

## BLUE DUMORTIERITE FROM, HABARANA, SRI LANKA: FIELD OCCURRENCE AND MINERAL CHEMISTRY

L.V.RANAWEERA<sup>1</sup>, L.R.K.PERERA<sup>2</sup>, YOSHIKUNAI HIROI<sup>3</sup>

<sup>1</sup> *Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka*

<sup>2</sup> *Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka*

<sup>3</sup> *Department of Earth Sciences, Chiba University, Yayoicho, Inage-ku, Chiba 263 – 8522, Japan*

### ABSTRACT

---

Dumortierite, a rare aluminum-rich borosilicate, occurs in sillimanite-bearing granitic to pegmatitic veins in a pelitic gneiss at Veheragala quarry North of Habarana, Sri Lanka. The veins (thickness ~1 to 4cm) containing the mineral occur both parallel and oblique to the foliation of the host gneiss. The Dumortierite is bluish-violet in hand-specimen with a vitreous lustre and a blue streak. Under the plane polarized light it shows a characteristic deep blue colour and a strong pleochroism from ink blue to violet to colourless. It is biaxial negative and shows first-order to low second-order interference colours. In thin section, some grains of dumortierite display a notable optical continuity.

It occurs in the form of bladed, acicular, fibrous, columnar and xenoblastic grains in close association with sillimanite, andalusite, biotite, muscovite, quartz, alkali-feldspar, plagioclase, tourmaline and apatite. Acicular grains are either randomly oriented or show a flow texture. Fibrous grains radiate from a central grain of dumortierite. In places, dumortierite partially replaces sillimanite and biotite, and is also intergrowth with andalusite. Some grains of dumortierite gradually transform into tourmaline while intergrowths of tourmaline and quartz occur elsewhere in the veins.

The textural relationships in thin-section suggest a first stage of growth of dumortierite in matrix and as inclusions in minerals like quartz, possibly related to the crystallization of boron-bearing granitic magma at depth. A retrogressive stage of growth is suggested by dumortierite, (a) partially replacing sillimanite and biotite, (b) intergrown with andalusite. This stage and transformation of dumortierite to tourmaline may be related to the metamorphic evolution of the host pelitic gneiss.

A representative electron probe micro analysis of Veheragala dumortierite is SiO<sub>2</sub> 31.3 Al<sub>2</sub>O<sub>3</sub> 58.0 B<sub>2</sub>O<sub>3</sub> 6.08 TiO<sub>2</sub> 1.74 FeO 0.81 MgO 1.00 wt % suggesting a crystal chemical formula of Fe<sub>0.06</sub> Ti<sub>0.12</sub> Mg<sub>0.14</sub> Al<sub>6.5</sub> B<sub>1</sub> Si<sub>2.98</sub> O<sub>17.25</sub> (OH)<sub>0.75</sub>.

---

## INTRODUCTION

Dumortierite ( $\text{Al}_{6.75}\text{X}_{0.25}$ ) ( $\text{BO}_3$ ) ( $\text{Si}_3\text{O}_{14.25}(\text{OH})_{0.75}$ ) (Moore and Araki, 1978) is the most abundant borosilicate after tourmaline group of minerals that occurs in a wide variety of rock types (e.g. Grew et al., 2002). It is also sensu stricto, the most important and widespread member of the dumortierite group which includes Magnesio-dumortierite and Holtite (Visser, 1995). It is a neso - silicate and crystallizes in the orthorhombic system. It may contain Fe, Ti, Mn and Ca as trace elements (Alexander et al., 1986). It could bear signatures of the deep crustal processes such as dehydration and melting reactions, hydrothermal processes related to the formation of pegmatites, vein deposits and as a tracer in surface geochemical processes (Visser, 1995; Grew et al., 2002) along with other prominent borosilicates. It was long believed to be anhydrous ( $\text{Al}_7\text{BSi}_3\text{O}_{18}$ ), but spectroscopic, analytical, structural and experimental works have proved that dumortierite contains essential hydroxyl groups (see Grew et al., 2002). The experimental work by Werding and Schreyer (1990) have shown that the composition of dumortierite is strongly dependent on the PT-condition of synthesis. Experimental data on synthetic and natural dumortierite indicates occurrence of the mineral both at low-grade and high-grade conditions (Ono, 1981; Werding & Schreyer, 1990; Grew et al., 2002).

Dumortierite was first reported in pegmatitic veins cutting a gneiss near Lyon, France (Bertrand, 1880) and was named

after the French paleontologist, Eugene Dumortier. Since its' discovery dumortierite has been reported from more than 40 localities worldwide (e.g. Alexander et al., 1986; Visser, 1995; Grew et al., 2002) in regional metamorphic rocks, granitic gneisses, mica schists, quartzites with aluminous minerals, aplites, pegmatites, granitic and quartz veins. It occurs with cordierite, apatite, zircon, monazite, garnet and other borosilicates and aluminous minerals (Visser, 1995; Grew et al., 2002). Most dumortierite is intensely coloured and pleochroic and thus even a small amount of dumortierite is relatively conspicuous in thin section (Grew et al., 2002). It occurs in colours of violet, bluish-violet, brownish, brown, red and pink. It forms mats, bundles, aggregates with a radial or nematoblastic texture, spherulites, tufts of fibrous or fine prisms not exceeding a few tenths of mm across (Sabzehei, 1971; Alexander et al., 1986; Visser, 1995; Grew et al., 2002).

A dumortierite with a characteristic deep blue colour occurs in sillimanite-bearing granitic to pegmatitic veins in a pelitic gneiss, at Veheragala quarry North of Habarana, Sri Lanka. Chemical and X-ray studies confirmed that the mineral is the rare aluminum rich boro-silicate dumortierite (Ranaweera, 2003; Ranaweera et al., 2004).

A cut gemstone and gem quality stones of a brown variety of dumortierite have been previously reported from Sri Lanka (Webster, 1970; Gunerathne and Dissanayake, 1995; Ranasinghe and Jagath,

2000). However, their sources or geological occurrences are unknown. Grew et al. (1995) reported the first in-situ occurrence of dumortierite which is also blue in colour and occurs in trace amounts associated with kornepine in a sheared pegmatite at Homagama, in western Sri Lanka.

This paper reports the chemistry, mineralogy, petrography and modes of occurrence of blue dumortierite from the Veheragala quarry, Habarana, Sri Lanka.

### **Occurrence and Description of Veins Hosting Dumortierite**

The pink feldspar granitic to pegmatitic veins containing dumortierite occur in the migmatitic-garnet-biotite gneiss in the Veheragala quarry just north of Habarana (Fig. 1). This migmatitic-garnet-biotite gneiss (Fig. 2) occupies a relatively narrow N-S trending belt on the western part of the Highland Complex (HC) of Sri Lanka. The Highland Complex is considered as the oldest of the Precambrian lithotectonic units of Sri Lanka (Milisenda et al., 1994) and represents a belt of palaeo-proterozoic rocks which consists of marbles, quartzites, metapelites, metasemipelites, hypersthene granulites. Post-tectonic granites and pegmatites intruded this belt ~550 Ma ago (Cooray, 1994; Kroner et al., 2003).

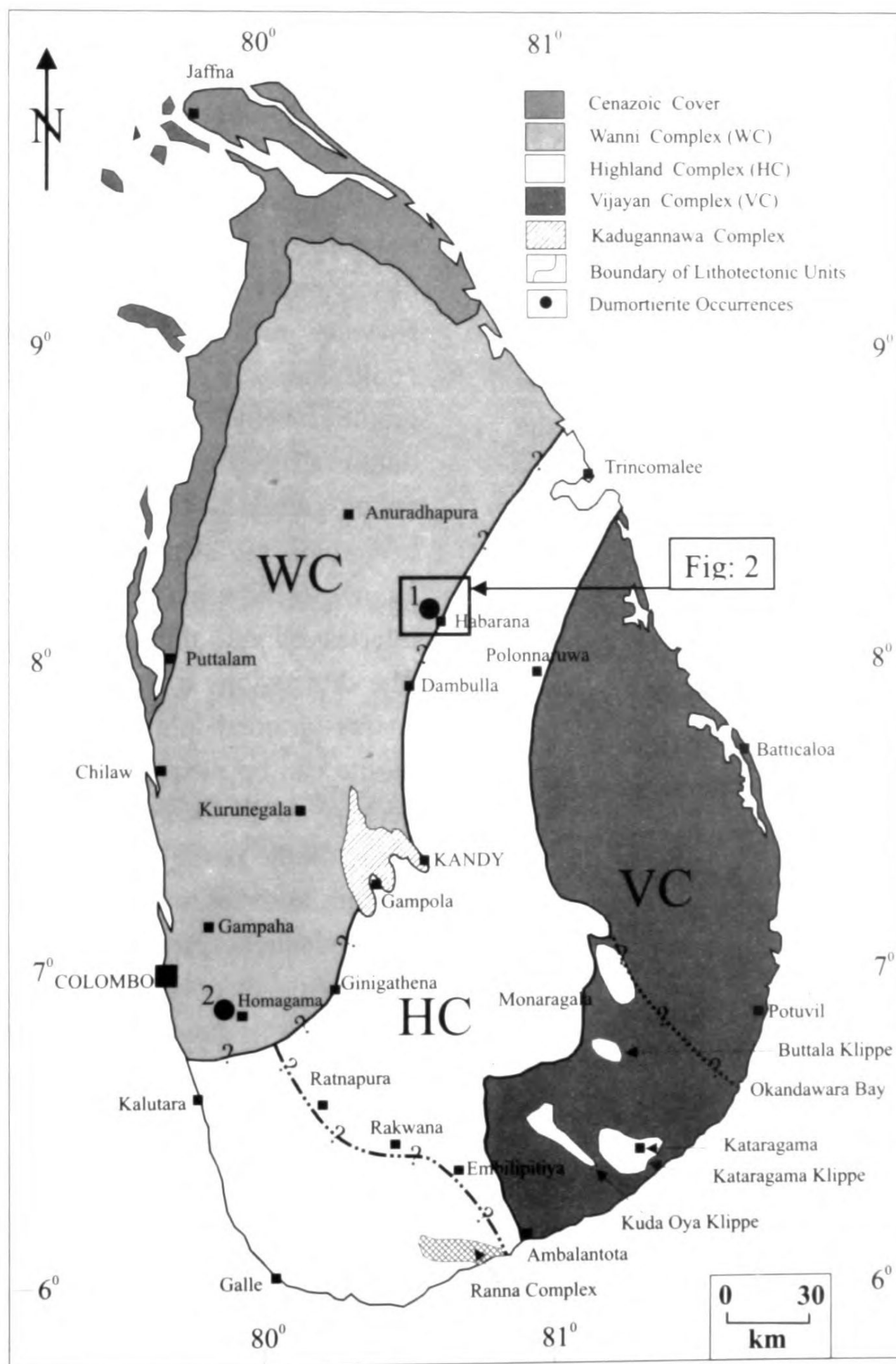
The finely-banded, and even-grained migmatitic-garnet-biotite gneiss, containing sillimanite-bearing layers host two types of veins. One is containing dumortierite and in the other dumortierite is absent. These veins have emplaced both parallel and oblique to the well-developed foliation of the host gneiss. The veins where dumortierite is

absent contains no sillimanite and are quartzo-feldspathic in composition, whereas veins bearing dumortierite contain sillimanite and granitic to pegmatitic in composition (Fig. 3a & b). The veins devoid of sillimanite seem to be consistently interleaved with the foliation of the host gneiss and contain fine - to medium-grained garnet. These felsic layers in some instances continue upto dumortierite-bearing granitic veins containing sillimanite. Sillimanite-bearing granitic veins are medium and even grained. They are about 1-4 cm in thickness. The dumortierite-bearing granitic veins do not appear to contain garnet. However, observations in thin-sections indicate that fine- to medium-grained isolated garnets could rarely occur in dumortierite-bearing granitic veins. In the vicinity of both dumortierite-bearing granitic and pegmatitic veins, garnet is found to be scarce in the host rock, too. Vithanage (1959) described quartzo-feldspathic veins and pegmatites interleaved with this gneiss at regional scale. The dimensions of pegmatitic veins having coarse grained pink feldspar, quartz and biotite can be measured only with difficulty because of the morphology of the exposed veins. Some parts of these pegmatitic veins contain both tourmaline-quartz intergrowths and slender prisms of coarse-grained tourmaline (see Fig. 3b). Pegmatitic veins containing dumortierite also contain sillimanite, andalusite, biotite, muscovite, quartz, alkali-feldspar, plagioclase, apatite and siderite. The dumortierite-bearing granitic veins contain sillimanite, biotite, quartz, alkali-feldspar, plagioclase, apatite, siderite and tourmaline. The sillimanite content is less in dumortierite bearing pegmatitic veins compared to that of dumortierite bearing granitic veins. The dumortierite in the pegmatitic veins is fine- to medium-grained and needle to columnar

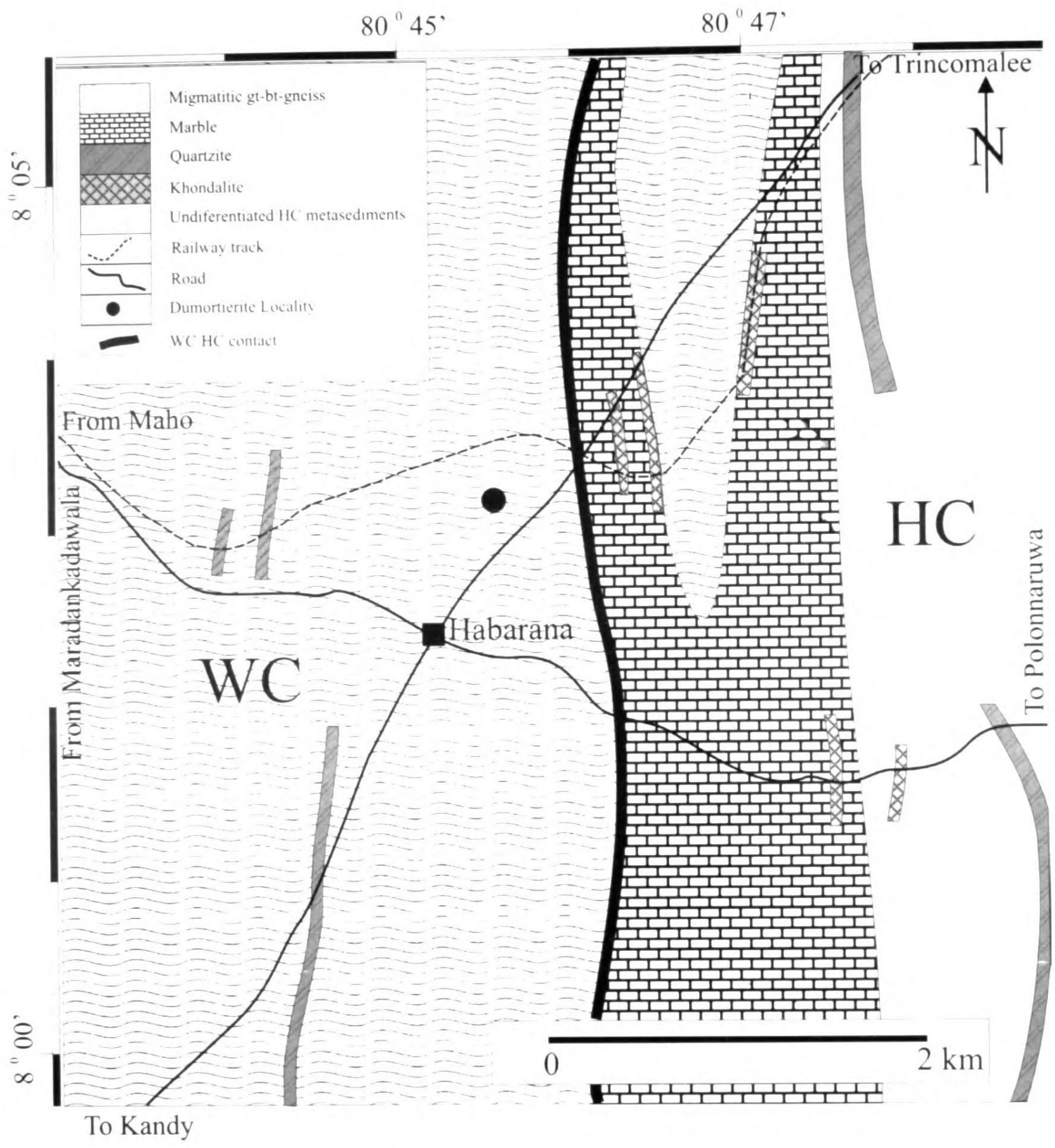
in habit. Dumortierite in granitic veins occur as prismatic and granular grains. The dumortierite that occurs in these granitic and pegmatitic veins are different in the context of form, size and associated minerals. Thus, the dumortierite-bearing pegmatitic veins are different from the dumortierite-bearing granitic veins with respect to their

mineralogy and modes of occurrence of dumortierite.

The host gneiss also contains hypersthene-bearing mafic rocks as boudins and lenses. Those probably represent once continuous layers of mafic rocks in original metasediments that have subsequently been deformed.



**Fig: 1.** Lithotectonic map of Sri Lanka (modified after Kehelpannala, 2003). Occurrence of dumortierite are indicated by black solid circles. 1 – this study. 2 – Grew et al. (1995) study. The dashed with dotted and dotted lines with question marks are the possible contacts of the HC with the WC and the VC respectively (see Kehelpannala, 2003).



**Fig: 2.** Geological Map of the area showing the dumortierite locality. Taken from the Polonnaruwa sheet (after Vithanage, 1959).

### Physical and Optical properties of Veheragala Dumortierite

The Dumortierite at Veheragala, Habarana is bluish-violet in hand specimen and shows a vitreous luster. It gives a blue streak. The dumortierite that is associated with quartz produces a colourless streak. The hardness is not measurable because the grain size and grain morphology do not permit separation of individual grains.

Under the plane polarized light, it shows a deep blue colour and a strong pleochroism from ink blue to violet to colourless. It shows first order to low second order interference colours. It is biaxial negative and most of the sections gave off centered BXa figures. It gives parallel extinction and negative elongation.

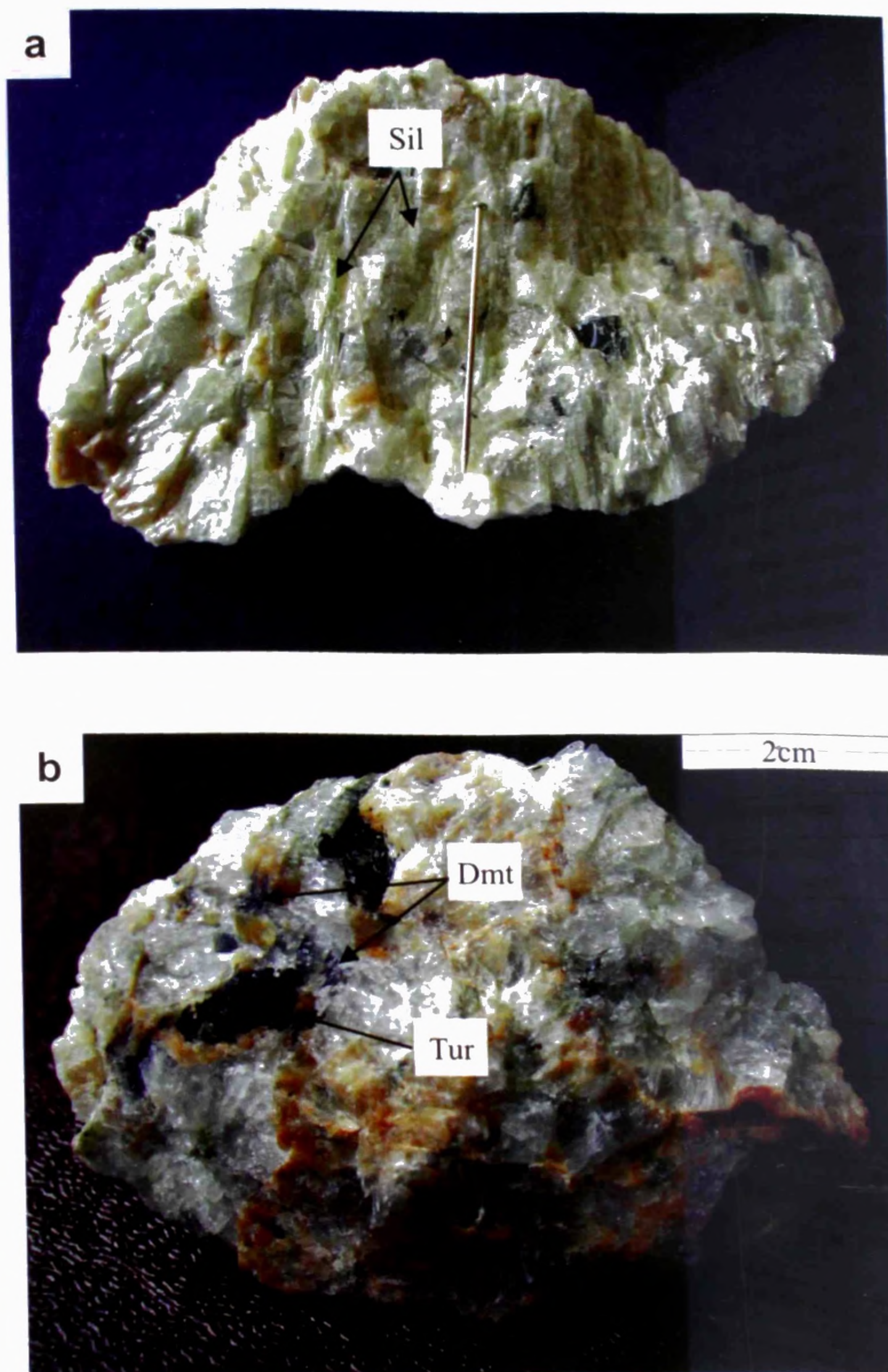


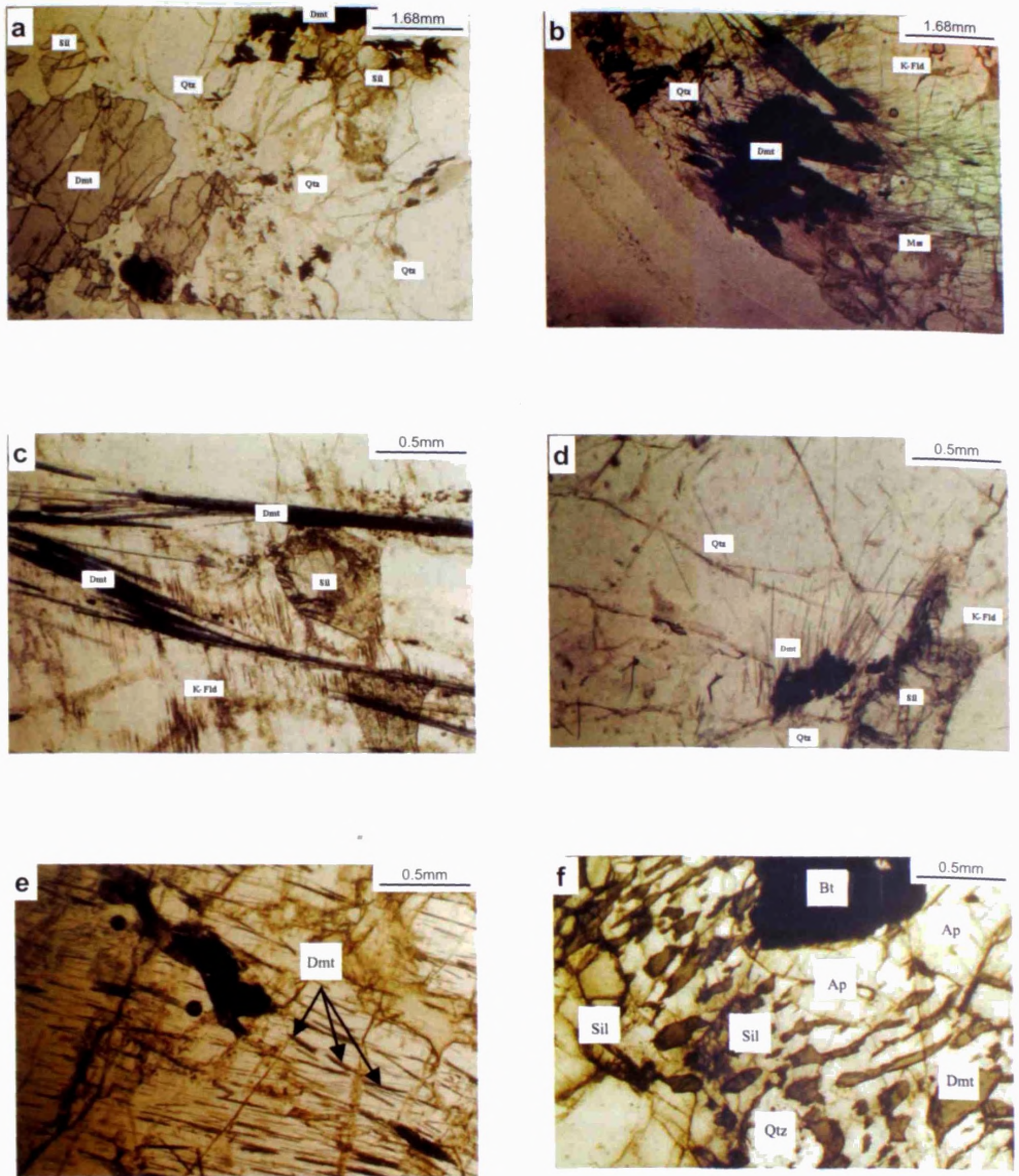
Fig: 3 (a) Photograph showing a portion of dumortierite containing sillimanite-bearing granitic vein (see the rod like parallel arrangement of coarse sillimanite parallel to the length of the photograph). (b) Photograph showing a portion of dumortierite containing pegmatitic vein. Dumortierite in these pegmatitic veins are different from the dumortierite in granitic veins from form, size and associated minerals.

It occurs in the form of bladed or xenoblastic, fibrous, columnar and acicular grains (Fig. 4a, b, c, d). Bladed or xenoblastic grains show indistinct cleavage parallel to the length of the crystal while some xenoblastic grains do not show cleavage. Instead, they show cross fractures. These xenoblastic grains of dumortierite occur with quartz and subordinate feldspar. In these places it seems that either sillimanite or biotite are absent or rare and dumortierite in these places appears to be more stable (see grain edges, Fig. 4a). Fibrous dumortierite occurs with secondary muscovite, which has been formed by

alteration of Feldspar. In this mode of occurrence it seems that fibrous dumortierite is radiating from a central grain of dumortierite (see Fig. 4b). Fibrous dumortierite is also found to have intergrown with andalusite. Columnar grains of dumortierite are shown in figure 4c. They are about 1.5 - 2 mm in length. Acicular grains are very fine and generally occur as inclusions in orthoclase and quartz (4d). They are randomly oriented or show a flow texture (Fig. 4e). Some grains of dumortierite show characteristic optical continuity (Fig. 4f). See Table 1 for summarized physical and optical properties.

**Table: 1.** *Physical and Optical properties of dumortierite from Veheragala, Sri Lanka and of dumortierite from elsewhere (e.g. Webster, 1970; Sabzehei, 1971; Philips et al., 1981; Alexander et al., 1986; Grew et al., 1986; Kawakami et al., 2003).*

	<b>Dumortierite - Veheragala</b>	<b>Dumortierite – previously reported</b>
<b>Color</b>	Deep blue, Violet	Deep blue, bluish violet, brownish, brown, pink
<b>Form</b>	Bladed, Prismatic, Columnar, Acicular, Fibrous, or Xenoblastic grains	Bladed, columnar, fibrous, acicular
<b>Relief</b>	High	High
<b>Hardness</b>	Not measured	7-8.5
<b>Pleochroism</b>	Ink blue to Violet to colorless	Deep blue to violet, pale
<b>Cleavage</b>	Indistinct parallel to the length of the crystal, some xenoblastic grains do not show cleavage. Instead they show cross fractures	Cleavage is distinct on {001} and poor on {110}
<b>Interference colour</b>	Mostly first order, sometimes low second-order.	First order, some times low second-order
<b>Interference Figure</b>	Biaxial (-), most sections studied give off centered BXa figures.	Biaxial (-)
<b>Optical Orientation</b>	Elongated sections show parallel extinction and negative elongation (lenth-fast).	



**Fig: 4.** Modes of occurrence of dumortierite. (a) Xenoblastic dumortierite (1.25X, PPL). Note the stable grain edges. (b) Fibrous dumortierite. See the association with muscovite (1.25X, PPL). (c) Columnar dumortierite (4X, PPL). (d) Accicular dumortierite occur as inclusions in orthoclase and quartz (4X, PPL). See the flow texture. (e) A closer look of the flow texture of acicular dumortierite grains. (f) Dumortierite grains showing optical continuity associated with sillimanite, apatite and quartz. Except biotite, sillimanite and apatite grains shown in the figure the rest is quartz (1.25X, PPL). (Mineral abbreviations as given: Quartz – Qtz, K-Feldspar – K-Fld, Sillimanite – Sil, Dumortierite – Dmt, secondary Muscovite – Mss, Biotite – Bt, Apatite - Ap)

## **Minerals associated with Dumortierite**

Dumortierite in the granitic and pegmatitic veins in the Veheragala quarry occurs in close association with sillimanite, andalusite, biotite, muscovite, quartz, alkali-feldspar, plagioclase, tourmaline and apatite.

### **Sillimanite**

Sillimanite characteristic of the veins is coarse-grained and shows parallel or sub parallel arrangement to each other (see Fig. 3a). Mega crystals of sillimanite (~10 cm) are also present in some of the granitic veins. Under the microscope sillimanite occurs as elongated and square cross-sections with and without cleavages. Sillimanite in the host gneiss is equigranular and medium-grained and in some instances occurs as clusters. They are distinctly different in size from the sillimanite in the veins.

Sillimanite appeared to be an unstable phase in all the thin-sections studied. Although the association of sillimanite with dumortierite is conspicuous in the thin-sections, the two minerals do not show stable grain contacts with each other. Some sillimanite grains show alteration into sericite. It is characteristic that most of the sillimanite investigated under the microscope show pseudo uniaxial figures.

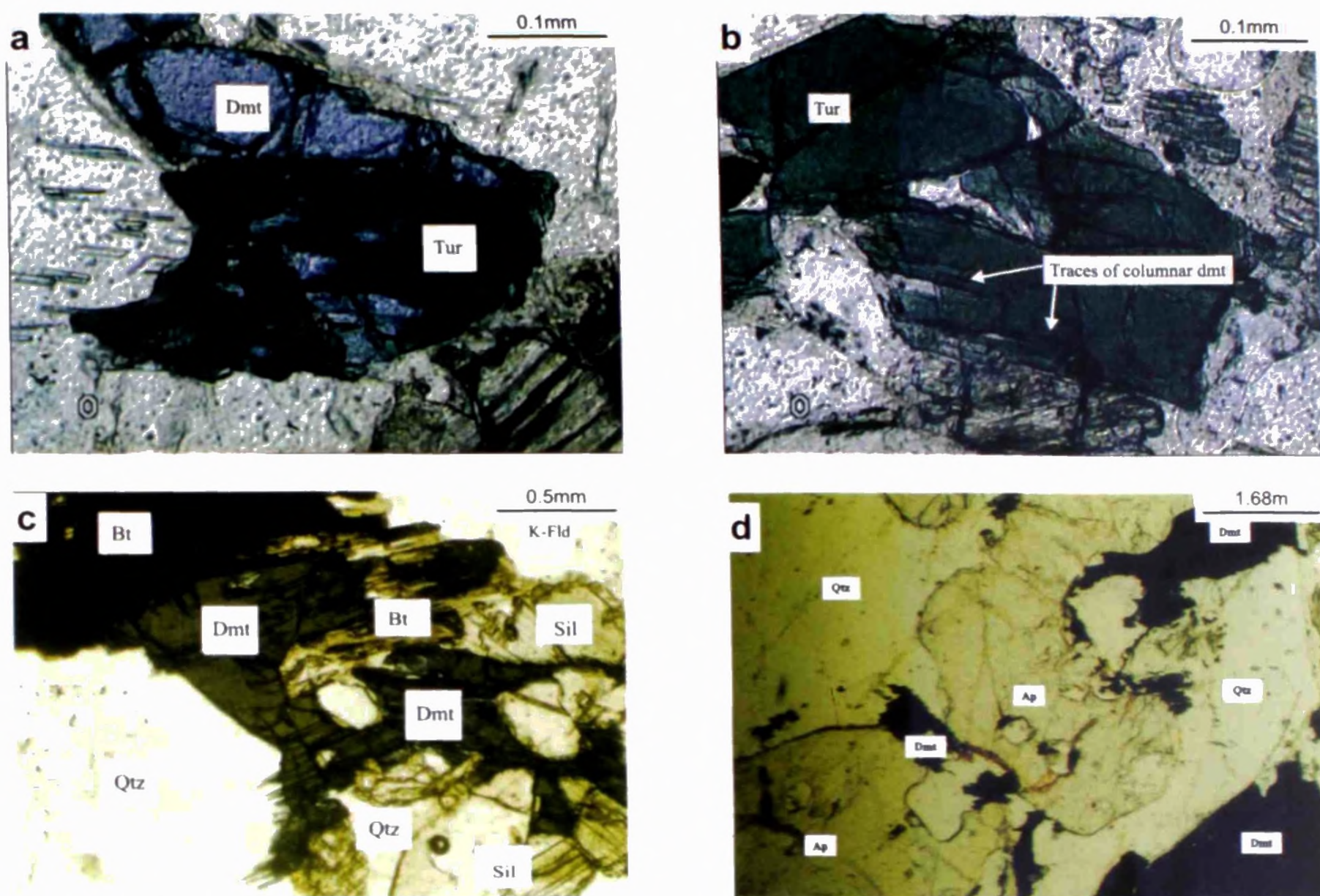
### **Tourmaline**

Tourmaline present in dumortierite-bearing veins shows pleochroism from pink to dark green and from pink to olive green to dark green in the thin-sections studied. Two modes of occurrence of tourmaline can be

recognized. One type of tourmaline occurs as quartz-tourmaline intergrowths, whereas the other occurs as slender prisms of tourmaline in the veins. It is evident that some of these slender prisms of tourmaline have overgrown on needle shaped dumortierite. Development of tourmaline along the discontinuities inside dumortierite grains (Fig. 5a) was also observed in the thin-sections and is noteworthy to report. Some tourmaline showing evidence of complete transformation after dumortierite (Fig. 5b) substantiates the above observation. This suggests that some tourmalines present in dumortierite-bearing veins are secondary in origin. Gayanin and Goryachev (1977) also reported tourmaline replacing dumortierite. Moreover, one sillimanite grain studied in a thin-section suggested replacement by tourmaline. On the other hand, sillimanite and tourmaline were found associated together as inclusions in a biotite grain.

### **Biotite**

Biotite present in dumortierite-bearing granitic veins is fine- to medium-grained while biotite present in dumortierite-bearing pegmatitic veins is coarse-grained. Biotite is associated with all the minerals present in the above veins except siderite and andalusite. Some of the biotite contains sillimanite inclusions. Biotite also shows alteration into muscovite and sericite and some biotite grains show unstable grain contacts with orthoclase. In one place, a dumortierite overgrown on biotite was also found (Fig. 5c).



**Fig: 5.** (a) Development of tourmaline along the discontinuities inside the dumortierite grain (b) Tourmaline after dumortierite. See the traces of dumortierite inside the tourmaline grain. (c) Dumortierite overgrown on biotite. See also the association of sillimanite with dumortierite and biotite. (d) Coarse grained apatite. See also the occurrence of dumortierite. (Mineral abbreviations as given: Tourmaline – Tur)

### Apatite, Andalusite , Siderite and Garnet

Apatite having a characteristic reddish brown colour occurs in both dumortierite- bearing granitic veins and pegmatitic veins. These apatite grains are coarse grained and in some instances show good crystal faces (Fig. 5d). In some places, this apatite is associated with dumortierite whereas in other instances it occurs with tourmaline, biotite, feldspar and quartz, where sillimanite could be present or not. Andalusite, Siderite and Garnet were observed only in one thin section. There, andalusite is found intergrown with dumortierite.

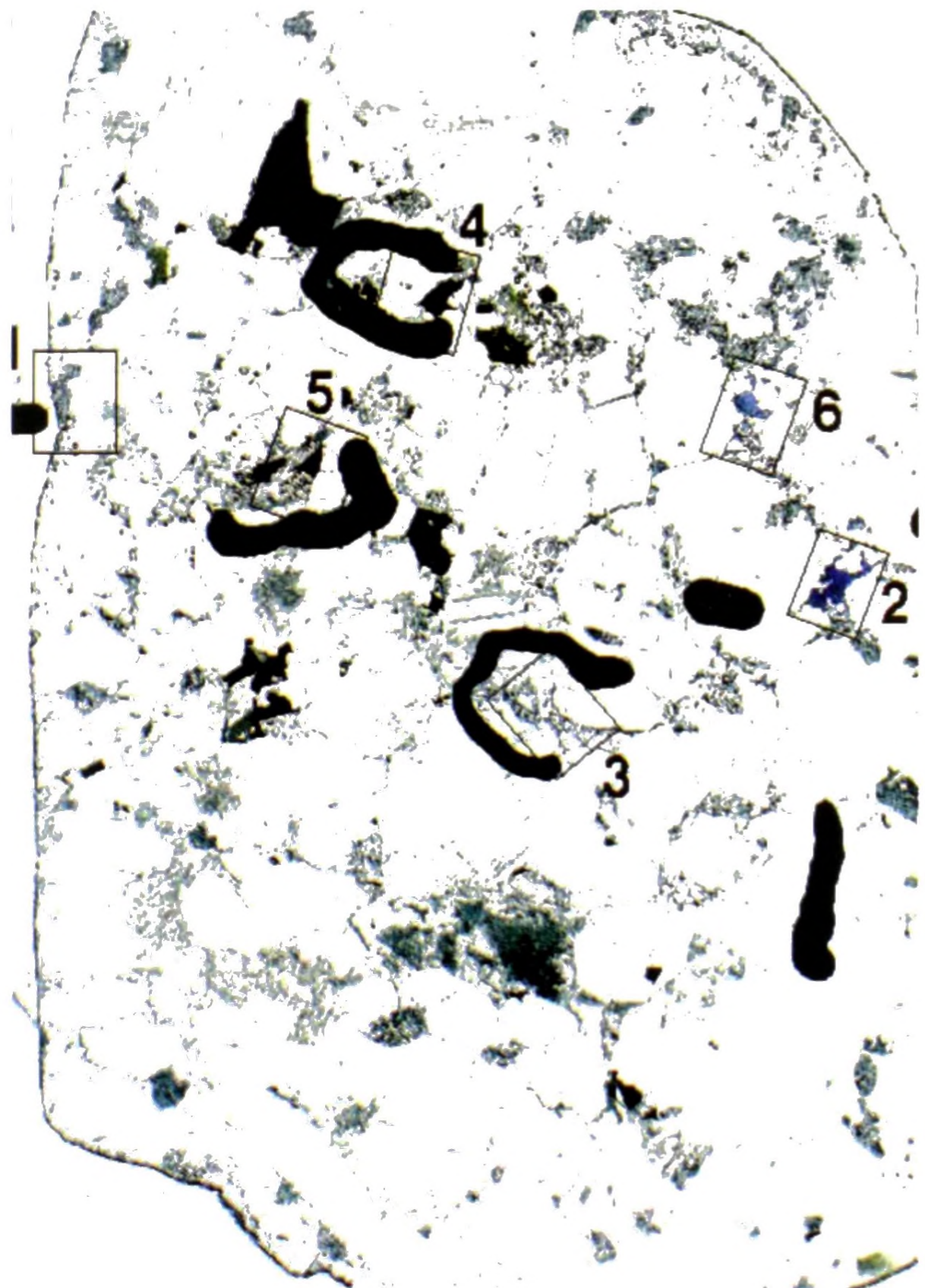
### Chemical Composition and XRD Data of Veheragala Dumortierite

The Veheragala dumortierite was analyzed using a JEOL EPMA at the National Institute of Polar Research (NIPR) in Tokyo, Japan. Thin-section numbered HBF3-03 was used for the analysis and the analysed spots are shown in Figure 6. Total of eight spots in 4 dumortierite grains were subjected to the EPMA analysis (Fig. 7). The EPMA data obtained are given in Table 2. Light elements present in the mineral were analyzed using a JOEL EPMA equipped with LDE2 crystal for light element analyses at the National Science Museum in Tokyo, Japan. It confirmed the presence of B in the mineral. Here, Danburite ( $\text{CaB}_2(\text{SiO}_4)_2$  : 28.32 wt%  $\text{B}_2\text{O}_3$ ) was used as the standard of B. The intensity

of B peak (Fig. 8) of the mineral was about  $\frac{1}{4}$  of that of standard danburite. Using this standard,  $B_2O_3$  content of the mineral was assumed. Cation calculations have been performed on the EPMA data obtained and are also given in Table 2. We used standard chemical formula of  $(Al_{6.75} X_{0.25})(BO_3)(Si_3O_{14.25}(OH)_{0.75})$  (Moore and Araki, 1978) as a guide for the calculations. Therefore, oxygen base used was eighteen and boron atoms per formula unit were assumed to be one. The experimental work by Werding and Schreyer (1990) also showed that all their synthetic dumortierite invariably contained 1.0 boron atoms per

formula unit. With these constraints, our analytical results gave the crystal chemical formula of:  $Fe_{0.05-0.07} Ti_{0.09-0.15} Mg_{0.12-0.15} Al_{6.3-6.6} B_{0.7-1.2} Si_{2.8-3.0} O_{18}$  for the Veheragala dumortierite.

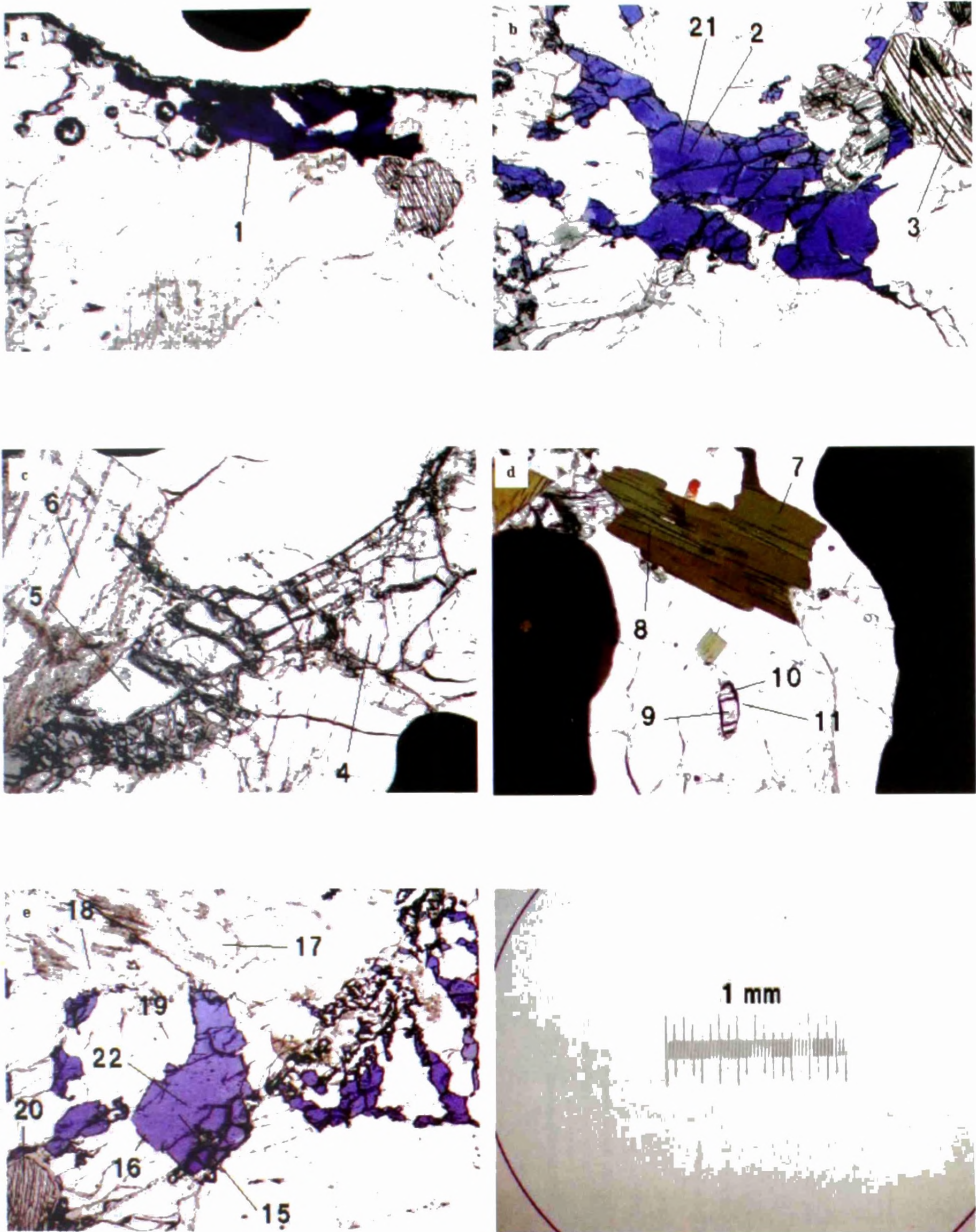
Powder X-ray data were obtained for the sample 020729HF3 fitted with an IP-Gandolfi camera at National Science Museum in Tokyo, Japan. XRD data obtained in this analysis are given in Table 3. The inter-planar spacing of atoms (d) has been calculated using  $2\theta$  values. The figure 9 shows the XRD pattern obtained for sample run.



**Fig: 6.** Spots of EPMA analyses of dumortierite grains in thin section HBF3-03. Refer to the figure 7 for grain positions.

Table: 2. EPMA analyses of dumortierite from Veheragala, Sri Lanka and of dumortierite from elsewhere. A – Horana, Sri Lanka (Ranasinghe et al., 2000). B – Nara Prefecture, Japan (Hiroi et al., 2001). C – Almgjotheii, Norway (Grew et al., 1998). Note: Cation proportions for all the values given have been calculated for an O base of 18. B<sub>2</sub>O<sub>3</sub> and H<sub>2</sub>O amount for Veheragala dumortierite and dumortierite from Nara Prefecture, Japan were calculated assuming ideal stoichiometry 1.0 B and 0.75 (OH). Cation calculations have not been done for A. H<sub>2</sub>O amount for dumortierite from Almgjotheii, Norway have been calculated assuming ideal stoichiometry 0.75 (OH). All Fe as FeO.

Spot	1	2	4	5	15	16	21	22	A	B	C	
Thin Section No. (HBF3-03) – Veheragala, SL									(brown)		(blue)	(rose)
SiO <sub>2</sub>	32.8	31.2	31.1	30.8	31.1	31	31.3	30.7	30.08	30.31	31.29	30.94
TiO <sub>2</sub>	1.46	1.84	1.45	2.06	1.88	1.77	1.74	2.04	4.70	2.27	0.23	4.02
Al <sub>2</sub> O <sub>3</sub>	59.7	57.6	58.6	57.8	58	58	58	58.1	58.00	59.06	60.26	57.16
Cr <sub>2</sub> O <sub>3</sub>	0	0	0	0	0	0	0.04	0		0.05		
FeO*	0.83	0.84	0.8	0.83	0.97	0.77	0.81	0.8	0.22	0.49	0.43	0.26
MnO	0	0.01	0.06	0	0	0	0.02	0		0.00		
MgO	1.05	0.97	1	0.83	1.02	0.98	1	0.95	0.02	0.15	0.35	0.32
CaO	0	0.03	0.02	0	0	0.02	0.02	0.01	0.02	0.01		
Na <sub>2</sub> O	0	0	0	1.02	0	0	0	0.01		0.00		
K <sub>2</sub> O	0	0.01	0	0	0	0	0	0.01	0.04	0.01		
P <sub>2</sub> O <sub>5</sub>	0	0	0	0.02	0	0	0	0		0.06		
V <sub>2</sub> O <sub>5</sub>									0.07			
ZrO <sub>2</sub>									0.03			
Nb <sub>2</sub> O <sub>5</sub>									0.02			
As <sub>2</sub> O <sub>3</sub>									0.04			
Ga <sub>2</sub> O <sub>3</sub>									0.01			
F	0	0	0	0	0	0	0.07	0.02		0.03		
Cl	0	0	0	0	0	0	0	0		0.00		
O	0	0	0	0	0	0	-0.03	0		-0.01		
B <sub>2</sub> O <sub>3</sub>	6.28	6.06	6.08	6.06	6.08	6.06	6.08	6.06	6.00	6.09	6.32	6.25
H <sub>2</sub> O	1.21	1.17	1.18	1.17	1.18	1.17	1.18	1.17		1.17	1.19	1.19
Total	103.33	99.73	100.3	100.6	100.2	99.77	100.2	99.87		99.68	100.07	100.14
O	18	18	18	18	18	18	18	18		18	18	18
Si	3.029	2.985	2.964	2.946	2.964	2.965	2.982	2.936		2.887	2.954	2.934
B	1	1	1	1	1	1	1	1		1.000	1.030	1.023
Ti	0.101	0.132	0.103	0.148	0.134	0.127	0.124	0.146		0.163	0.016	0.287
Al	6.498	6.493	6.681	6.517	6.514	6.538	6.538	6.551		6.630		6.389
Cr	0	0	0	0	0	0	0.003	0		0.004		
Fe	0.064	0.067	0.063	0.066	0.077	0.061	0.064	0.064		0.039	0.034	0.021
Mn	0	0	0.004	0	0	0	0.001	0		0.000		
Mg	0.144	0.138	0.142	0.145	0.145	0.139	0.142	0.135		0.021	0.049	0.045
Ca	0	0.003	0.002	0	0	0	0.002	0.001		0.001		
Na	0	0	0	0.003	0	0	0	0.001		0.000		
K	0	0	0	0	0	0	0	0		0.001		
P	0	0	0	0	0	0	0	0		0.005		
F	0	0	0	0	0	0	0	0		0.009		
Cl	0	0	0	0	0	0	0	0		0.000		
H	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75		0.741	0.75	0.750
Total cations	10.81	10.96	10.83	10.83	10.83	10.86	10.83	10.83		10.751	10.787	10.699



**Fig:** 7(a), (b), (c), (e) see the blue colour of dumortierite. Spots 9, 10, & 11 in Figure 7d indicate a garnet grain. This is the only garnet grain observed in dumortierite containing sillimanite - bearing granitic to pegmatitic veins. Cation calculations made for these spots are given in table 2.



**Table 3:** Powder X-ray diffraction data obtained for Veheragala dumortierite (Sample No: 020720HF3) using IP-Gandolfi camera at National Science Museum, Tokyo, Japan.

2theta	d (Å)	I/I <sub>0</sub>	2theta	d (Å)	I/I <sub>0</sub>
8.72	10.10	9	51.66	1.768	29
12.49	7.08	3	52.29	1.748	9
15.18	5.83	88	53.09	1.723	22
17.50	5.07	45	53.87	1.700	5
19.58	4.53	20	55.08	1.666	13
20.99	4.23	22	55.68	1.649	23
22.3	3.99	8	57.02	1.614	24
23.23	3.83	25	58.47	1.577	4
24.79	3.59	6	58.98	1.565	9
25.94	3.43	86	59.53	1.552	14
27.10	3.29	27	60.23	1.535	19
27.75	3.21	98	61.24	1.512	]
24.26	3.05	62	61.82	1.499	13
30.24	2.96	23	63.10	1.472	23
30.65	2.92	28	63.80	1.458	21
31.05	2.88	74	64.68	1.440	3
31.78	2.82	4	65.11	1.431	5
33.03	2.71	15	65.74	1.419	14
33.71	2.66	37	66.70	1.401	9
35.27	2.54	23	67.45	1.387	8
35.57	2.52	11	68.15	1.375	6
36.33	2.47	30	69.34	1.354	15
36.60	2.45	23	70.09	1.341	5
37.31	2.41	40	70.94	1.327	21
39.77	2.27	1	73.03	1.294	32
40.40	2.23	17	74.51	1.272	4
41.43	2.18	10	75.19	1.263	22
42.59	2.12	8	76.42	1.245	24
43.52	2.08	100	77.96	1.224	9
45.40	2.00	12	81.48	1.180	9
45.96	1.973	2	82.46	1.169	8
46.76	1.941	12	83.64	1.155	3
47.49	1.913	21	84.57	1.145	5
47.97	1.895	6	85.73	1.132	5
48.72	1.867	13	86.28	1.126	6
49.80	1.829	22	87.36	1.115	3

## DISCUSSION

### Chemical composition of Veheragala Dumortierite

Dumortierites in column B (Nara Prefecture, Japan) and C of Table 2 (the blue variety of Almgjotheii, Norway) have slightly higher aluminum content than that of Veheragala dumortierite. The higher aluminum content of spot 1 in the

Veheragala dumortierite is clearly in error. Its higher SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and B<sub>2</sub>O<sub>3</sub> contents are inconsistent with the other spot analyses from Veheragala and lead to a total higher by 3 wt %. The Veheragala dumortierite shows comparatively similar aluminum oxide content with that of two dumortierites in column A (Homagama, Sri Lanka) and C of Table 2 (the rose variety of Almgjotheii, Norway). The TiO<sub>2</sub>, FeO and MgO contents of Veheragala dumortierite compared with previously reported values from three other locations given in Table 2, indicates high FeO and considerably high MgO contents at Veheragala. Veheragala dumortierite also contain a significant amount of TiO<sub>2</sub> (1.45-2.06 wt %). Dumortierite analyses in columns A and C of table 2 represent two Ti-rich brown and pale red varieties. Compared to A and C the Veheragala dumortierite is poor in Ti and shows affinity to a Fe, Ti and Mg rich variety. It also should be born in mind that part of the FeO at Veheragala may represent Fe<sub>2</sub>O<sub>3</sub> and it may affect slight changes in the ferrous oxide values.

Representative X-ray diffraction data for ten most intense lines for two dumortierites and Veheragala dumortierite are given in Table 4. They are compared with the ICDD-12-270 standard dumortierite (Oriva et al., 2001). Although the intensities are different, the calculated values of d spacing are in approximate comparison. These structural data along with the chemical data confirmed the Veheragala mineral is dumortierite.

**Table: 4.** Representative X-ray diffraction data for ten most intense lines for three dumortierite. 1 – this study. 2 – Dehesa, California (Oriva et al., 2001). 3 – GRR-1815, Madagascar (Oriva et al., 2001).

ICDD	(1) Veheraala,	(2) Dehesa,	(3) Madagascar
12-270	Sri Lanka	(California)	(GRR-1815)
5.85(100)	5.83(83)	5.84(100)	5.87(100)
5.06(90)	5.07(45)	5.07(85)	5.06(85)
4.26(50)	4.23(22)	4.27(60)	4.25(50)
3.84(50)	3.83(25)	3.83(55)	3.83(45)
3.43(60)	3.43(86)	3.43(85)	3.44(85)
3.22(60)	3.21(98)	3.21(80)	3.15(50)
2.91(60)	2.88(74)	2.90(75)	2.90(50)
2.54(20)	2.54(23)	2.54(55)	
2.09(80)	2.08(100)	2.09(90)	2.08(90)
1.33(50)	1.34(5)	1.34(70)	1.33(50)

### Vein emplacement, mineral textures and origin of Veheragala dumortierite

The dumortierite in Veheragala is hosted by sillimanite bearing - granitic to pegmatitic veins. These veins have emplaced both oblique and parallel to the host gneiss. This suggests that the emplacement of sillimanite bearing magmatic liquids or partial melts of granitic to pegmatitic material hosting the mineral may have taken place after the peak metamorphism of the basement rocks of Sri Lanka. These pegmatitic and granitic veins may indicate a single granitic melt but differences in the cooling history and minor compositional changes may have attributed to the mineralogical and textural variations described in the text. Sometimes, these two types of veins may indicate contrasting two generations of magma injection. The tourmaline present in both these granitic to pegmatitic veins may be used to

discriminate a contrasting origin. Tourmaline bears a B signature and its chemistry will help to understand origin from a single magma or not.

The host gneiss also contains hypersthene-bearing basic rocks as boudings and lenses. They represent one of the earliest basic magma injected to the original metasediments subsequently deformed.

In the mineral textures, conspicuous association of dumortierite with sillimanite indicates its occurrence in the sillimanite field. Association of dumortierite with andalusite may indicate a retrogressed origin for some dumortierite. Therefore, it is possible that there were two generations of dumortierite. One at a high T, P with sillimanite and the other at LP, IT with andalusite. We infer dumortierite inclusions in quartz and feldspar (Fig. 4d) represent as crystallized directly from a pegmatitic magma. We suggest a primary origin at high P, T for this dumortierite occurs as inclusions in quartz and feldspar. Fiala (1954) reported columnar dumortierite occurs with tourmaline in quartz crystallized directly from a pegmatitic magma (Grew et al., 2002). We suggest, at intermediate P, T, a secondary origin for the Veheragala dumortierite as given by partial replacement of sillimanite and biotite by dumortierite (Fig. 5c) and dumortierite overgrown on andalusite and occur with muscovite. Grew et al. (1986) suggest a retrograde origin for dumortierite locally occurs in pseudomorphs, possibly after cordierite which now consists of fine-grained muscovite. Huigsmans et al. (1982) suggests that dumortierite in the Rogaland pegmatite, Norway crystallized as a later phase.

## **Source for the Boron in Veheragala Dumortierite and its significance to the tectonic evolution of Sri Lanka**

The source for the B in Veheragala dumortierite is yet to be understood. Most B rich granitic rocks are siliceous and peraluminous in nature. Elevated levels of Li, Be, Cs and B of these granitic rocks suggest likely sources for such magmas are metasediments that contain an abundance of both white and dark micas in addition to quartz and plagioclase (Grew et al., 2002). Probably, sillimanite in the host metasediments might have given rise to the B for the partial melts from which dumortierite bearing veins in Veheragala were formed. Although poor, sillimanite act as a carrier for B (Grew et al., 2002). Hence, it is also important to investigate the sillimanite in host metasediments to understand the source of B in dumortierite bearing veins in Veheragala. Grew et al., (2002) explains that B enrichment in pegmatites takes place by remobilization of B present in the host rock, incorporation of the remobilized boron in partial melts and crystallization of the melts as pegmatite bodies with borosilicates.

It is also noted that, much of the B originally present in viable protoliths may be driven off by dewatering and dehydration reactions during subduction or any other increase in metamorphic grade. This is understood by the observation that most deep crustal rocks (i.e. granulites and migmatites) contain < 2 to 3 ppm B (Grew et al., 2002). It thus appears that the retention of more than a couple of tens to hundreds of ppm B in a protolith to high grade metamorphic condition requires the

formation of a stable phase in which B is concentrated perhaps at weight percent level. Tourmaline, kornepurine, grandidiarite and dumortierite are the only common B enriched minerals known to survive to the Upper amphibolite or granulite facies conditions (Grew et al., 2002). In this respect, it is also interesting to note that the veins containing Veheragala dumortierite hosted by metasediments, partly migmatized indicating partial melting are lying close to the Highland and Wannu Complex inferred lithotectonic boundary (see Fig. 1). The origin of this lithotectonic boundary has recently been interpreted as subduction related (Kehelpannala, 2004). Since the recent advancements of B as an indicator mineral for deep crustal processes (Grew et al., 2002), it is worth looking for possible aspects of B mineralogy in constructing the tectonic evolution of plate boundaries in Sri Lanka. A kornepurine bearing sheared pegmatite (Grew et al., 1995) lies in the Wannu complex but away to the HC/WC lithotectonic boundary (see Fig. 1).

### **Estimated conditions of formation of Veheragala dumortierite**

Condition of formation of dumortierite has been investigated by mineralogists in two ways (I) Dumortierite have been synthesized in laboratory under a range of conditions of P,T with starting materials showing variable Al/Si ratios (II) Dumortierite formation have inferred on the basis of geothermobarometric estimates on associated rocks. Werding and Schreyer (1990) synthesized dumortierite in the ABSH – system ( $A=Al_2O_3$ ,  $B=B_2O_3$ ,

S=SiO<sub>2</sub>, H=H<sub>2</sub>O) between 3 and 20 kbar, 650°C and 800 °C using starting materials with a range of Al/Si ratios and analyzed the single phase products for all components including H<sub>2</sub>O. They also conducted synthesis experiments at 30 to 45 kbar and obtained dumortierite having normal orthorhombic symmetry. In a reconnaissance experiment at 80 kbar, 800°C, dumortierite was found to break down into “topaz-OH”, Al<sub>2</sub>SiO<sub>4</sub>(OH)<sub>2</sub>, (Grew et al., 2002) plus at least one additional unknown phase. Above values shows upper stability of dumortierite between 45 kbar and 80 kbar (Grew et al., 2002).

Hiroi et al. (2001) reported low P-T conditions for formation of dumortierite as (T > 700 °C, P > 4 kbar). Some reported P, T conditions for dumortierite are given in Table 5 (Grew et al., 2002). Experimental work by Grew et al. (2002) also shows that dumortierite is a stable phase at low-grade metamorphic conditions (at 3 kbar, 380 °C & 5 kbar, 360 °C) which correlates with the reported conditions of formation of natural dumortierites.

Here it is attempted to determine the formation conditions of Veheragala dumortierite in more indirect way. Comprehensive geothermobarometric studies of the HC have shown that the pressure during the peak metamorphism was in excess of 9 kbar in the eastern and south-eastern parts and becomes as low as 4-5 kbar towards the west of the HC. Relative abundance of sillimanite both as inclusions

as well as in the matrix of garnet bearing metapelites indicate peak metamorphic equilibration was in the sillimanite field. The geothermometric studies gives temperature estimates in the range of 700-900 °C (Hiroi et al., 1994), recording higher values towards east and south-eastern parts of the HC.

The correlation of P-T-t path obtained for metapelites by Hiroi et al. (1994) and thermobarometric and thermometric data of HC with dumortierite stability diagram (Fig. 10) suggests pressure of 5-7 kbar and 700-800 °C for inferred primary dumortierite and pressure below 4 kbar and temperature about 550-600 °C for the inferred secondary dumortierite at Veheragala, Sri Lanka as they occur with andalusite.

**Table: 5.** Pressure and temperature estimated for formation of dumortierite (see Grew et al. (2002), pp.400).

Locality	T (°C)	P (kbar)	Reference
Areskutan nappe, Sweden	>650	>5-7	Grew et al. (2002), pp. 400
Bamble Sector, Norway	450-550	3-4	
Bamble Sector, Norway	<700	8	

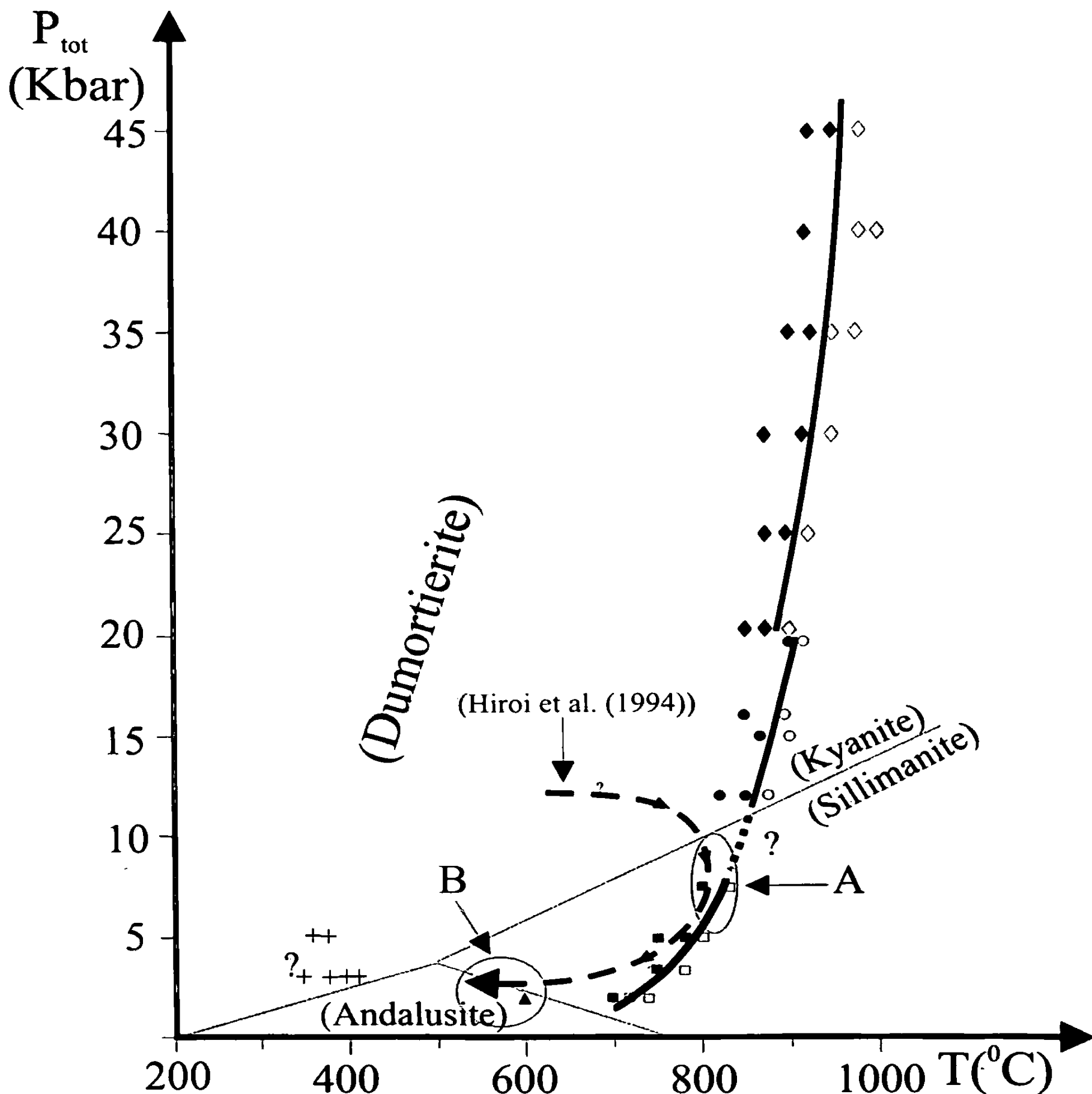


Fig: 10. Preliminary P-T stability of dumortierite (heavy line), for two different conditions of fluid chemistry below and above 20 kbar (modified after Grew et al., 2002). P-T-t trajectory (Hiroi et al., 1994) obtained for metapelites of HC is plotted. The primary dumortierite of Veheragala is approximated to form in zone A while secondary dumortierite of Veheragal is approximated to form in zone B. Solid symbols and crosses = growth of dumortierite. Open symbols = breakdown of dumortierite. (see Grew et al. (2002) for details).

### ACKNOWLEDGEMENTS

L.V. & L.R.K. acknowledge Dr. Satoshi Matsubara, National Institute of Polar Research (NIPR) and Dr. Kazumi Yokoyama, National Science Museum,

Tokyo in Japan for kindly carrying out the chemical analyses. L.V. extends his sincere thanks to Prof. Wilbet Kehelpannala for the facilities provided at Institute of Fundamental Studies and for discussions.

## REFERENCES

- Bertrand, E. (1880) Sur un mineral bleu de Chaponost, pres Lyon. Sur un autre mineral bleu du Chili: Bull Soc, Franc Mineral, Vol. 3, 171-172.
- Cally, H. (1995) Eyewitness handbooks. Gemstones. Dorling kidersley. London.
- Cooray, P.G. (1994) The Precambrian of Sri Lanka: a historical review. Precambrian Research, vol. 66, 3-18.
- Faulhaber, S. and Raith, M. (1991) Geothermometry and geobarometry of high-grade rocks: a case study on garnet-pyroxene granulites in southern Sri Lanka. Mineral. Mag., vol. 55, 17-40.
- Fiala, F. (1954) Dumortierite from Miscovise, Czechoslovakia. Sbornik Narodniho Musea v Praze, Vol. 10B, 3-38.
- Fleet, M.E. and Muthupari, S. (2000) Boron K-edge XANES of borate and borosilicate minerals. American Mineralogist, vol. 85, 1009-1021.
- Grew, E.S., Hiroi, Y., Motoyoshi, Y., Kondo, Y., Jayatilake, S.J.M., and Marquez, N. (1995a) Iron-rich kornepupine in sheared pegmatite from the Wannu Complex, at Homagama, Sri Lanka. Eur J Mineral, vol. 7, 623-636.
- Grew, E.S. (1986) Petrogenesis of Kornepupine at Waldheim (Sachsen), German Democratic Republic. Z. geol. Wiss., vol 14, 525-558.
- Grew, E.S. (1998) Boron and Beryllium minerals in granulite-facies pegmatites and implications of Beryllium pegmatites for the origin and evolution of the Archean Napier Complex of East Antarctica. Mem. Natl. Inst. Polar. Res., Spec. Issue, vol. 53, 74-92.
- Grew, E.S., McGee, J.J., Yates, M.G., Peacor, D.R., Rouse, R.C., Huijsmans, J.P.P., Shearer, C.K., Wiedenbeck, M., Thost, D.E. and Su, S.C. (1998) Boralsilite ( $\text{Al}_{16}\text{B}_6\text{Si}_2\text{O}_{37}$ ): A new mineral related to sillimanite from pegmatites in granulite - facies rocks. American Mineralogist, vol. 83, 638-651.
- Grew, E.S. (2002) Borosilicates (exclusive of tourmaline) and Boron in Rock-forming minerals in metamorphic environments. In: Grew, E.S. and Anovitz, M. (Editors), Boron: Mineralogy, Petrology and Geochemistry. Reviews in Mineralogy, vol. 33, 388-502.
- Gunaratne, H.S and Dissanayake, C.B. (1995) Gems and Gem Deposits of Sri Lanka. The National gem and Jewellery authority, 160 pp.
- Hiroi, Y., Grew, E. S., Motoyoshi, Y., Peacor, D. R., Rouse, R.C., Matsubara, Y., Yokoyama, K., Miyawaki, R., Macgce, J.J., Shu-Chun-Su., Hokada, T., Furukawa, N. and Shibasaki, H.(2001) Omenilite,  $(\text{Fe}, \text{Mg})\text{AlBSiO}_9$  (Fe analogue of grandidierite), a new mineral from popyritic granite in Japan. American Mineralogist. vol. 87, 160-170.
- Hiroi, Y., Ogo, Y. and Namba, K. (1994) evidence for prograde metamorphic evolution of Sri Lanka: pelitic granulites, and implications for the development of continental crust. Precambrian Research, vol. 66, 254-263.
- Huijsmann, J.P.P., Borton, M. and van Bergen, M.J. (1982) A pegmatite containing Fe<sup>2+</sup>-rich grandidierite, Ti-rich dumortierite and tourmaline from the Precambrian, high-grade metamorphic complex of Rogaland, S.W. Norway. N Jahrb Mineral Abh, vol. 143, 249-261.

- Jones, M.P. (1987) Applied Mineralogy. A quantitative approach. Graham and Trotman Ltd, pp. 46-133.
- Kawakami, T. and Ikeda, T. (2003) Boron in metapelites controlled by the breakdown of tourmaline and retrograde formation of borosilicates in the Yanai area, Ryoke metamorphic belt, SW Japan. *Contrib Mineral Petrol*, vol. 145, 131-150.
- Kehelpannala, K. V.W. (2003) Structural evolution of the middle to lower crust in Sri Lanka. *J. Geol. Soc. Sri Lanka*, vol. 11, 45-86.
- Kehelpannala, K.V.W. (2004) Arc Accretion Around Sri Lanka During the Assembly of Gondwana. *Gondwana Research*, vol. 7, No. 4S, 41-46.
- Kerr, P.F. (1977) *Optical Mineralogy*. McGraw - Hill, Inc. Fourth edition, 405 pp.
- Kriegsmann, L. (1991) Sapphirine bearing granulites from central Sri Lanka-Outcrop description and mineral chemistry. The crystalline crust of Sri Lanka, part 1, summary of research of the Sri Lankan - German Consortium. *Geol.Surv.Dept.Sri Lanka*, Prof. paper 5, 5-21.
- Kroner, A., Kehelpannala, K.V.W. and Hegner, E. (2003) Ca. 700-1000 Ma magmatic events and Grenvillian-age deformation in Sri Lanka: Relevance for Rodinia supercontinent formation and dispersal and Gondwana amalgamation. *J. Asian Earth Sci.*, vol. 22, 279-300.
- Mathavan, V., Prame W.K.B.N. and Cooray, P.G. (1998) Geology of the High Grade Proterozoic Terrains of Sri Lanka and the Assembly of Gondwana: An Update on Recent Developments. *Gondwana Research*, V.2. No.2, 237-250.
- Milisenda, C.C., Liew, T.C., Hoffmann, A.W. and Kohler, H. (1994) Nd isotopic mapping of the Sri Lanka basement: update, and additional constraints from Sr isotopes. *Precambrian Res.*, vol. 66, 95-110.
- Moore, P.B. and Araki, T. (1978) Dumortierite,  $\text{Si}_3\text{B}(\text{Al}_{6.75}\text{O}_{17.25}(\text{OH})_{0.75})$ : A detailed structure analysis. *Neues. Jahrbuch für Mineralogie, Abhandlungen*, vol. 132, 231-241.
- Oreva, J.S.G., Chim, A. and Ossman, R.R. (2001) Fibrous Nano-inclusions in Massive Rose Quartz: The origin of rose colouration. *American Mineralogist*, vol. 86, 466-472.
- Peacor, D.R., Rouse, R.C. and Grew, E.S. (1999) Crystal structure of boralsilite and its relation to a family of boroaluminosilicates, sillimanite, and andalusite. *American Mineralogist*, vol. 84, 1152-1161.
- Perera, L.R.K. (1984) Co-existing cordierite-almandine – a key to the metamorphic history of Sri Lanka. *Precambrian Research*, vol. 25, 349-364.
- Phillips, W.M.R. and Griffen, D.T. (1981) *Optical Mineralogy: The Nonopique Minerals*. W.M. Freeman and Company, pp. 138, 528, 626, 618, 129, 622.
- Raase, P. and Schenk, V. (1994) Petrology of Granulite-Facies Metapelites of the Highland Complex, Sri Lanka: Implications for the Metamorphic Zonation and the p-t Path. *Precambrian Research*, vol. 66, 265-294.
- Ranasinghe, P.N. and Jagath, A.S. (2000) A Titanium rich Borosilicate (Dumortierite ?) From Sri Lanka. *Jour. of Geol. Soc. of Sri Lanka*, vol. 9, 25-28.

- Ranaweera, L.V. (2003). Dumortierite: A Rare Blue Aluminum-Rich Boro-Silicate from Sri Lanka. B.Sc. Thesis, University of Peradeniya, Sri Lanka.
- Ranaweera, L.V., Perera, L.R.K. and Hiroi, Y. (2004). Dumortierite: A Rare Blue Aluminum-Rich Boro-Silicate from Sri Lanka. Abstracts: Twentieth Annual Technical Sessions, Geological Society of Sri Lanka, pp. 7.
- Sabzehei, M. (1971) Dumortierite from Iran: a first record. Short Communications, Mineralogical Magazine, vol. 38, 526-527.
- Sandiford, N., Powell, R., Martin, S.F. and Perera, L.R.K. (1988) Thermal and Baric evolution of garnet granulites from Sri Lanka. J. Metamorph. Geol., vol. 6, 351-364.
- Shelley, D. (1975) Manual of Mineralogy. Elsevier Scientific Publishing Company, Amsterdam, Oxford, Newyork. pp. 115.
- Schumacher, R. and Faulhaber, S. (1994) Summary and discussion of *P-T* estimates from garnet-pyroxene-plagioclase-quartz-bearing granulite-facies rocks from Sri Lanka. Precambrian Research, Vol. 66, 295-308.
- Vanders, I. and Kerr, P. (1967) Mineral Recognition. John Wiley and Sons.
- Velinda, D.A., Griffen, D.T. and Martin, T.J. (1986) Crystal chemistry of some Fe- and Ti-poor dumortierites. American Mineralogist, vol. 71, 786-794.
- Vitanage, P.W. (1959 b) The Geology of the Country around Polonnaruwa. Ceylon Geol.Surv.Mem.,I.
- Webster, R. (1970) Gems: Their Sources, Description and Identification. Fifth edition. Butterworth Heinemann.
- Werding, G. and Schreyer, W. (1990) Synthetic dumortierite: its PTX-dependent compositional variations in the system  $Al_2O_3$ - $B_2O_3$ - $SiO_2$ - $H_2O$ . Contrib Mineral Petrol., vol. 105, 11-24.
- Winchell, H. and Winchell, A.N. (1968) Elements of Optical Mineralogy, part II: Description of Minerals. Wiley Eastern (Pvt) Ltd. Publishers, 259 pp.
- Werding, G. and Schreyer, W. (1990) Synthetic dumortierite: its PTX-dependent compositional variations in the system  $Al_2O_3$ - $B_2O_3$ - $SiO_2$ - $H_2O$ . Contrib Mineral Petrol., vol. 105, 11-24.
- Yardley, B.W.D. An Introduction to Metamorphic petrology. Longman Earth Science series, pp. 74-90.
- Zussman, J. (1967) Physical Methods in Determinative Mineralogy. Academic press, pp. 286-291.
- Zussman, J., Howie, R.A. and Dear W.A. (1992) An Introduction to the Rock Forming Minerals. Longman Scientific and Technical, pp. 216-220.
-

National Digitization Project

*National Science Foundation*

Institute : National Science Foundation

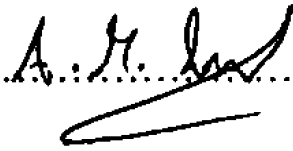
1. Place of Scanning : Sanje (Private) Ltd, Hokandara

2. Date Scanned : .....02/06/2017.....

3. Name of Digitizing Company : Sanje (Private) Ltd, No 435/16, Kottawa Rd,  
Hokandara North, Arangala, Hokandara

4. Scanning Officer

Name : .....Angelo Melvin Luwis.....

Signature : ..........

Certification of Scanning

*I hereby certify that the scanning of this document was carried out under my supervision, according to the norms and standards of digital scanning accurately, also keeping with the originality of the original document to be accepted in a court of law.*

Certifying Officer

Designation : .....Information Officer.....

Name : .....Renuka Sugathadasa.....

Signature : ..........

Date : .....02/06/2017.....

*“This document/publication was digitized under National Digitization Project of the National Science Foundation, Sri Lanka”*