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Mineralogy and Origin of Dumortierite from Girola Area, Bhandara District, Eastern Maharashtra

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Abstract: Dumortierite an aluminium borosilicate mineral occurring as aggregates of fibrous, nodular and displaying variable colours is found at Girola hill of Bhandara district. It is associated with kyanite, sillimanite, andalusite, muscovite (sericite), quartz, topaz, rutile, tourmaline and pyrophyllite. It is pink, violet and blue (indigo blue) in colour associated with quartz veins. It shows strong pleochroism from colourless to light pink and pale blue to violet (azure blue).

The structural formula of dumortierite is calculated as $Si_{2\cdot98}Al_{6\cdot81}B_{0\cdot98}O_{18}$ on the basis of X-ray analysis. Its origin is related to late stage pneumatolytic activity or due to interaction of hydrothermal solution rich in boric acid and titanium dioxide with alumina rich rocks.

Keywords: Dumortierite, Structural formula, Pneumatolytic activity, Girola, Bhandara.

INTRODUCTION

Dumortierite is known from Girola and Mogra area (55 O/16) of Bhandara district, Eastern Maharashtra (Chatterjee, 1930, 1931, and 1971; Bhoskar, 1982). It is associated with quartz veins and in metamorphites (schists). The associated minerals are polymorphs of aluminosilicates- kyanite, sillimanite and andalusite. Muscovite (sericite), quartz, topaz, rutile, tourmaline and pyrophyllite are secondary associates in the Girola area (Meshram, 2003, 2005; Meshram and Ingle, 2005). The other reported occurrences in India are in quartzite near Jaipur, Rajasthan (Murty et al. 1967), at Singhbhum Copper Belt, Bihar where it is found in quartz-schist at Rakha and in quartz-dumortierite-tourmaline-schist with a little sillimanite at west Khasi hills, Mawashinrum, Meghalaya (Prasad, 1996). This is also reported in tourmaline-quartz bearing pegmatite from Susunia Hill, Bankura district, West Bengal, India (Mahapatra and Chakrabarty, 2011).

At few localities in the world, it occurs as a minor constituent in pegmatitic, aplitic and granitic rocks (Finlay, 1907; Graham and Robertson, 1951; Huijsmans et al. 1982). It is associated with andalusite (Taner and Martin, 1993), pneumatolytic-hydrothermal deposits (Kerr and Jenny, 1935; Sabzehei, 1971; Black, 1973) and regionally metamorphosed rocks such as quartzite, para gneisses and granulites (Christophie-Michael-Leavy et al. 1959; Schreyer et al. 1975; Vrana, 1979; Takahata and Uchiyama, 1985; Beukes et al. 1987). The present paper deals about characteristics and origin of dumortierite in Girola area.

GEOLOGICAL SETTING

The Girola hill is located 1.5 km east of Girola (79°56' N; 21°03' E, 55 O/16) in Bhandara district of Eastern Maharashtra. The significant fundamental studies of the area were done by various workers (Dutta, 1908; Dunn, 1927; Sarkar, 1971; Adhikari, 1976). The area falls within Sakoli Fold Belt and Roy et al. (1994) given lithological description of SFB (Fig.1).

The Sakoli group of rocks is occurred in the Sub-traingular Supracrustal belt of Central Indian Peninsular shield (CIPS) (Sarkar, 1957-58). The Supracrustal belt of middle amphibolite facies is folded volcano-sedimentary sequence. The dominant rock types are quartz-chlorite-muscovite schist (± magnetite ± andalusite ± chloritoid ± garnet ± staurolite). Phyllite and slate with quartz-pyrophyllite veins exposed at a few places in NE part of the area. It is buff coloured, fine grained and soft with soapy feel at places. The general strike of the rock is NNE-SSW with steep dip of 58° to 68° due east (Meshram, 2003). Gabbro-dolerite, granite-pegmatite and quartz veins intruded the sequence as concordant and discordant sheets.

Essentially the rocks are made up of a mixture of kyanite or sillimanite, tourmaline, rutile, quartz with some muscovite

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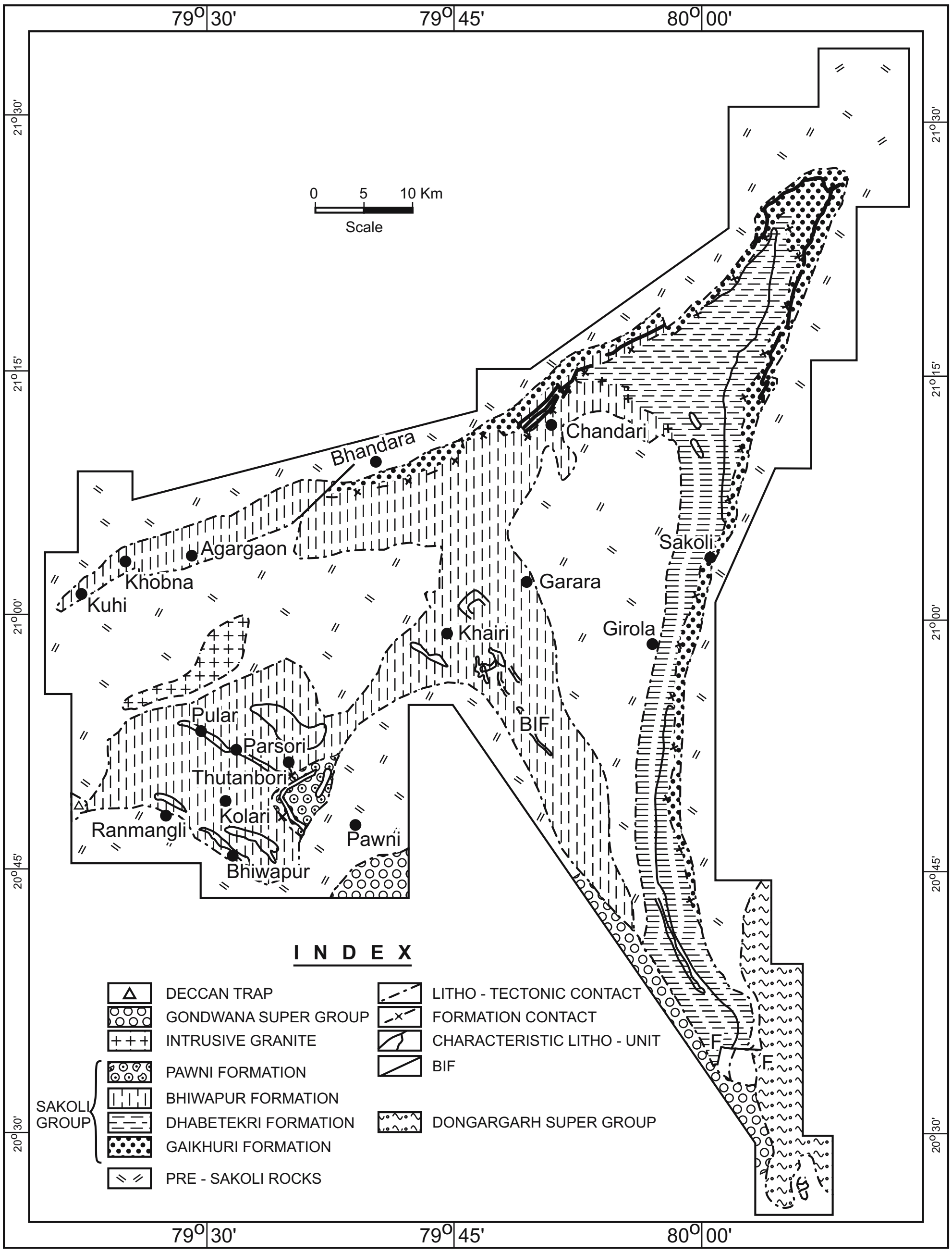

Fig.1. Geological map of Sakoli Fold Belt depicting location of Girola village, Nagpur, Bhandara and Chandrapur districts, Maharashtra, Central India (*after* Roy et al. 1994).

or sericite. Between the kyanitic rocks and chlorite-muscovite-schist intervened certain transitional rocks (phyllite?), which are cut through by abundant narrow veins or stringers of kyanite. The transitional rocks are fine-grained, compact and contain shreds of chlorite. The chlorite-muscovite-schist occurring at the foothill on the western side is highly tourmalinised and overlies a strip of exceedingly fine grained quartzite rich in rutile (Meshram, 2003).

The distribution of kyanite, sillimanite, andalusite and dumortierite is recorded. Dumortierite along with white or colourless topaz is found in the kyanite bearing rocks, where topaz is important accessory ingredient. The dumortierite is pink, violet and blue (indigo blue) in colour occurring within the quartz vein and sericite (muscovite) schist with altered andalusite (Fig.2A, B and C). The xenolith of metaphyllite is also noticed in the dumortierite vein (Fig.2D). It also occurs in the kyanite bearing rocks, where it is mostly

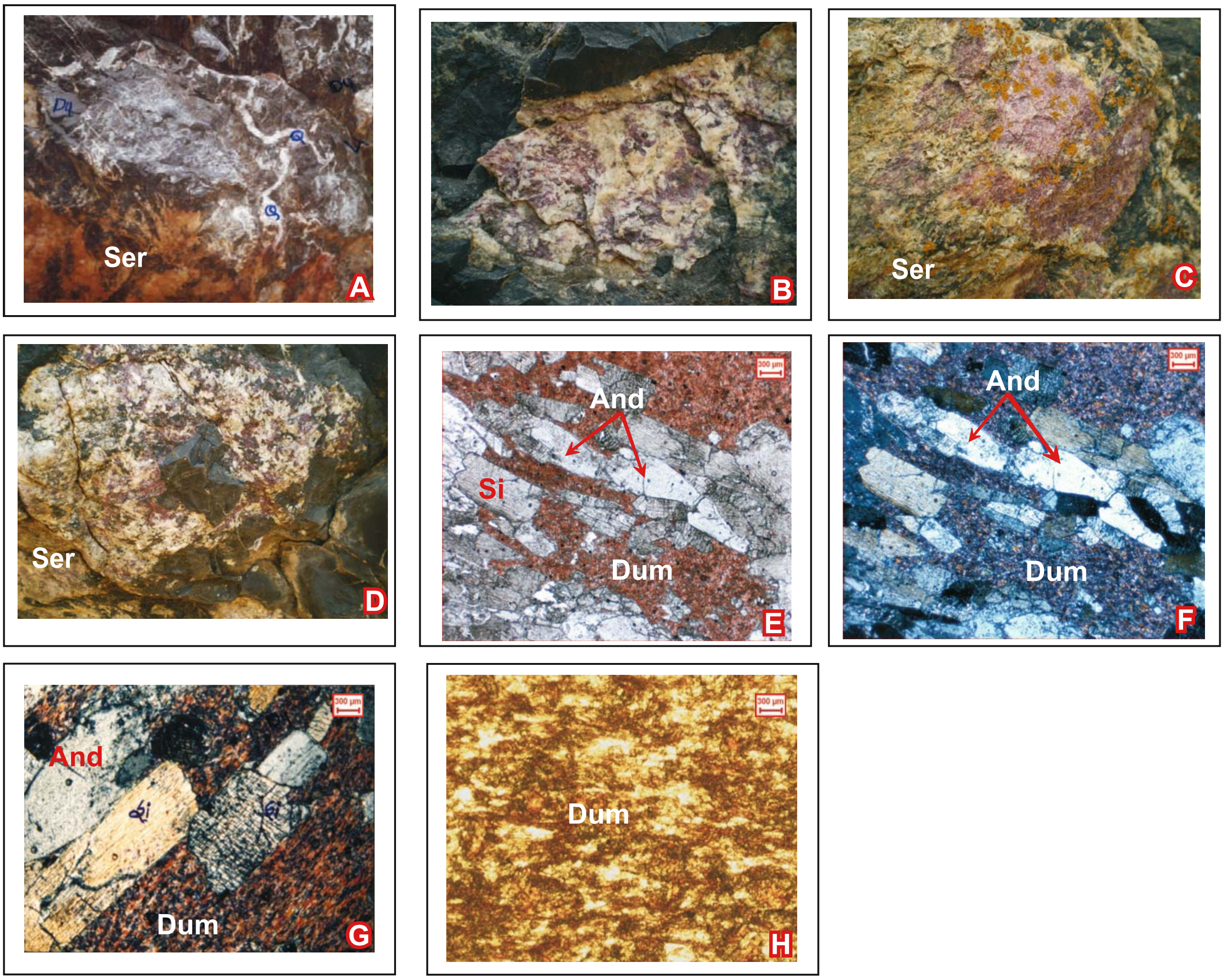

Fig.2. Field photographs **(A-D)** and photomicrographs **(E-H)** of dumortierite. **(A)** Quartz-dumortierite (Q-Du) veins and sericite in metaphyllite, **(B)** Quartz-dumortierite (purple) veins in metaphyllite, **(C)** Pink dumortierite in metaphyllite, and **(D)** xenolith of metapyllite in purple dumortierite-sericite vein. **(E)** Pink colour fibrous aggregates of dumortierite associated with sillimanite and carat shaped andalusite, **(F)** The fibrous aggregates of dumortierite showing violet and blue colours (in cross nicol), **(G)** Pink colour fibrous aggregates of dumortierite associated with sillimanite and carrot shaped andalusite (ppl) and **(H)** Pink coloured dumortierite showing sieve texture (PPL). *Abbreviations:* And - andalusite, Si- sillimanite, Ser - sericite and Dum - dumortierite.

found as poikilitic inclusions of acicular crystals, long, within kyanite, either along the cleavage planes or without an apparent order of distribution. Laths of it are occasionally found cutting through any other mineral in the kyanitic rocks. The quartz, kyanite and pyrophyllite are main associates while rutile, tourmaline and roscoelite (vanadium bearing mica) are minor associates.

PETROGRAPHY

Diagnostic feature of dumortierite is its strong colour, pleochroic scheme, high relief and extinction. The mineral is usually fresh and seldom sericitised. Dumortierite occurs in the form aggregates and needle shaped mineral of varying colours and shows strongly pleochroism from colourless to light pink and pale blue to violet (azure blue) to lavender. It also shows pleochroism from colourless to pink when associated with sillimanite and andalusite (Fig.2E and F). Sillimanite is light yellow coloured, and occurs as subidioblatic (prismatic) crystal within the aggregates of dumortierite. It shows fractures on its surface and well developed crystal outline. Andalusite is also colourless (light grey) and occurs as long carat shaped crystals which showing parallel extinction (Fig.2G) and aggregates of dumortierite form sieve texture (Fig.2H).

The colour of dumortierite is fascinating subject to many pioneer workers who studied this mineral since long time. It is commonly deep blue colour due to trace of Ti_2O_3 (Damour, 1881), various hues of green (Linck, 1899; Rimann, 1914), deep purple- red colour due to 1.5 % of Ti_2O_3 (Schallar, 1905), blue colour due to Ti_2O_3 and red due to TiO_2 (Peck, 1926). Other colour variants are blue colour (Bowen and Wyckoff, 1926), purple brown (Brammal, 1928; Groves, 1928), colourless (pale yellow) to yellow (Wilson, 1929), and orange yellow colour (Aubel, 1931). The Fe and Ti are responsible for the blue or pink colour of dumortierite, depending on the relative importance of Fe^{2+}-Fe^{3+} and Fe^{2+}-Ti^{4+} charge transfers, respectively (Alexander et al. 1986). Based on the classification of colours by the ratio Fe/(Fe+Ti) in dumortierite (Alexander et al. 1986), the chemistry of Girola dumortierite lies in the blue colour region. If the pink, violet and blue colour of the dumortierite is related to the relative concentration of Fe and Ti, the Fe and Ti concentrations in this study are surprisingly low. Though the observed percentage of Fe and Ti are very small, and therefore it is doubtful hence the origin of colour of the dumortierite can not be explained satisfactorily by the ratios of these elements.

MINERALOGY

X-ray diffraction analysis of dumortierite was carried out by instrument PANalytical X'Pert PRO XRD System at PPOD Lab, AMSE Wing, GSI, Bangalore. The results were recorded at 40 kV and 25 mA by counting at 2 s and step size of 0.017°θ. The major associated minerals with dumortierite are muscovite, kyanite, pyrophyllite and corundum while dravite (tourmaline), gobbinsite, diaspore and microcline are present in minor to trace amounts. The structural formula of dumortierite is calculated as $Si_{2\cdot98}\,Al_{6\cdot81}\,B_{0\cdot98}\,O_{18}$. The results of XRD mineralogy are given in Table 1 and X-ray diffractograms are given in Fig.3A and B. Dimensions of the unit cell were calculated and compared with dumortierite from various localities (Table 2).

The CAMECA X SS100 EPMA was utilized to carry out analysis of dumortierite thin polished section at PPOD Laboratory, Geological Survey of India, Bangalore and simultaneously BSE images were also taken (Fig. 4A and B). Analyses were performed with 15 keV acceleration voltage and 15nA beam current and total Fe determined as FeO. The molecular formula of the analysed dumortierites

Table 1. X-ray mineralogical composition of dumortierite from Girola area

Reference code	Compound Name	Chemical Formula	Remarks
Sample No. RM-1 Dumortierite			
01-084-1007	Du Dumortierite	$Si_{2\cdot98}\,Al_{6\cdot81}\,B_{0\cdot98}\,O_{18}$	Major
01-089-6216	Muscovite	$(K_{0.727}\,Na_{0.17}\,Ca_{0.011})\,(Al_{0.933}\,Fe_{0\cdot016}\,Mg_{0\cdot011})_2\,(Si_{0.782}\,Al_{0.221}Ti_{0.005})_4O_{10}\,(OH)_2$	Minor
01-072-1447	Kyanite	Al_2SiO_5	Minor
00-046-1308	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	Minor
01-083-1561	Dravite	$Na_{0.65}Ca_{0.27}Mg_{2.64}Al_{6.36}Si_6B_3O_{27\cdot50}\,(OH)_{3.50}$	Trace
Sample No. RM-2 Dumortic-sillimanite			
01-082-2450	Muscovite	$(Na_{0\cdot07}K_{0\cdot90}Ba_{0\cdot01})\,(Al_{1.84}\,Ti_{0\cdot04}Fe_{0\cdot07}\,Mg_{0\cdot04})\,(Si_{3\cdot02}\,Al_{0\cdot98})\,O_{10}(OH)_2$	Major
01-084-1007	Dumortierite	$Si_{2\cdot98}Al_{6\cdot81}B_{0\cdot98}O_{18}$	Major
01-082-1867	Gobbinsite	$Na_4\,Ca_{0\cdot94}\,(Si_{10.4}\,Al_{5\cdot6}\,O_{32})\,(H_2O)_{16.185}$	Minor
01-083-1561	Dravite	$Na_{0\cdot65}Ca_{0\cdot27}Mg_{2\cdot64}Al_{6\cdot36}Si_6\,B_3\,O_{27\cdot50}(OH)_{3.50}$	Trace
Sample No. RM-3 Dumortierite-muscovite schist			
01-077-2255	Muscovite	$KAl_2\,(Al\,Si_3O_{10})\,(OH)_2$	Major
00-011-0046	Kyanite	Al_2SiO_5	Major
01-084-1007	Dumortierite	$Si_{2\cdot98}Al_{6\cdot81}B_{0\cdot98}O_{18}$	Minor
00-046-1308	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	Minor
01-045-1340	Dravite, chromian	$Na_{\,0.24}(Mg, Al, Cr)_3Al_6(BO_3)Si_6O_{18}\,(OH)_4$	Trace
Sample No. RM-4 Dumortierite-kyanite-muscovite schist			
01-089-7717	Corundum	Al_2O_3	Major
01-084-1007	Dumortierite	$Si_{2\cdot98}\,Al_{6\cdot81}\,B_{0\cdot98}\,O_{18}$	Minor
01-089-6216	Muscovite	$(K_{0\cdot727}Na_{0\cdot170}Ca_{0\cdot011})\,(Al_0.9_{33}\,Fe_{0\cdot016}\,Mg_{0\cdot011})_2\,(Si_{0\cdot782}\,Al_{0\cdot221}Ti_{0\cdot005})_4O_{10}\,(OH)_2$	Minor
01-074-1879	Diaspore	Al O (OH)	Minor
01-087-1708	Kyanite	$Al_2\,(SiO_4)\,O$	Minor
00-022-0687	Microcline	$KAlSi_3O_8$	Trace

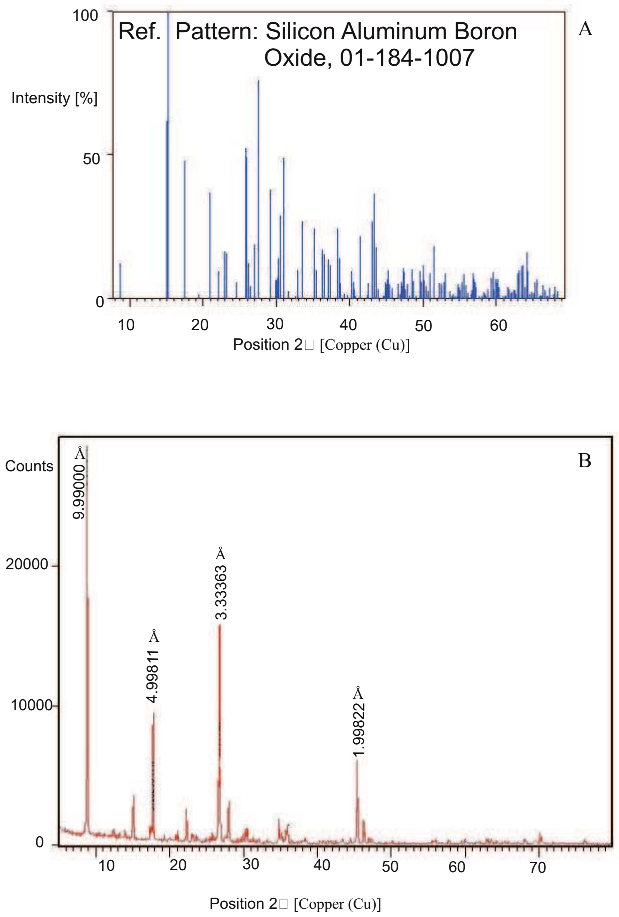

Fig.3. X-ray diffraction pattern for **(A)** dumortierite (Sample No. RM-1 to RM-4). **(B)** muscovite a major mineral associated with dumortierite (Sample no. RM-1 to RM-2).

was calculated on 18 oxygen atom basis (Table 3). Due to analytical constraint for 'B' determination by EPMA, the stoichiometric calculations were performed assuming 1B *apfu* and subsequently weight percentage of B_2O_3 was calculated on the basis of 1B *apfu* methods of Alexander et al. (1986) and (Choo and Kim, 2001).

Table 2. Comparison of unit cell dimensions of dumortierite from various localities

Locality	a (Å)	b (Å)	c (Å)	Volume (Å)
Girola	11.80	20.22	4.69	1121.27
Susunia Hill	11.79	20.21	4.71	1120.20
Miryang Mine	11.71	20.39	4.70	1129.48
Yuma County, Arizona	11.79	20.21	4.70	1119.30
Dehesa, California	11.79	20.20	4.69	1118.50
San Diego, California	11.78	20.18	4.69	1115.40
Virgin Mountains, Nevada	11.80	20.21	4.71	1123.10
Dora-Mara Massif, Italy	11.91	20.40	4.73	1149.00

(1 - Present study, 2 - Mahapatra and Chakrabarty, 2011; 3 - Choo and Kim, 2001; 4, 5, 6 & 7 - Alexander et al. 1986; 8 - Chopin et al. 1995).

Table 3. Microprobe analysis of dumortierite from Girola area

Na_2O	0.02	0.02	0.02	0.02	0.02	0.06	0.05	0.71
K_2O	0	0.03	0.02	0.02	0.01	0.04	0.03	9.75
MgO	0.32	0.3	0.47	0.37	0.37	0.37	0.44	0.33
CaO	0.02	0	0.02	0.02	0.01	0.04	0.01	0.04
MnO	0.04	0.03	0.01	0.03	0.05	0.04	0.05	0.02
FeO*	0.26	0.15	0.3	0.22	0.19	0.23	0.24	0.28
Al_2O_3	59.63	59.82	59.12	59.82	59.71	57.11	58.03	36.68
SiO_2	30.78	30.94	28.89	29.37	30.38	29.32	29.97	44.6
TiO_2	1.88	1.82	1.99	1.9	1.94	1.81	1.77	0.4
P_2O_5	0.04	0.01	0.95	0.56	0	0.05	0.02	0.02
B_2O_3**	6.51	6.51	6.46	6.48	6.49	6.38	6.43	6.39
Total	**99.47**	**99.58**	**98.24**	**98.76**	**99.16**	**95.47**	**96.99**	**99.2**
Na	0.01	0.02	0.01	0.02	0.01	0.04	0.04	0.53
K	0	0.03	0.02	0.01	0.01	0.04	0.02	8.1
Mg	0.19	0.18	0.28	0.23	0.22	0.23	0.27	0.2
Ca	0.01	0	0.02	0.01	0.01	0.03	0	0.03
Mn	0.03	0.02	0	0.02	0.04	0.03	0.04	0.01
Fe	0.2	0.11	0.24	0.17	0.15	0.18	0.19	0.22
Al	31.56	31.66	31.29	31.66	31.6	30.23	30.71	19.41
Si	14.39	14.46	13.5	13.73	14.2	13.71	14.01	20.84
Ti	1.13	1.09	1.19	1.14	1.16	1.09	1.06	0.24
P	0.02	0.01	0.41	0.24	0	0.02	0.01	0.01
O	45.43	45.52	44.81	45.08	45.27	43.5	44.24	43.22
B	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*Total Fe determined as FeO, **B_2O_3 determination by stoichiometry method of Alexander et al., 1986; Choo and Kim, 2001 and formula based on ^{18}O.

MAJOR ELEMENT GEOCHEMISTRY

Four dumortierite samples were analysed for major and minor elements by XRF using X'UNIQUE II (PHILIPS) X-ray Spectrometry System at PPOD Lab, AMSE Wing, Bangalore. The chemical composition of dumortierite from Girola area is given in the Table 4. Al_2O_3 and K_2O are higher while P_2O_5 is lower when compared to the normal dumortierite (Willner and Schreyer, 1991; Taner and Martin, 1993). Low amount of TiO_2 (0.28 to 1.10 %), lower contents of MgO (0.19 to 0.94) and moderate amount of $Fe_2O_3^T$ (0.56 to 2.52) are also observed in the dumortierite of Girola.

ORIGIN

Boron in dumortierite has been assumed to be present in three-fold coordination (Tagg et al. 1999). Dumortierite is the most favoured for 'B' after tourmaline. Boron is noted for being a mobile element in many geochemical environments and any introduction of 'B' into a system will potentially produce dumortierite as well as tourmaline (Henry and Dutrow, 1996). The dumortierite group consists

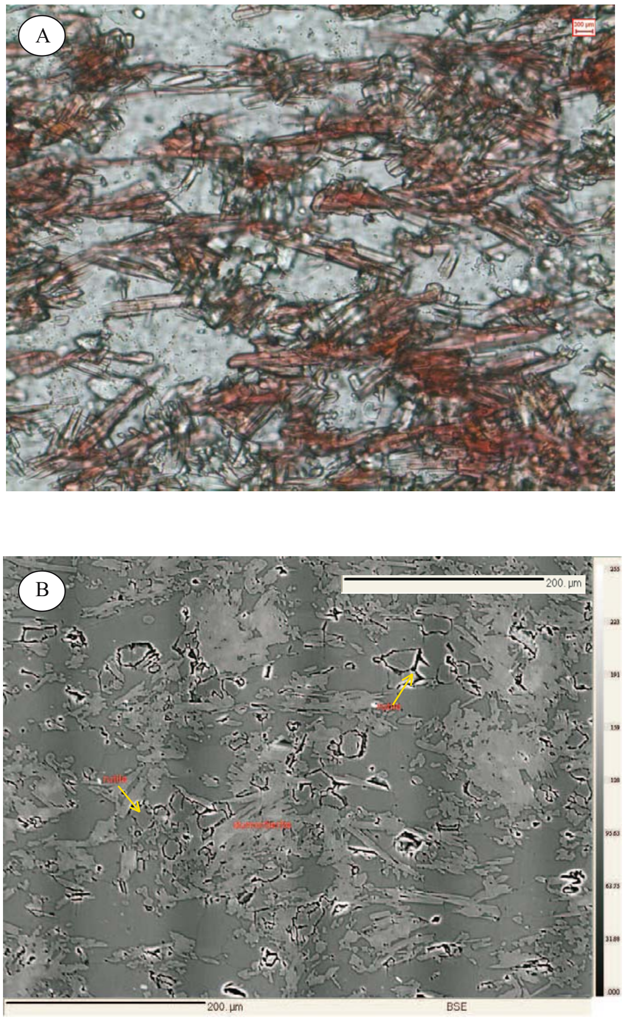

Fig.4. (A) Interlocking dumortierite crystals (PPL). **(B)** BSE image of interlocking dumortierite crystals and rutile.

of two types of minerals, namely, dumortierite and magnesiodumortierite. The transition from dumortierite to Ti-free magnesiodumortierite is favoured by increasing pressure (Chopin et al. 1995).

The ionic potentials of elements such as Fe, Ti and Mn with or without boron at normal temperature operate towards the breaking of Al-Si tetrahedron complex. The simultaneous liberation of silica and its partial leaching at slightly elevated temperature in the initial stages of hydrothermal alteration, which triggers in the rehabilitation of the Al-Si tetrahedron mixture with impoverished silica (Chatterjee, 1971). Hot boron rich liquid and water are essential ingredients in dumortierite (Clraringbull and Hey, 1958).

Dumortierite is formed due to external agency i.e. intrusion of hydrothermal solution in schist which is considered to have been rich in boric acid and titanium dioxide, with accessory fluorine, titanium fluorite, sodium fluoride, hydroxides and vanadium. If it is considered the

Table 4. Chemical composition of dumortierite from Girola area

Oxide	RM-1	RM-2	RM-3	RM-4
SiO_2	40.68	41.78	38.99	24.74
TiO_2	1.10	0.57	0.37	0.28
Al_2O_3	48.76	44.21	50.46	67.31
$Fe_2O_3^T$	2.52	0.56	1.26	0.93
MnO	0.01	bld	bld	0.01
MgO	0.94	0.63	0.67	0.19
CaO	0.74	0.28	0.37	0.59
Na_2O	0.35	1.21	0.39	0.19
K_2O	2.79	6.77	4.05	1.97
P_2O_5	0.15	0.07	0.30	0.55
S	0.11	0.08	0.12	0.08
NiO	0.01	bld	0.01	bld
BaO	0.01	0.02	0.03	0.03
LOI	1.82	3.82	2.96	3.12
Total	**99.99**	**100.00**	**99.98**	**99.99**

bld- below level of detection.

host lithologies of the Bhandara area as a composite unbuffered system, governed by an external agency, the pronounced shift of the hydrothermal liquor to alkalinity in the later phases seems to be reflected in the accretion of Ti^3 and Fe^2 in lieu of Ti^4 and Fe^3 for the development of dumortierite (Eugster, 1950). Ti^3 is credited, albeit partially, with imparting a charming lilac hue to the Bhandara dumortierite occurrence.

Dumortierite is found in sericite (muscovite) schist where andalusite has altered partly or fully to dumortierite due to late stage pnuematolytic activity. It also occurs in quartz veins that cut across the aluminous schist, and related to boron rich hydrothermal solutions. The EPMA analysis recorded B_2O_3 6.51% indicating strong enrichment in the hydrothermal solution during late stage pnuematolytic activity which caused the formation of dumortierite in Girola area.

CONCLUSION

The major minerals associated with dumortierite are muscovite, kyanite, pyrophyllite and corundum while dravite (tourmaline), gobbinsite, diaspore and microcline are in minor and trace minerals. It shows pleochroism from colourless to light pink and pale blue to violet (azure blue) in the form of aggregates of needle-like or fibrous crystals. Based on the classification of colours by the ratio Fe/(Fe+Ti) in dumortierite, the chemistry of Girola dumortierite lies in the blue colour region. The structural formula of dumortierite calculated as $Si_{2\cdot98}Al_{6\cdot81}B_{0\cdot98}O_{18}$ on the basis of X-ray analysis and EPMA analysis shows enrich B_2O_3. It is related to late stage pneumatolytic activity or due to intrusion of hydrothermal solution rich in boric acid and titanium dioxide in aluminous rich metamorphic rocks.

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