 and 87 degrees. Both the pyroxenes are involved in the ophitic/ subophitic texture.

Fig.2 Left : Porphyritic pyroxene measuring up to 1cm (Paper clip = 2.8cm). Right: subophitic texture in olivine dolerite. Notice the olivine in the central parts, plagioclase laths and clinopyroxene (black bar=500 microns)

Olivine

Very pale yellow coloured anhedral grains, generally measuring close to 1mm are quite common. Very high relief of the olivine grains along with the pale yellow to yellow pleochroism favours their identification as fayalite. Serpentine and magnetite comprise the material in the ubiquitous cracks within olivine. The persistent reaction rim between olivine and calcic plagioclase suggests that in all likelihood gave rise to orpthopyroxene + sodic plagioclase rim by the reaction:

$$2xpl + 6ol => 12\ opx + 2(x\text{-}x^{2})\ an + x^{2}\ Na\text{-}fluid$$

where x is the mol fraction of albite in plagioclase (Turner and Stuwe, 1992). These reactions are unlike the ones recorded by Sharma et al. (1987) from Sandmata area in Rajasthan, as the latter formed as a consequence of metamorphism of a norite dyke intruded during waning stages of metamorphism, while the Khunt dyke was intruded into cold rocks. A passing reference has also been made by Singh and Kumar (2010) to these coronas. The chemical analyses by EPMA confirm that the olivines are essentially fayalite (Fa) and the Fa component marginally increases from 53.3% in the core to 59.6% in the rim suggesting increase in Fe content and impoverishment of magnesia of the basic magma with its evolution.

Pyroxene

Clinopyroxene (diopside and augite) grains are more common than orthopyroxenes and are involved in the ophitic texture. Clinopyroxenes are characterized by second order interference colours and inclined extinction while the few orthopyroxenes grains show first order interference colours and parallel extinction. Inclusions of magnetite and ilmenite are seen in both the pyroxenes. A representative EPMA analysis of clinopyroxene grain yielded wollastonite (Wo) = 36.99, enstatite (En) = 38.36 and ferrosilite (Fs) = 24.66%. Thus it is clearly a calcic pyroxene. Ti contents of pyroxenes indicate that these are titanium rich pyroxenes with TiO_2 reaching up to 1.26 wt %.

Amphiboles, biotites and chlorites occur as retrogression products in the dolerites in the vicinity of the country rocks through ingress of water from the latter during the intrusion and consequent retrograde reactions at the ambient physical conditions. Amphiboles with characteristic two set cleavage at 124^{o} are pleochroic. The trichroism varies from light yellowish green to light green, from light green to dark green and from light greenish yellow to dark green. Amphiboles show masked second order interference colours. Biotites are seen intimately associated with both the amphiboles and the chlorite. Light brown biotite flakes show pleochroism from light brown to dark brown, straight extinction and masked second order interference colours. In cases of more severe retrogression chlorites have developed. Chlorite flakes show one set perfect mica cleavage, straight extinction, light green to dark green pleochroism, and first order grey interference colours. At places blotchy chlorite is also developed.

Well developed euhedral magnetite and anhedral ilmenites occurring both as inclusions within the pyroxenes and plagioclase and also in the intergranular space and apatite and sphene are the important accessory minerals.

Chemistry

The bulk chemistry of 5 representative dolerite samples analyzed at the Wadia Institute of Himalayan Geology, Dehradun, on XRF is given below. Care was taken to pick fresh samples from the central parts of the dyke representing grain size variations

from fine to coarse to make them representative. The major oxides (in wt. %), and trace elements including REE (in ppm) are given in Table-1.

Table 1: Major oxides (in wt. %), and trace elements including REE (in ppm) for the Khunt olivine dolerite dyke

Sample No.	**A7**	**AB2**	**AK4**	**AK7**	**BD3**
Major oxides					
(%)					
Na2O	2.87	2.86	2.85	2.81	2.31
MgO	5.1	5	5.07	5.09	6.23
Al2O3	13.91	14.08	14.04	14.1	12.56
SiO2	49.09	48.92	49	48.94	45.97
P2O5	1.73	1.69	1.68	1.63	1.4
K2O	2.4	2.4	2.37	2.28	2.54
CaO	8.76	8.7	8.81	8.96	8.64
TiO2	4.03	3.82	4.02	4.03	3.75
MnO	0.17	0.16	0.17	0.17	0.18
Fe2O3	12.33	11.7	12.03	12.06	14.2
SUM	100.39	99.33	100.04	100.07	97.78
Trace elements					
(ppm)					
Ba	1256	1242	1188	1190	1280
Cr	73	90	87	128	77
V	308	300	316	317	359
Sc	56	52	53	56	57
Co	36	34	32	37	34
Ni	34	35	35	39	30
Cu	24	21	21	25	22
Zn	102	94	100	102	130
Ga	22.16	21.6	21.04	20.99	21.87
Pb	3.8	3.5	4.3	4.7	15.9
Th	1.78	1.82	1.27	1.18	1.09
Rb	18	18	18	17	22
U	0.95	0.97	0.96	0.97	0.95
Sr	1014	1025	1012	1031	1008
Y	22	21	21	21	24
Zr	148	144	144	140	155
Nb	12.8	12.8	12.4	12.1	14

The chemical data are plotted in tectonic discrimination diagrams shown in Fig. 3.

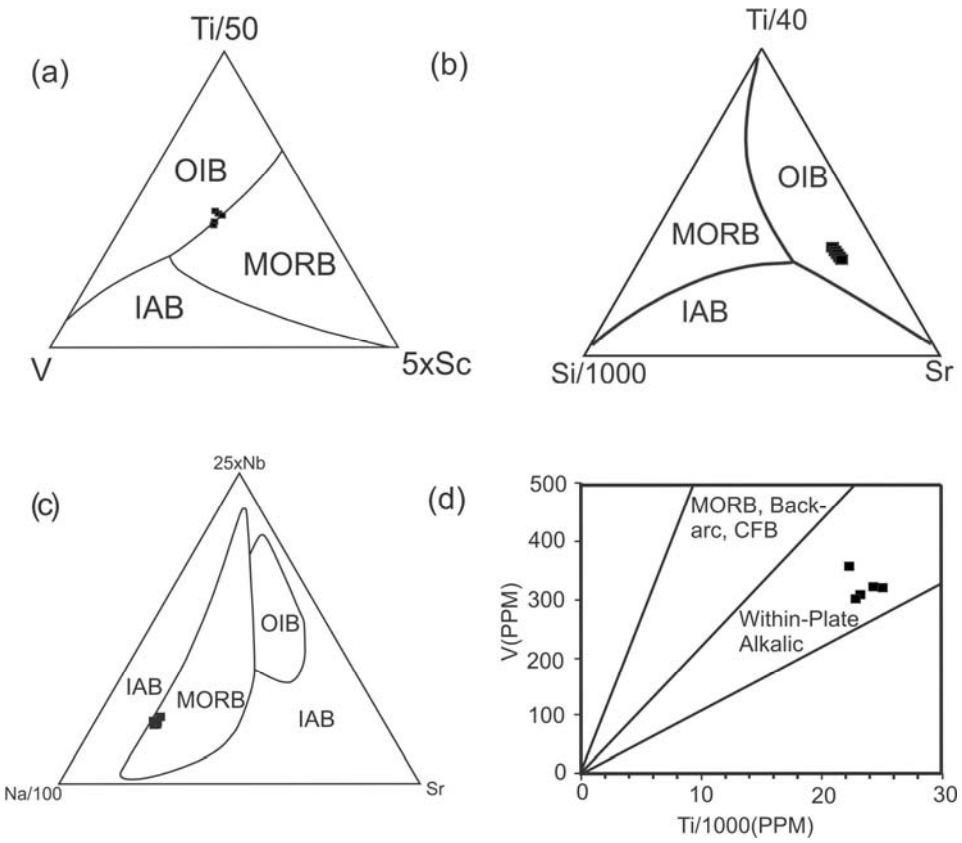

Fig. 3 : Tectonic discrimination diagrams. (a) Ti-Sc-V diagram, (b) Ti-Si-Sr diagram and (c) Nb-Na-Sr diagrams of Vermeesch (2006). (d) V-Ti diagram modified after Shervais (1982)

The analyzed samples plot in the OIB, MORB and IAB plots (Vermeesch, 2006), which are considered to be more reliable for discriminating the tectonic environments. The three plots are univocal in suggesting that the magma was largely uncontaminated from the crust in respect of V, Ti, Sc, Sr and Nb, suggesting a quick ascent of the magma. The V-T diagram modified after Shervais et al. (1982) however shows Within Plate Alkalic signatures reflecting assimilation during the magma's movement through the crust.

Discussion and conclusions

The fresh olivine dykes were intruded into the metamorphosed amphibolite facies schists and gneisses of the Almora Nappe and the dolerite shows chilled borders with the grain size increasing from the margins towards the central parts of the dyke. It is clear that the intrusion post dates regional metamorphism of the country rocks and is a consequence of a post metamorphic extensional event that is highly unlikely to be of Himalayan (Tertiary) age as there is no evidence of any extensional event strong

enough to tap the mantle during the Himalayan orogeny. The only other known extensional event in the region is the sill like Champawat Granitoid intrusion and its equivalent intrusives discussed by Singh et al.(1993) in the Almora Nappe, who suggested 'A'-type affinities for the Champawat Granitoids. These granitoids have been dated at 560±20 Ma by Trivedi et al. (1984) by Rb-Sr method. Identification of the contact aureoles developed around the Champawat Granitoids in the eastern part of the nappe by Joshi et al. (1994) clearly brought out the hot intrusive nature of the intrusion. McMahon (1887) has recorded dolerite dykes from Chor mountain of Himachal Himalaya -- a tectonic setting quite similar to that of the Almora Nappe and it would be interesting to work in some detail on those dolerites to understand similarities and differences between the two for discussing the regional implications of these dykes .

Ar - Ar whole rock dating by Joshi et al. (2015) has yielded a date of ~ 640Ma for the olivine dolerites. Interestingly, the plateau ages, the isochron ages and the inverse isochron ages are tightly constrained around 639Ma with the error ranges between ±2.3 and ±5.6 Ma for the two samples of the Khunt dyke. Putirka's (2008) barometry yielded pressures in the range of 2.8 to 4 kbar. Joshi et al. (2015) estimated temperatures around 990^{o}C employing Nimis & Taylor (2000) for the dolerites. Pressures around 3kbar have also been estimated by Joshi et al. (1994) for the contact metamorphism induced by Champawat Granodiorites in the Almora Nappe. As the topographic levels of emplacement for the granitoids and the olivine dolerite dykes are comparable, it is not unlikely that the Champawat Granitoids dated at 560±20 (Rb-Sr, Trivedi et al. 1984) and the Cryogenian dykes have a time connect albeit with any downward refinement of the Rb-Sr granitoid ages which is not unlikely.

There is no major rift event known in the Cryogenian period of Neoproterozoic Era from the metamorphics of the Kumaun Lesser Himalaya. Geochemically the plots of the analyzed dolerites fall in the OIB, MORB and IAB fields of Vermeesch(2006), which suggests little contamination from the crust while some of the plots falling in the Within Plate Alkalic filed of the V-Ti discrimination diagram (modified after Shervais, 1982) suggests some assimilation of the crustal material and partial contamination. Although a bit speculative, but it is not unlikely that the granitoids and the olivine dolerite dykes may turn out to have bimodal relationships provided the age of the granitoids dated by Rb-Sr method is revised downwards. These isolated dykes within the metamorphic ensemble could also relate to Rodinian signatures with more detailed work in future.

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