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The occurrence of dumortierite in the Espinhaço Range, Minas Gerais, Brazil, and its mineralogical-crystallographic comparison with other specimen

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Abstract Samples of dumortierite from various localities of Brazil (Serra do Espinhaço-Minas Gerais, Macaúbas-Bahia) were analyzed with microprobe and the results were compared with those obtained from samples from Louvincourt dumortierite deposit (Quebec, Canada), Lincoln Hill-Champion Mines dumortierite deposit (Nevada, USA) Jack Creek dumortierite deposits (Montana), Acuélos (Chile) and from Madagascar (locality unknown). Infra-red spectroscopy (FTIR), ERP, Mössbauer effect spectroscopy (MS) were performed on the samples. Fourier transform infrared spectroscopy (FTIR), electron paramagnetic resonance (EPR) and Mössbauer spectroscopy have been used to study dumortierite samples of Brazil and of other origins. FTIR spectroscopy shows the existence of various environments for the OH- groups, which are related to substitutions and/or vacancies in the M1 octahedral site. Mössbauer spectroscopy consistently reveals the presence of divalent iron in 2 different octahedral sites, trivalent iron in one octahedral site and minor IVCT or IMMT iron. EPR also shows that isolated Fe3+ is present in various types of sites. The other signals ascribed to paramagnetic Fe3+ correspond to tetrahedral or more distorted octahedral sites.

Keywords: dumortierite; Espinhaço Range; Rio Paraúna Super Group; Bahia; infra-red.

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1. Introduction

Dumortierite is the second most abundant borosilicate mineral after tourmaline in crustal rocks. It has been reported in pegmatites (HUIJSMANN et al., 1982; GREW et al., 1995; GREW et al., 1998, GREW, 1996), per aluminous granites (VISONA; FUCHS, 1997), contact metamorphic rocks (GONZALÈS; RIVANO, 1979) quartzite and per aluminous rocks that have undergone hydrothermal alteration (BEUKES et al., 1987; WILLNER; SCHREYER, 1991; VISSER et al., 1997). Dumortierite has also been found in hydrothermal systems in association with andalousite and pyrophyllite (KAYUPOVA; TILEPOV, 1979; FOIT et al., 1989; PAULET, 1992; PAULET et al., 1991; TANER; MARTIN, 1993; FUCHS; MAURY, 1995; CHOO; KIM, 2002).

The color of many pink and blue rocks and minerals (such as blue or pink quartz can be related to their dumortierite content (GOREVA et al., 2001; CHI et al., 2002). Synthesis of dumortierite was achieved by Werding and Schreyer (1983a, 1983b) who describes later (WERDING; SCHREYER, 1986a, 1986b, 1988, 1990) the exact physical and chemical conditions.

1.1. Regional geology

The dumortierite occurs in units of the Paraúna and Espinhaço Super groups (ALMEIDA; HASUI, 1984; ALMEIDA-ABREU, 1989; CASSEDANNE, 1990) never far from tectonic contacts, and frequently associated to hydrothermal phenomena affecting the metamorphosed sediments. Dumortierite presents either a dark blue (Fazenda Formação 2) or a reddish to pale blue color (Macaúbas; Fazenda Formação 1).

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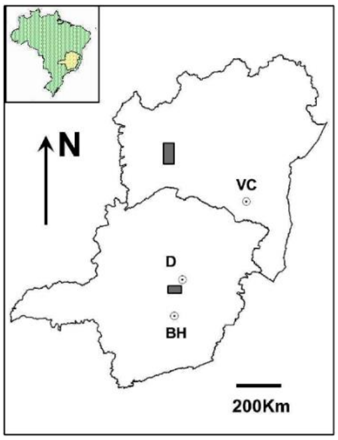

Figure 1 – Localization map of Vaca Morta (a) and Fazenda Bandeirinha (b) working áreas on the map of Minas Gerais State. The cities of Belo Horizonte (BH), Vitória da Conquista (VC) and Diamantina (D) are indicated.
Source: IBGE (2014).

The two main localities of dumortierite occurrences are Vaca Morta, near Macaúbas in the South Western part of the Bahia state and Fazenda Bandeirinha south of Diamantina, northeastern of the state Minas Gerais (FIG. 1).

1.2. Localities

1.2.1 Vaca Morta

The dumortierite occurs together with colored to colorless lazulite and with other phosphates like crandallite, scorzalite in the quartzites of Espinhaço Super group (FIG. 2; Lower Middle Proterozoic b).

A subdivision of the Espinhaço units into Boquira and Tiros formation was proposed by Kaul (1970) and more precisely defined by Schobbenhaus (1972).

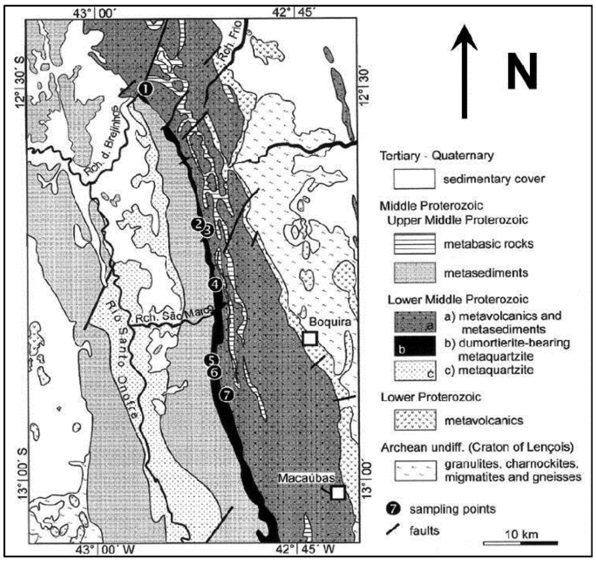

Figure 2 – The detailed map of the Vaca Morta area is from Lopez and Souza (1985). The numbers are identifications of sampling points at different quarries.
Source: modified after Morteani; Ackermand, 2005; Schobbenhaus, 1972a, 1972b.

The dumortierites occurrences are located within 1700-2200Ma old quartzites, that are extremely folded and fractured and contains hydrothermal Pb-Zn deposits (Boquira Formation), (CASSEDANNE, 1966; CASSEDANNE; MELLO, 1966; FLEISCHER, 1971; VISSER et al., 1997 and HORN et al., 1998A).

The dumortierite rich quartzites are found on the eastern flank of the Serra da Vereda indicated by black unit in the map (CASSEDANNE; FRANCO, 1966) extending over 15km with a thickness of approximately 30m.

This dumortierite deposits are subdivided in three lithological types (FLEISCHER, 1971):

Type 1: A fine quartzite, with little ore, no re-crystallization and visible layering indicated by blue layers from 20 to 50cm thick.

Type 2: A fine highly re-crystallized quartzite with concoidal fractures showing no layering but a homogenous blue color.

Type 3: A quarzitic poorly recrystallized micro-conglomerate with dumortierite and disthene together in blue stains and irregular veins.

1.2.2 Fazenda Bandeirinha

On the map of Diamantina (SE-23-Z-A-III) at 1:100.000, dumortierite occurs with lazulite, some rare sulfide minerals and quartz-veins, cyanite, talc nodules and tourmaline concentrations. The associated rocks are overlain by conglomerates, finer sand lenses, argilitic lenses, sills of Hematite Phyllite and covered by overlain Espinhaço quartzites.

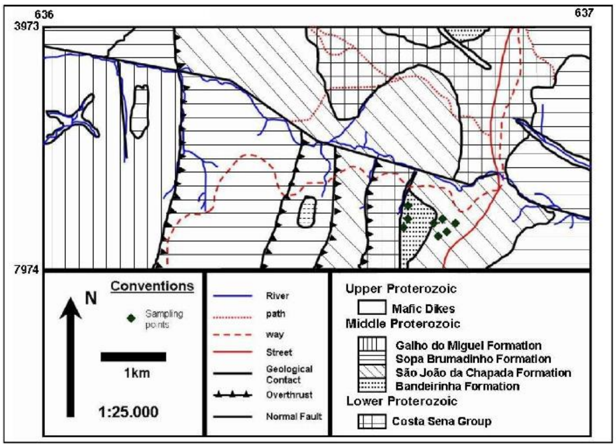

Figure 3 – Location map of the Bandeirinha site indicating geology and sampling points. This map shows also the geological situation and principal accesses to the working area (KNAUER, 1984; ALMEIDA-ABREU, 1989).
Source: Knauer (1984); Almeida-Abreu (1989).

The host rocks of the dumortierite varieties are the quartzites from the upper part of Rio Paraúna Super Group (Barão de Guaicuí Schist) near the tectonic contact with the overlaying Espinhaço Super Group. The contact is possibly a strongly tectonically deformed old surface overlaying by intemperized and highly foliated volcano-sedimentary units, so called Hematite Phyllite or a lower conglomeratic to coarse grained sandy units.

The whole sediments were metamorphosed during Brasiliano event to green schist facies level. The subdivision and description were first done by Fogaça et al., (1984), Schöll and Fogaça (1979, 1981) and Horn et al., (1996, 1998b).

Within a profile from East to West, the sequences of the mineral and lithological variations are well visible (FIG. 3).

The secondary transportation of dumortierite and lazulite as pebbles, crystals and sand grains is well documented in the papers by Scholl and Fogaça (1979), Fogaça et al., (1984), Hoffmann (1979) and Morteani et al., (1999). The investigated dumortierite specimens were collected in these two distinct areas of Brazil.

2. Sampling

Dumortierite samples were collected at two localities in Minas Gerais and Bahia States which geological environments are relatively well known:

A. At the Espinhaço Range, south of Diamantina;
B. In the Vaca Morta Region at the Southeastern part of Bahia state. This area belongs geographically to the occidental Espinhaço Range, and the samples are from Espinhaço Super Group rocks.

The collected samples were compared with dumortierite samples of different worldwide origins.

2.1 Dumortierite from Brazil

2.1.1 Rio Paraúna Super Group (10 samples)

Samples from two defined places were used:

- Near Fazenda Bandeirinha at the tectonic contact with the Espinhaço Super group.
- In the surroundings of Fazenda Formação.

2.1.2 Espinhaço Super Group (5 samples)

- Near Macaúbas in the South-East of Bahia at the locality of Vaca Morta (CASSEDANNE, 1990; HORN et al., 1998; CASSEDANNE; CASSEDANNE, 1975).

2.2 Comparative dumortierite samples from other contries

- One sample from the Louvincourt (Québec, Canada) dumortierite deposit (TANER; MARTIN 1993).
- Five samples from the Lincoln Hill-Champion Mine dumortierite deposit (Nevada, USA): (PAULET et al., 1991; PAULET, 1992).
- A specimen from the Jack Creek dumortierite deposit (Montana, USA) (FOIT et al., 1989; FUCHS; MAURY 1995).
- Two samples from the Aculéis (Chile) dumortierite deposit (GONZALES; RIVANO, 1979).
- A dumortierite specimen from Madagascar (exact origin unknown).

3. Structure of dumortierite

Dumortierite structural formula can be ideally written: $(Al_{1-x}\square_x)Al_2Al_4Si_3BO_{18-x}(OH)_{3x}$ in which aluminium can be partly substituted mainly by Fe and Ti but also by Mg (Ferraris et al., 2001; CHOPIN et al., 1995). Dumortierite structure was published by Golovastikov (1963) and refined by Moore and Araki (1978) and Alexander et al., (1986). Dumortierite is orthorhombic, space group Pmcn with Z=4 formula units per unit cell.

The structure is characterized by three types of chains of interconnected octahedral, running parallel to [001]. The chains are linked by isolated SiO_4 tetrahedral and planar BO_3 groups (FIG. 4).

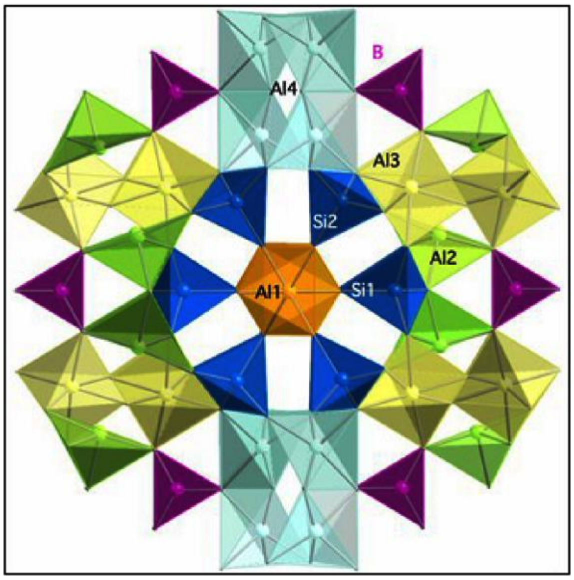

Figure 4 – Structure of dumortierite down to the c axis (Golovastikov, 1963; Moore and Araki, 1978; Alexander et al., 1986).
Source: Golovastikov (1963); Moore and Araki (1978); Alexander et al. (1986).

The straight Al(1) chain is formed by face sharing octahedra. This straight Al(1) chain contains void octahedral (vacancy□□) in the ratio 1:4 (MOORE; ARAKI, 1978).Ordering of vacancies along this Al(1) chain may, thus, induce to dimmers, trimers and more extended one dimensional clusters of occupied face sharing or octahedral.

A second chain is formed by Al(2)Al(3) zigzag structure of edge connected octahedra, doubled by an inversion center.

The third type an Al(4) chain is formed by pairs of face-sharing octahedra which are parallel to [100], in a way that the shortest distance between two Al in this chain occurs perpendicular to [001]. These pairs of face sharing octahedral are connected together by common edges and form kinked “double chain” running so parallel to [001].

4. Metodology

Were executed field investigations at the geological sites and laboratory studies on the samples specimen.

4.1 Field studies

Observations about the mineral currencies, there different properties, the orientation, host rock situation and mineral assemble were done.

4.2 Laboratory investigations

Elemental analyses were performed using the SX 100 electron microprobe of Camparis center (University Pierre et Marie Curie, Paris) at 15kV and 10nA.

For infrared spectroscopy, powdered dumortierite samples (7mg) were pressed with KBr (150 mg) to form a thin disc of 2cm². The spectrums were then recorded in transmission on a Fourier Transform Nicollet 560ESP spectrometer in the frequency range 4000 cm^{-1}-400 cm^{-1}.

For electron paramagnetic resonance (EPR) measurements, calibrated silica tubes (suprasil grade) were filled with dry powdered samples. EPR measurements at 9.42 GHz (X-band) were performed using a Bruker ESP300E spectrometer. The experimental parameters were as follows: 100 kHz frequency modulation and 40 mW microwave power, 5.10^{-4} T modulation amplitude. The EPR spectra were recorded in the 0 to 0.9 T magnetic field range. Magnetic field calibration was performed with the DPPH standard ($g = 2.0037 \pm 0.0002$). Frequency calibration was done with a Hewlet Packard frequency meter.

To record Mösssbauer spectrum, the powders were stored in a plexiglas crucible having a surface area of 2 cm^2. The spectrums were recorded on a spectrometer with constant acceleration mode using a 57Co source diffused into a rhodium matrix. The hyperfine data were refined with the MOSFIT program (VARRET, 1981), using Lorentzian functions without thickness corrections. The zero velocity corresponds to the centroïd shift for an α-Fe foil at room temperature.

5. Results

5.1 Field geological results

5.1.1 Fazenda Bandeirinha

In the investigated area an association between the two Dumortierite types occurs directly at the upper contact of Paraúna Super group near the lower partt of the Espinhaço Super group. From eastern contact westwards the reddish blue dumortierite diminishes in quantity whereas after an intensively tectonized quartzite the lazulite concentration grows up in direction of the western contact. The crystals of the reddish blue dumortierite occur as cm-needles on fracture planes, showing a strongly dominant orientation toward a NW direction.

The dumortierite is associated with kyanite nodules, quartz veins and pyrite, arseno- and chalcopyrite, which have suffered an intensive weathering. Lazulite is the dominant mineral versus dumortierite in the lower part of the profile (with a ratio of nearby 99,9 to 0,1) whereas at the higher part the ratio is inverted, dumortierite being the dominant mineral.

5.1.2 Vaca Morta

The dumortierite occurs in the quartz-schist and quartzite without specific orientation. Associated lazulite is very rare. No sulfide is reported.

5.2 Chemical composition of samples

Results of chemical analyses (TAB. 1) show important variations of the Al_2O_3 and SiO_2 content (TAB. 1).

	Louvicourt	**Lincoln Hill**	**Jack Creek**	**Acuélos**	**Unknown locality**	**Vaca Morta**	**Fazenda Formação**	**Fazenda Formação**
	(Québec)	**(Nevada)**	**(Montana)**		**Madagascar**	**Bahia**	**Minas Gerais**	**Minas Gerais**
	Canada	**USA**	**USA**	**(Chile)**		**Brazil**	**Brazil**	**Brazil**
Nb of analyses	28	76	62	26	13	27	12	10
SiO_2	29.589	30.728	26.931	29.327	31.155	30.902	31.018	30.994
Al_2O_3	59.207	60.573	61.681	60.301	62.053	59.916	60.141	58.553
TiO_2	1.311	0.555	1.169	0.964	0.471	1.068	0.949	0.990
As_2O_5	0.066	0.282	1.343	0.679	BDL	0.056	0.032	0.023
Sb_2O_3	0.008	0.339	0.022	0.034	0.109	0.010	0.029	0.033
FeO	0.056	0.239	0.325	0.911	0.386	0.250	0.237	0.274
ZnO	0.045	0.081	0.043	na	na	0.026	na	na
MgO	0.682	0.033	0.020	0.013	BDL	0.128	0.173	0.720
Na_2O	0.016	0.009	0.010	0.026	0.012	0.004	0.004	0.004
P_2O_5	0.490	0.059	0.266	0.570	0.051	0.082	0.099	0.115
B2O3	na	na	na	na	na	na	na	na
F	0.056	0.028	0.062	0.039	0.088	0.007	0.004	0.004
Sum	90.107	91.301	91.124	89.628	93.208	91.886	91.159	89.547

Table 1 - Microprobe analysis of dumortierite samples (in oxide weight %).
NA = non analysed; BDL = below detection limit; * except for As, Sb = 85, for P and F= 55.
B can not be executed by microprobe.
Análises de microssonda em dumortierita (in % peso).
NA = não analisado; BDL = abaixo do limite de detecção; * com exceção para As, Sb = 85 e F = 55.
B não pode ser determinado com microssonda.
Source: Elaborated by authors.

	Louvicourt	Lincoln Hill	Jack Creek	Acuélos	Loc. unknown	Vaca Morta	Fazenda Formação	Fazenda Formação
	(Québec)	(Nevada)	(Montana)		Madagascar	Bahia	Minas Gerais	Minas Gerais
	Canada	USA	USA	Chile	Madagascar	Brazil	Brazil	Brazil
Si	2.859	2.677	2.622	2.858	2.927	2,920	2,956	2,958
Al	6.744	7.153	7.075	6.914	6.858	6,854	6,755	6,760
Ti	0.095	0.020	0.085	0.070	0.028	0,033	0,077	0,068
As	0.004	0.017	0.080	0.054	BDL	0,000	0,007	0,004
Sb	0.000	0.013	0.001	0.034	0.004	0,004	0,000	0,001
Fe	0.005	0.005	0.026	0.073	0.034	0,030	0,020	0,019
Zn	0.003	0.006	0.003	na	na	0,000	0,002	0,002
Mg	0.098	0.005	0.003	0.002	BDL	0,000	0,018	0,025
Na	0.003	0.001	0.002	0.005	0.002	0,002	0,001	0,001
P	0.040	0.005	0.022	0.045	0.004	0,004	0,006	0,007
F	0.017	0.010	0.022	0.012	0.026	0,026	0,002	0,001

Table 2 – Calculated values for the element distribution for structural formula on the basis of the Moore and Araki (1978; idealized formula in apfu). See Table 1 for the explanation of the acronyms.
Source: Elaborated by authors.

Idealized structural formulas (TAB. 2) were calculated on the basis of 0.75 OH per formula unit. The number of Si atoms is less than 3 indicating that some substitutions do occur in the tetrahedral Si sites. High P_2O_5 contents (~ 0.5%) are observed in the Louvincourt and Acuelos dumortierite. These concentrations are however below the phosphorus contents up to 0.65 wt% observed by Willner & Schreyer (1991) in dumortierite from Busmanland (South Africa,) by Vrana (1979) in dumortierite of Waldheim (Saxony, Germany) (up to 0.90 wt%). The As_2O_5 average content reaches 1.34% in Jack Creek specimens (average) and 0.68% in the Acuélos ones. Sb_2O_3 content reaches 0.34 wt% in the Lincoln Hill dumortierite but is far below the average value (2.04wt%) of the Ben Lomond dumortierite (Queensland, Australia) (with a maximum up to 4.89 %, Fuchs unpublished data). Relatively high As and Sb content are known in other dumortierite occurrences. As and Sb in dumortierite up to 1.67 and 0.34wt% were also reported by Voloshin et al. (1987) and Grew (1995) found As_2O_5 content from 0.90 up to 1.67 wt%, (0.082 apfu) in dumortierite of a kornerupine bearing pegmatite of Sri Lanka.

These high Sb and As contents lead to the hypothesis that solid solution exist between dumortierite and holtite an orthorhombic mineral $(Si_{2.25}Sb_{0.75})B[Al_6(Al_{0.43}Ta_{0.27}\square_{0.30})O_{15}(O,OH)_{2.25}]$ (VOLOSHIN et al. 1976, HOSKINS et al., 1989) with an As rich member described by A. Pieczka and M. Marszalek (1996) with: $(Si_{2.18}Sb^{5+}_{0.26})B(Al_{6.03}Mg_{0.23}Ti_{0.13}Ta^{5+}_{0.15}Nb^{5+}_{0.03}As^{5+}_{0.02}Fe^{3+}_{0.02}\square_{0.39})(O_{17.44}\square_{0.56})$ for structural formula.

TiO_2 content varies from 0.47 up to 1.31% far below the 3.05 wt% TiO_2 of the dumortierite in the Namaqua metamorphic quartzite (BEUKES et al., 1987), the 3.80 wt% in dumortierite of the metamorphic rocks from Zambia (VRANA, 1979) and the 4.6% , (0.33 apfu) in the dumortierite of the Rogaland pegmatite (HUIJSMAN et al., 1982).

5.3 Infra-red spectroscopy

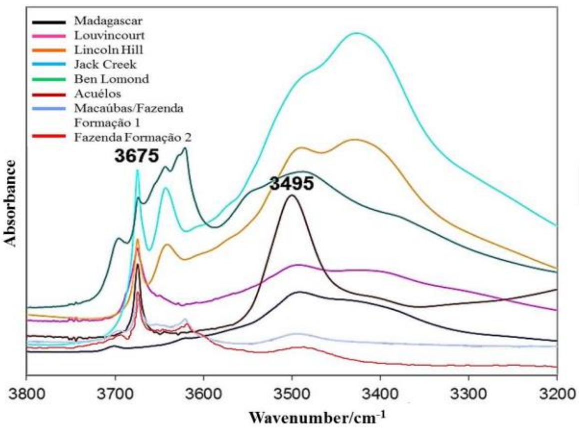

Figure 5 - FTIR spectrums of some dumortierite samples in the OH stretching absorption zone.
The samples from Macaúbas and Fazenda Formação 1 are similar to the samples from Lincoln Hill and Jack Creek. The samples from Macaúbas and Farm 1 Formation are similar to the samples from Louvincourt, Lincoln Hill and Jack Creek.
Source: Elaborated by authors.

The study of the OH stretching bands (3800-3200 cm^{-1}) of dumortierite samples (FIG. 5) brings information on the M1 site occupancy as hydroxyl groups substitute for O(2) and O(7) (i. e. between the M1 octahedron and the $[SiO_4]$ tetrahedron) to charge-balance vacancies in the M1 site. OH groups can also balance the substitutions of $Mg^{2+,}$ Fe^{2+} for octahedral Al^{3+} or substitutions of Al^{3+} and/or Fe^{3+} for tetrahedral Si^{4+}. Dumortierite spectra shows 3 major bands at ~ 3490, ~3620 ~ 3675 $cm^{-1}$and a broad band at ~ 3400-3430 cm^{-1}. This last band corresponds to water molecules trapped in the channel type structure of dumortierite. The ~ 3490 cm^{-1} band is present in all specimens. The ~ 3620 cm^{-1} and ~ 3675 cm^{-1} band are present in all samples but very weak in the Madagascar one for the first and totally absent for the second. Other absorption bands are present. Table 3 gives the result of Mössbauer and reflect the complexity of the environment of the hydroxyl groups.

According to Moore and Araki (1978) each Al(1) vacancy requires 3OH- substitutions for O(2) or O(7) oxygen. That means the corresponding OH groups are surrounded by a 7 charges environment (Si^{4+}, Al^{3+}, □), which would correspond to the absorption band observed at ~ 3675 cm^{-1}. Similarly, Alexander et al. (1986) showed that the frequency of OH stretching bands could vary as a function of the charge of the cations substituting for Al in the Al(1) site [6]M1. Following this model, substitutions involving R^{2+} elements (Mg, Fe^{2+}) and leading to Si^{4+} Al^{3+} R^{2+} environments (9 charges environments) can be associated to the band observed at 3490 cm^{-1}. Substitutions leading to Si^{4+} R^{2+} R^{2+} environments correspond to 8 charges and can be associated to the band at 3620 cm^{-1}. Other bands may be associated to other substitutions. For example, R^{3+} (Fe^{3+}), or R^{4+} (Ti) can substitute for Al in the [6]M1 site, whereas substitutions of Al^{3+}, Fe^{3+} for Si^{4+} in tetrahedron sites can induce various complicated environments for the OH groups.

5.4 EPR spectroscopy

The X-band EPR spectrum of dumortierite selected samples (FIG. 6) display various signals that can be related to: (i) paramagnetic Fe^{3+} ions, (ii) electron holes trapped on oxygens, (iii) superparamagnetic domains (FIG. 6).

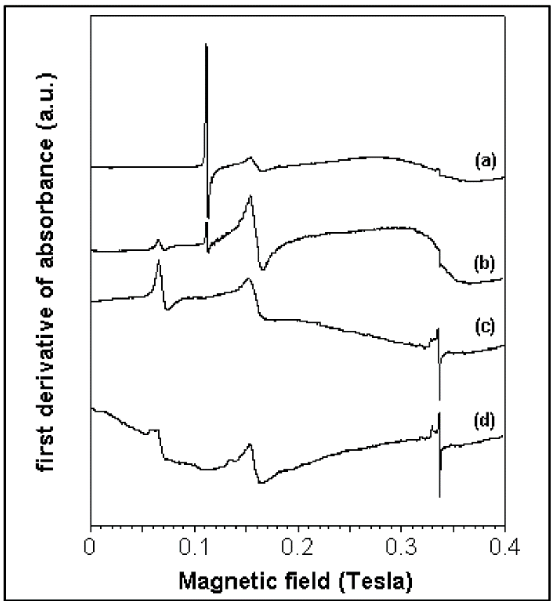

Figure 6 – Room temperature X-band EPR spectra of four selected dumortierite samples: (a) Louvincourt, (b) Lincoln Hill, (c) Acuélos and (d) Jack Creek. The two upper spectra correspond to pink samples whereas the two lower spectrums correspond to blue samples. Note the broad superparamagnetic signal producing the wavy baseline. The sharp signals are related to paramagnetic species. The spectra of the samples from Brazil (Macaúbas; Fazenda Formação 1) are similar to the samples a and d.
Source: Elaborated by authors.

Electronic holes are responsible for the thin signal observed at 0.34 T (present in all spectrum but particularly well marked in the Jack Creek (Montana) and Acuélos (Chile) samples. They are related to isolated Fe^{3+} ions in dilute configuration. In contrast, the very broad signal corresponding to the ondulating baseline of the spectrum is related to super-paramagnetic domains, i. e. Fe^{3+} ions concentrated in magnetic domains of nanometric size. The relative Brazil like shown in figure 7 for samples from Jack Creek and Lincoln Hill.

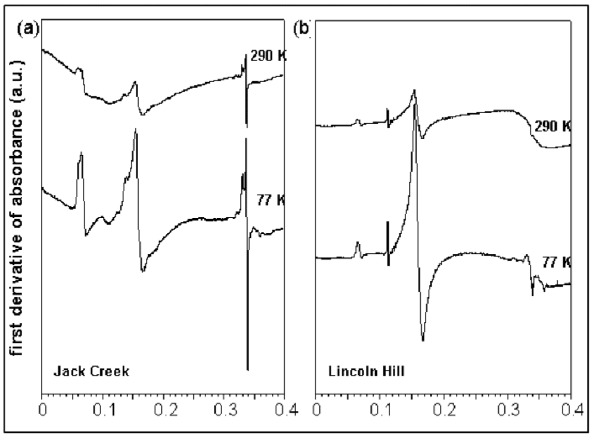

Figure 7 – X-band EPR spectrum of the Jack Creek (left) and Lincoln Hill (right) samples recorded at room (top) and liquid nitrogen temperature (bottom). Note the decrease at low temperature of the relative intensity of the broad signal ascribed to super-paramagnetic phases. Except this variation of relative intensity, the general shape of the spectrum is not strongly affected by the temperature change.
Source: Elaborated by authors.

Other iron species such as large magnetic domains or Fe^{2+} ions cannot be observed by EPR spectroscopy using the above detailed experimental conditions (FIG. 7). The three signals related to isolated Fe^{3+} present some variations of their relative intensity from one spectrum to another. Accordingly, these three signals should correspond to at least three different sites for the incorporation of Fe^{3+} in the dumortierite structure. The strong and sharp signal observed at 0.113 T in the EPR spectrum of pink dumortierite samples (Lincoln Hill, Nevada and Louvincourt, Quebec) is related to a site with a pure axial distortion, i. e. a site symmetry with a n-fold (n = 3) rotation axis. It likely indicates the substitution of Fe^{3+} for Al^{3+} in the (M1) octahedron chain located on the 6-fold axis of the dumortierite structure. The axial symmetry of the site further indicates that no substitution occur in the neighboring SiO_4 tetrahedron. In contrast the signals observed at 0.07 and 0.16 T correspond to more distorted sites. In particular, the signal at 0.16T corresponds to a strong rhombic distortion. These signals could be related to Fe_{3+} ions located in tetrahedral sites or in distorted octahedral sites.

5.5 Mössbauer effect spectrometry

Mössbauer spectrometry was used to determine site occupancy and valence state of iron and to obtain Fe^{2+}/Fe^{3+} ratio. Mössbauer spectroscopy of dumortierite is difficult to perform due to their low FeO content (from 0.06 wt % in the Louvicourt dumortierite, the Brazilian samples with around, 0.2 to 0.3% up to 0.91% in the Acuélos dumortierite. Therefore only two samples only could be properly recorded and the spectrum fitted: Acuélos (0.91% FeO) and Jack Creek (0.33% FeO) (FIG. 7). Results are given in TAB. 3. The uncertain results from Brazilian samples are near to those from Jack Creek, but have to be seen carefully.

Fitting of the Acuélos dumortierite was particularly difficult to achieve because of the importance of sub-crystalline magnetic inclusions (magnetite) that could not be eliminated with physical nor chemical method. However, the Mössbauer results for this sample show two doublets that can be attributed respectively to Fe^{2+} and Fe^{3+} both in octahedral site with dominantly divalent iron in a ratio Fe^{2+}/Fetotal ~ 2/3 (TAB. 3).

The Mössbauer spectrum for the Jack Creek dumortierite does not show magnetic signal. A first attempt made to perform Mössbauer spectroscopy brought misleading results with dominating Fe^{3+}. The error came from the process used to isolate dumortierite using HF etching of the sample and probably inducing oxidising phenomena. Further essay based on hand separation of the minerals of the crushed rock under microscope was long but leads to results representing the true oxidation state of Fe in the Jack Creek dumortierite. Fe is mostly divalent (~89%). Fe^{2+} and Fe^{3+} ions appeared to be located in octahedral sites in this sample but there are two different sites for Fe^{2+}.

	K	Speed (mm/s)		δ	Γ/2	Δ	H in Kœ	%
Acuélos (Chile)	300	10	magnetic component	0.374(3)	0.18	-0.22(7)	513	88,7
			Fe^{2+}	1.10(3)	0.18	2.588	_	7,4
			Fe^{3+}	0.24(6)	0.18	0.445		3.9
Jack Creek Montana, USA	300	4	Fe^{2+}	1.09(1)	0.13	2.41(2)	_	66.1
			Fe^{2+}	1.05(1)	0.13	1.65(3)		22.6
			Fe^{3+}	0.25(6)	0.13	0.71(1)		11.3

Table 3 – Mössbauer parameters from the Jack Creek, Acuélos and Macaúbas dumortierite.
The results from Macaúbas and Fazenda Formação dumortierite are similar to Acuélos.
Source: Elaborated by authors.

6. Conclusions

6.1 Laboratory

Spectroscopic methods enable us to obtain specific information on the site population in dumortierite. The results of infra-red spectroscopy measurements confirm that hydroxyl groups are replacing O(2) and O(7) between a [SiO_4] tetrahedron and an M1 central octahedron when the M1 site is vacant or when a R^{2+} cation substitutes for Al^{3+} in this site. At T<250°C adsorbed water is present in the channel-like structure of dumortierite. Results of EPR, and Mössbauer spectroscopy are remarkably concordant. Fe is present in different types of sites.

1. Fe^{3+} substitutes for Al (1) in the octahedral chain located on the 6 fold axis. In this site EPR signal reveals only pure axial distortion located i. e. a site symmetry with an n-fold (n = 3) rotation axis. The axial symmetry of the site further requires that no substitution occur in the neighboring SiO^4 tetrahedra. The strong signal at 0.113tesla in EPR spectroscopy character phenomenon in Lincoln Hill and particularly in Lovincourt dumortierite (FIG. 5).

2. Unlike the former specimens, paramagnetic Fe^{3+} in the Acuélos and Jack Creek samples is located in more distorted sites which could correspond to tetrahedral sites or distorted octahedral sites.

3. Due to short distances between octahedral centers in the M1 site chains iron-iron pair can be observed.

A thin signal observed at 0.34 T, characterizes electronic holes. It is present in all samples but particularly well marked in the Acuélos and Jack Creek one. It is related to isolated Fe^{3+} ions in dilute configuration. In contrast, a very broad signal corresponding to the ondulating baseline of the spectra and related to super-paramagnetic domains, i. e. Fe^{3+} ions concentrated in magnetic domains of nanometric size is very strong in the Acuélos and Jack Creek samples.

The existence of super-paramagnetic domains can be attributed to iron-iron pairs. This might suggest that these samples do not show only randomly distributed iron atoms (the thin EPR signal at 0.34 T) but that some irons "see" each other.

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A ocorrência de dumortierita na Serra do Espinhaço, Minas Gerais, Brasil, e sua comparação mineralógico-cristalográfica com outras variedades

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Resumo Amostras de dumortierita de várias localidades do Brasil (Serra do Espinhaço-Minas Gerais Macaúbas-Bahia) foram analisadas com microssonda e os resultados comparados com amostras dos depósitos de dumortierita de Louvincourt (Quebec, Canada), Lincoln Hill-Champion Mine (Nevada, USA), do Jack Creek (Montana), do Acuélos (Chile) e do Madagascar (localidade de origem desconhecida). Foram executadas nestas amostras análises com FTIR, ERP, Mössbauer. A espectroscopia FTIR mostra a existência de vários ambientes para o OH- grupos que são relacionadas com a substituição ou a vacância de posições octaedrais M1. Mössbauer espectroscopia indica Fe^{++} em duas diferentes posições octaedrais e Fe^{+++} em uma posição octaedral e IVCT e IMMT. ERP mostra também a presença de Fe^{+++} em várias posições. Os outros sinais indicam que a Fe^{+++} paramagnético a uma posição tetraédrica ou posições octaedrais mais torcidas.

Palavras-chave: dumortierita; Serra do Espinhaço; Supergrupo Rio Paraúna; Bahia; infravermelho.

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