

Original paper

# Mn<sup>3+</sup>-rich andalusite to kanonaite and their breakdown products from metamanganolite at Kojetice near Třebíč, the Moldanubian Zone, Czech Republic

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A zoned Mn<sup>3+</sup>-rich andalusite to kanonaite occurs as shortly prismatic, black-green crystals, up to 2 mm in size, randomly distributed in quartz matrix of quartzitic rock with metamanganolite portions from Kojetice near Třebíč. Minor spessartine, braunite, K-feldspar, albite, hyalophane, rare paragonite and accessory magnetite-rutile intergrowths, tephroite, chernovite-(Y), monazite-(Ce), pyrophanite, Sb-rich rutile, cobaltite, pseudobrookite(?) and pale pink flakes of late muscovite were identified in this rock. Zoned subhedral grains of Mn<sup>3+</sup>-rich andalusite to kanonaite have strong pleochroism: X = yellow, Y = green, Z = deep green, when narrow Mn<sup>3+</sup>-enriched rims feature slightly more intensive colors. Electron microprobe study shows that the core has always lower contents of Mn<sub>2</sub>O<sub>3</sub> relative to commonly narrow rim of kanonaite. Chemical composition varies from Mn<sup>3+</sup>-rich andalusite with 0.21 apfu Mn<sup>3+</sup> (9.72 wt. % Mn<sub>2</sub>O<sub>3</sub>) to kanonaite with up to 0.60 apfu Mn<sup>3+</sup> (26.09 wt. % Mn<sub>2</sub>O<sub>3</sub>). Minor amount of Fe<sub>2</sub>O<sub>3</sub> from 0.07 to 0.14 apfu Fe<sup>3+</sup> apfu (6.12 wt. % Fe<sub>2</sub>O<sub>3</sub>) is typical. In thin sections, subhedral grains of Mn<sup>3+</sup>-rich andalusite to kanonaite are enclosed in massive quartz and locally overgrown or replaced by spessartine plus albite/paragonite and later replaced by muscovite. No difference in degree of muscovitization was observed between Mn<sup>3+</sup>-rich andalusite and kanonaite. In particular, the abundance of feldspars as well as the total absence of Al<sub>2</sub>SiO<sub>5</sub> minerals and the presence of some rare accessory minerals in Kojetice are different from the other localities of Mn<sup>3+</sup>-rich andalusite and kanonaite. The presence of K-feldspar may suggest higher temperature relative to the other mostly low- to medium-grade kanonaite-bearing metamorphic rocks. The following mineral reactions are indicated from textural relations: 3 Mn<sup>3+</sup>-rich andalusite (kanonaite) + Na<sup>+</sup> + 3 quartz = spessartine + albite/paragonite, and 3 Mn<sup>3+</sup>-rich andalusite (kanonaite) + K<sup>+</sup> + H<sub>2</sub>O = muscovite + 3 Mn. The newly formed spessartine requires a decrease in *f*O<sub>2</sub>, which is also indicated by the presence of accessory tephroite. This is in contrast to the other localities of Mn<sup>3+</sup>-rich andalusite to kanonaite described to date, where increasing *f*O<sub>2</sub> during replacement of these minerals is typical.

**Keywords:** Mn<sup>3+</sup>-rich andalusite, kanonaite, spessartine, paragonite, muscovite, electron microprobe, metamanganolite, Kojetice, Moldanubian Zone

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## 1. Introduction

Kanonaite <sup>VI</sup>Mn<sup>3+</sup>AlSiO<sub>5</sub> – a mineral species related to andalusite – was first described from a locality near Kanona, Zambia, by Vrána et al. (1978). Only three new occurrences of kanonaite have been discovered to date: classical locality Le Coreux, Salm Valley, Stavelot Massif, Ardennes Mountains, Belgium (Kramm 1979a; Schreyer et al. 2001, 2004); Serra das Bicas, Carrancas, Minas Gerais, Brazil (Pires et al. 2000) and Bani Hamid, Oman ophiolite, United Arab Emirates (Kugimiya et al. 2004).

Chemical compositions of Mn<sup>3+</sup>-rich andalusite (formerly “viridine” – Klemm 1911) to kanonaite fall into the ternary solid solution of andalusite (AlAlSiO<sub>5</sub>), kanonaite (Mn<sup>3+</sup>AlSiO<sub>5</sub>) and “Fe-andalusite” (Fe<sup>3+</sup>AlSiO<sub>5</sub>), which only exceptionally attains ~ 12 mol. % of Fe<sup>3+</sup>AlSiO<sub>5</sub> (Abs-Wurmbach et al. 1981; Schreyer et al. 2004). Incorporation of Mn<sup>3+</sup> (kanonaite component) into the an-

dalusite structure significantly enlarges its stability field to higher temperatures and pressures. Moreover, very high oxygen fugacity close to the pyrolusite/partridgeite buffer (log *f*O<sub>2</sub> ~ -3 to 2) is required (Abs-Wurmbach et al. 1983, Abs-Wurmbach and Peters 1999). The Mn<sup>3+</sup>-rich andalusite as well as kanonaite are more stable during dehydration reactions involving Al-silicates (e.g., pyrophyllite, kaolinite) relative to the pure andalusite. The presence of Mn<sup>3+</sup> in the structure also significantly modifies physical properties (e.g., Weiss et al. 1981; Gunter and Bloss 1982). Consequently, strong pleochroism in yellow to emerald green colors (compared to weakly pleochroic ordinary andalusite) enables to recognize the Mn<sup>3+</sup>-rich andalusite easily in thin sections even if the content of Mn<sup>3+</sup> in such andalusite is merely ~ 2 wt. % Mn<sub>2</sub>O<sub>3</sub> (Kramm 1979b).

The Mn<sup>3+</sup>-rich andalusite and kanonaite are commonly associated with quartz, Mn-rich minerals (braunite,

spessartine, cryptomelane, coronadite and hollandite),  $\text{Al}_2\text{SiO}_5$  phases (kyanite, andalusite and sillimanite) as well as muscovite. The two occur in Mn-rich rocks (metamanganolites) metamorphosed under different P–T conditions varying from LT/LP schists and associated quartz veins (Kramm 1979a; Schreyer et al. 2001, 2004), through HT–MT/LP contact hornfelses (Abraham and Schreyer 1975) to HT/MP leucocratic quartz-feldspar leptites (Kramm 1979b), quartzites (Kulish 1961; Abs-Wurmbach et al. 1981; Abs-Wurmbach and Peters 1999), and metacherts associated with an ophiolite complex (Kugimiya et al. 2004). Nevertheless, unlike in the case of  $\text{Mn}^{3+}$ -rich andalusite, the formation of kanonaite is commonly related to a retrograde stage of metamorphic evolution (Schreyer et al. 2004; Kugimiya et al. 2004). Here we present new data about  $\text{Mn}^{3+}$ -rich andalusite to kanonaite from Kojetice. It represents rather unusual occurrence related to high-grade polyphase metamorphism, where  $\text{Mn}^{3+}$ -rich andalusite to kanonaite formed during prograde stage and was replaced by spessartine and, later, by muscovite.

## 2. Geological setting

The Kojetice locality is situated in the Drosendorf Unit of Moldanubian Zone, about 4 km W of the Třebíč Durbachite Pluton. Dominant biotite–sillimanite gneisses, locally slightly migmatized, contain common intercalations of quartzite, graphite quartzite with V-rich muscovite, calc-silicate rock, calcite/dolomite marble and orthogneiss. Metamorphic evolution of the host rock sequence has not been studied so far. Dolomite marble, the only rock examined in detail in this area, shows the mineral assemblage dolomite + calcite + phlogopite + forsterite + spinel, whereby the formation of the assemblage forsterite + spinel was probably related to the HT/LP metamorphism at *c.* 540–750 °C for pressures of ~ 2–4 kbar (Novák and Houzar 1996; Houzar and Novák 2006).

František Slavík first mentioned rhodonite from this locality (in Burkart 1953). Pavel Chlupáček sampled the majority of the specimens currently located in the collection of the Moravian Museum in Brno. Burkart (1953) listed the following minerals: rhodonite, garnet, manganite, hematite, psilomelane, pyrolusite and rhodochrosite. Novák (1991) presented a brief report with description of the individual rock types and representative electron microprobe analyses for some of the minerals. The following phases were identified: major to minor – rhodonite, spessartine, celsian, hyalophane and  $\text{Mn}^{3+}$ -rich andalusite; accessory – pyrophanite, ilmenite, magnetite, barite, Sb-rich rutile, chernovite-(Y), monazite-(Ce) and cobaltite.

## 3. Petrography

Rare fragments of highly weathered Mn-rich rocks and their quartzite matrix occur in fields ~ 1 km S of the Kojetice village. No outcrops are known and the size of the metamanganolite fragments usually reaches several cm. Consequently, textural relations among the individual types of metamanganolites enclosed in quartzite matrix and described below are only poorly known. The quartzite formed an intercalation, probably up to 0.5 m thick, enclosed in gneiss (Burkart 1953). Greyish, fine- to medium-grained, massive to slightly foliated and banded quartzite is locally enriched in feldspars, tending to leucocratic quartzo-feldspathic rock. Anhedral quartz in quartzite exhibits locally strong undulose extinction. Minor to locally major minerals – K(Ba)-feldspars and/or plagioclase (albite to oligoclase) – occur as porphyroblasts, larger than the quartz grains in the matrix. Minor to accessory minerals in the quartzite matrix include spessartine, braunite, rhodonite, and secondary muscovite.

We recognized the following textural and compositional types of metamanganolites (see also Novák 1991):

*Braunite-dominant rock* is evidently the most abundant. Oval nodules to irregular nests, up to 10 cm in diameter, with apparent folding features show sharp to transitional contact with the host quartzite. This rock is black, fine- to medium-grained. Braunite and quartz are the major phases besides minor hyalophane, spessartine, magnetite–rutile intergrowths, and accessory pyrophanite and ilmenite. Zoned spessartine grains sporadically host small inclusions of chernovite-(Y) and arsenogoyazite.

The *Mn<sup>3+</sup>-rich andalusite rock* is much less abundant (only 3 samples have been found to date). It forms elongated layers parallel to the banding of the host quartz-feldspathic rock to quartzite, up to 2–3 cm thick. It has a dark grey–green color in hand specimen and contains short prismatic crystals of zoned  $\text{Mn}^{3+}$ -rich andalusite to kanonaite that are randomly distributed in the quartz matrix. Minor braunite, feldspars (K-feldspar, albite and hyalophane), spessartine and paragonite were identified as well as accessory magnetite–rutile intergrowths, tephroite, chernovite-(Y), monazite-(Ce), pyrophanite, Sb-rich rutile, cobaltite and pseudobrookite(?). Late muscovite replaces  $\text{Mn}^{3+}$ -rich andalusite to kanonaite and scarcely also spessartine.

*Garnet-rich rock* represents a less common type characterized by dark brownish black to reddish black color in hand specimen. Euhedral grains of zoned Fe-rich spessartine, up to 3 mm in diameter, and quartz are major minerals besides minor flakes of Fe-rich phyllosilicate (stilpnomelane?) and pyrophanite, both typically enclosed in garnet. Accessory braunite, magnetite, ilmenite, monazite-(Ce), cryptomelane, rhodonite and zircon were found.

*Rhodonite-dominant rock* is rare; only several small fragments have been found. It also forms about 2 mm thick layers in quartzite. The rock has a deep raspberry red color on fresh surfaces with randomly distributed yellow grains of spessartine, up to 2 mm in size. Minor to accessory minerals include barite, zoned celsian, quartz, pyrophanite, zircon and monazite-(Ce).

#### 4. Methods

Chemical analyses of Mn<sup>3+</sup>-rich andalusite to kanonaite and other associated minerals (braunite, spessartine, feldspars, micas, accessory minerals) were performed with the electron microprobe Cameca SX100 at the Laboratory of Electron Microscopy and Microanalysis, the joint facility of the Masaryk University and Czech Geological Survey in Brno. The system was operating at an accelerating voltage 15 kV, a beam current 20 nA and a beam diameter 1 µm. Following standards and lines were used for Mn<sup>3+</sup>-rich andalusite to kanonaite: Si K<sub>α</sub>, Al K<sub>α</sub> (andalusite), Mn K<sub>α</sub> (rhodonite), Fe K<sub>α</sub>, Ca K<sub>α</sub> (andradite), Ti K<sub>α</sub> (titanite), Mg K<sub>α</sub> (MgO), K K<sub>α</sub> (sanidine), Na K<sub>α</sub> (albite), Cr K<sub>α</sub> (chromite), P K<sub>α</sub> (apatite), Ni K<sub>α</sub> (NiO) and Ba L<sub>β</sub> (barite). The peak counting times were 20 s for Si, Al, Fe, Mn, Mg, Ca and Na and 40 s for Ti, K, Cr, P, Ni and Ba. The counting times for each background corresponded to the one half of the peak counting time. Raw data were converted to concentrations using the automatic PAP correction (Pouchou and Pichoir 1985). From 13 elements measured in Mn<sup>3+</sup>-rich andalusite and kanonaite, only Si, Al, Fe, Mn and Ti were found to be above their respective detection limits, which was 200 to 500 ppm (based on the counting statistics). The 220 µm long X-ray profile of the Mn, Al and Fe concentrations across the zoned Mn<sup>3+</sup>-rich andalusite to kanonaite was carried out at the following conditions: an accelerating voltage 15 kV, a beam current 40 nA, a beam diameter ~ 1 µm and a dwell time 1 s; the step was 0.5 µm. The formulae of Mn<sup>3+</sup>-rich andalusite to kanonaite (Tab. 1) were normalized to 5 O assuming all Fe and Mn as trivalent.

#### 5. Mn<sup>3+</sup>-rich andalusite to kanonaite

##### 5.1. Samples and description

Three samples containing Mn<sup>3+</sup>-rich andalusite to kanonaite were studied in detail; the sample Koj2 (A 5551) was collected by P. Chlupáček in 1933, the samples Koj1 and Koj5 by R. Škoda in 2003. The Mn<sup>3+</sup>-rich andalusite-rich layer is *c.* 2–3 cm thick in all samples with randomly distributed black-green prismatic grains of Mn<sup>3+</sup>-rich andalusite, up to 1–2 mm

**Tab. 1** Representative chemical analyses of Mn<sup>3+</sup>-rich andalusite to kanonaite, Kojetice.

Mineral	MnA	MnA	MnA	kan	kan	kan
Sample	Koj2	Koj5	Koj1	Koj1	Koj1	Koj1
SiO <sub>2</sub>	35.11	34.82	33.73	33.27	32.71	33.73
TiO <sub>2</sub>	0.08	0.08	0.09	0.03	0.06	0.11
Al <sub>2</sub> O <sub>3</sub>	51.26	44.17	41.87	38.42	36.02	37.88
Fe <sub>2</sub> O <sub>3</sub>	3.10	4.31	5.29	3.69	5.33	6.12
Mn <sub>2</sub> O <sub>3</sub>	9.72	16.59	19.17	24.96	26.09	23.42
Total	99.27	99.97	100.15	100.37	100.21	101.26
Si <sup>4+</sup>	1.000	1.014	0.995	0.995	0.991	1.002
Ti <sup>4+</sup>	0.002	0.002	0.002	0.001	0.001	0.002
<sup>v</sup> Al <sup>3+</sup>	1.000	1.000	1.000	1.000	1.000	1.000
<sup>vi</sup> Al <sup>3+</sup>	0.721	0.516	0.456	0.354	0.286	0.327
<sup>vi</sup> Mn <sup>3+</sup>	0.211	0.368	0.430	0.568	0.602	0.530
<sup>vi</sup> Fe <sup>3+</sup>	0.066	0.094	0.117	0.083	0.122	0.137
Σ cat	3.000	2.995	3.001	3.001	3.002	2.998
O	5.000	5.000	5.000	5.000	5.000	5.000

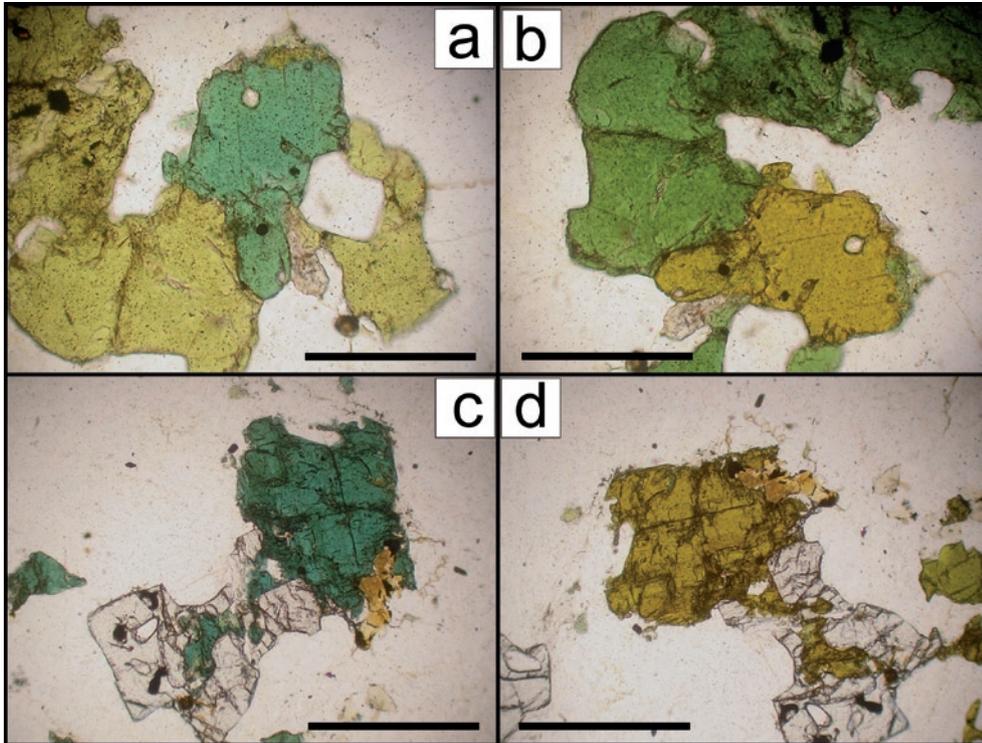
MnA – Mn<sup>3+</sup>-rich andalusite

kan – kanonaite

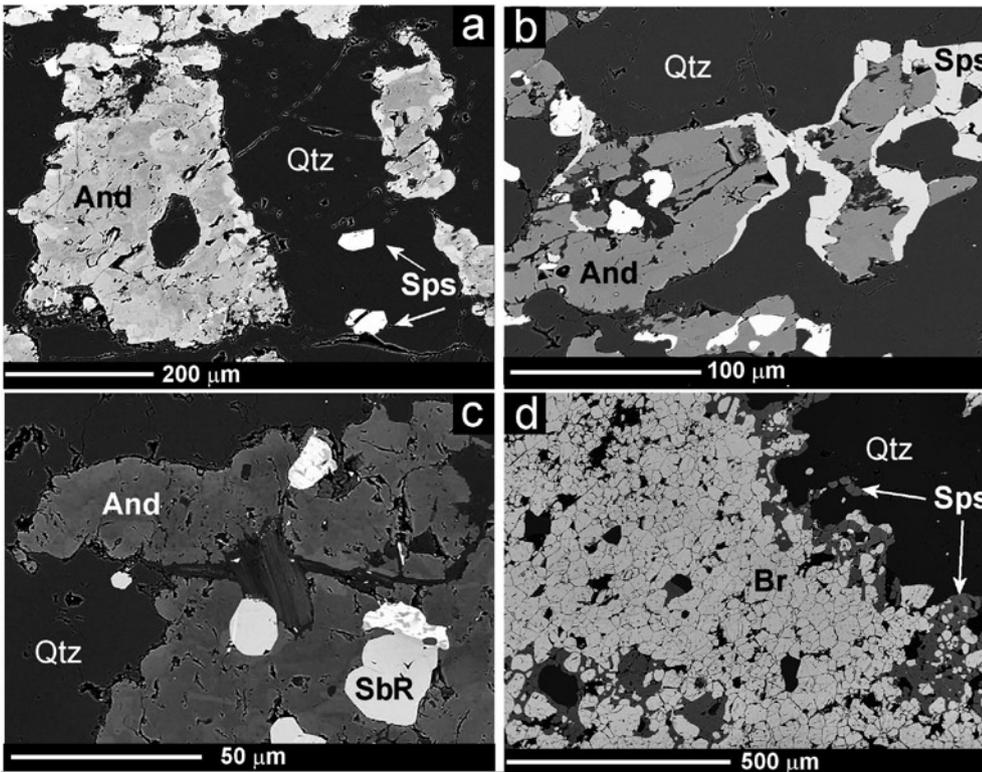
long (Figs 1a–b, 2a), and pale pink flakes of secondary muscovite, up to 2 mm in size. In thin section, zoned subhedral grains of Mn<sup>3+</sup>-rich andalusite to kanonaite show strong pleochroism: X = yellow, Y = green, Z = deep green (Fig. 1), when narrow Mn<sup>3+</sup>-enriched rims feature slightly more intensive colors. Subhedral grains of Mn<sup>3+</sup>-rich andalusite to kanonaite are enclosed in massive quartz and locally replaced (Fig. 1c–d) or overgrown (Fig. 2b) by spessartine with numerous inclusions of Sb-rich rutile (Fig. 1c). Spessartine is closely associated with small grains of albite and particularly paragonite (Fig. 2b–c). Grains of Mn<sup>3+</sup>-rich andalusite to kanonaite are also locally replaced by late muscovite. No differences in degree of muscovitization were observed between Mn<sup>3+</sup>-rich andalusite cores and kanonaite rims. Minor braunite overgrown by spessartine is also locally present (Fig. 2d).

##### 5.2. Chemical composition

Electron microprobe study revealed simple zoning in the samples examined. Core has always moderate contents of Mn relative to commonly narrow, Mn-rich rims (Fig. 2a). Chemical composition varies in a wide range from Mn<sup>3+</sup>-rich andalusite with 0.21 apfu Mn<sup>3+</sup> (9.72 wt. % Mn<sub>2</sub>O<sub>3</sub>) to kanonaite with up to 0.60 apfu Mn<sup>3+</sup> (26.09 wt. % Mn<sub>2</sub>O<sub>3</sub>). Minor amounts of ferric iron varying from 0.07 apfu (3.10 wt. % Fe<sub>2</sub>O<sub>3</sub>) to 0.14 apfu Fe<sup>3+</sup> (6.12 wt. % Fe<sub>2</sub>O<sub>3</sub>) are typical (Tab. 1). Low concentrations of



**Fig. 1** Subhedral grains of  $Mn^{3+}$ -rich andalusite to kanonaite in quartz **a**) and **b**), and replacement of  $Mn^{3+}$ -rich andalusite by spessartine **c**) and **d**). Note strong pleochroism of  $Mn^{3+}$ -rich andalusite in yellow to green colors and small dark grains of rutile in spessartine. Scale bar – 0.2 mm.

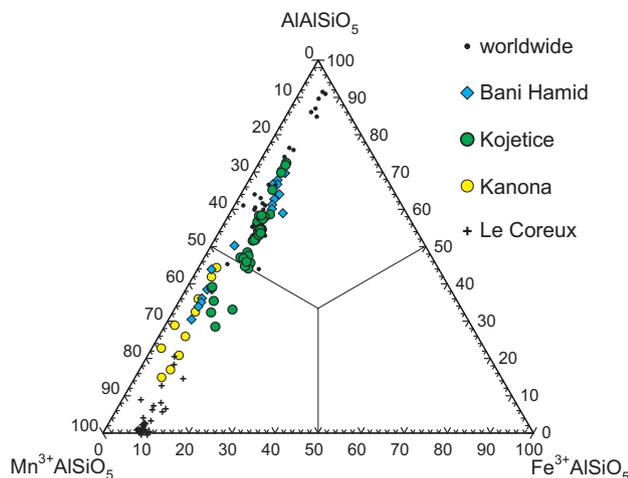


**Fig. 2** BSE images of selected mineral assemblages of the  $Mn^{3+}$ -rich andalusite rock; **a** – zoned  $Mn^{3+}$ -rich andalusite (And) to kanonaite (bright rim) in quartz (Qtz) with grains of spessartine (Sps); **b** –  $Mn^{3+}$ -rich andalusite (And) to kanonaite in quartz (Qtz) overgrown by spessartine (Sps) and paragonite (gray grains in center of  $Mn^{3+}$ -rich andalusite grain); **c** –  $Mn^{3+}$ -rich andalusite (And) to kanonaite with inclusions of Sb-rich rutile (SbR) and intergrowths of magnetite with rutile (bright), heterogeneous flake of paragonite is located in the center of the picture; **d** – braunite-rich domain of  $Mn^{3+}$ -rich andalusite rock, braunite (Br) is overgrown by spessartine (Sps), particularly along its contact with quartz (Qtz).

TiO<sub>2</sub> (<0.003 apfu Ti; 0.13 wt. % TiO<sub>2</sub>) represent the only minor-trace element found.

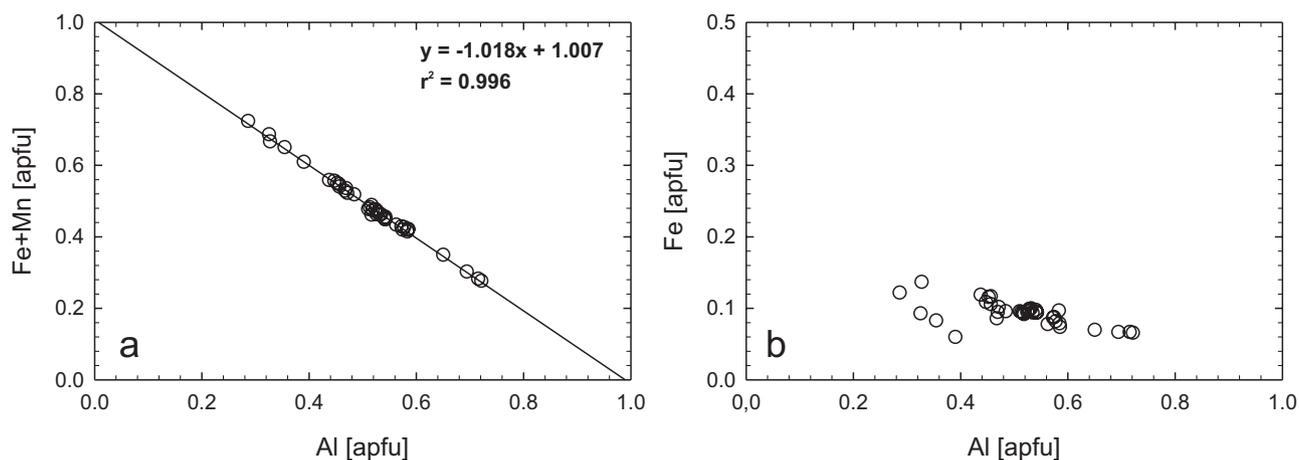
## 6. Discussion

Chemical composition of Mn<sup>3+</sup>-rich andalusite to kanonaite from Kojetice is very similar to those from the other localities showing narrow Mn<sup>3+</sup>-enriched rims (Schreyer et al. 2001, 2004; Kugimiya et al. 2004; Fig. 3). The concentration of Fe<sup>3+</sup>, up to 0.14 apfu, is



**Fig. 3** Ternary diagram showing composition of Mn<sup>3+</sup>-rich andalusite to kanonaite from selected localities.

slightly higher relative to the other localities (see Fig. 3). The perfect negative correlation Fe<sup>3+</sup>+ Mn<sup>3+</sup> with Al with high correlation coefficient  $r^2 = 0.996$  (see Fig. 4a) confirms the substitution  $(\text{Fe} + \text{Mn})^{3+}\text{Al}_{-1}$ . Slightly negative correlation occurs between Fe<sup>3+</sup> and <sup>VI</sup>Al (Fig. 4b). In the X-ray profile negative correlation of Fe<sup>3+</sup> versus Mn<sup>3+</sup> was

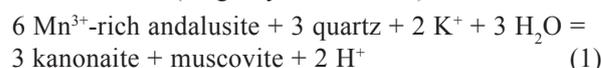


**Fig. 4** Diagrams illustrating chemical variation in Mn<sup>3+</sup>-rich andalusite to kanonaite; **a** – Fe + Mn versus <sup>VI</sup>Al; **b** – Fe versus <sup>VI</sup>Al.

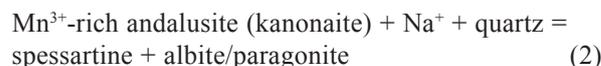
found in the center of the grain but no correlation of Fe<sup>3+</sup> and Mn<sup>3+</sup> was observed in the kanonaite rim (Fig. 5).

The mineral assemblage of the Mn<sup>3+</sup>-rich andalusite-to kanonaite-bearing rock from Kojetice with quartz as a dominant associated mineral is analogous to the other localities (Vrána et al. 1978; Schreyer et al. 2001; Kugimiya et al. 2004). However, the abundance of feldspars, total absence of pure Al<sub>2</sub>SiO<sub>5</sub> phases and the presence of some rare accessory minerals listed above are distinct. Presence of K-feldspar and absence of primary muscovite may suggest temperatures higher than on the other localities, where mostly low- to medium-grade metamorphic conditions were proposed.

Moderate abundance of secondary muscovite and local formation of spessartine after Mn<sup>3+</sup>-rich andalusite and kanonaite were reported from Bani Hamid (e.g. Kugimiya et al. 2004). The degree of muscovite replacement of Mn<sup>3+</sup>-rich andalusite in center and kanonaite in rims is however distinct and the textural relations of Mn<sup>3+</sup>-rich andalusite and kanonaite at Bani Hamid indicate the mineral reaction (Kugimiya et al. 2004):



At Kojetice, both Mn<sup>3+</sup>-rich andalusite and kanonaite show locally replacement (or overgrowing) by spessartine plus albite/paragonite and the following simplified reaction is indicated:



Spessartine forming according to the reaction (2) requires decreasing  $f\text{O}_2$ , which is supported by the presence of accessory tephroite (Abs-Wurmbach and Peters 1999). Also influx of Na and K is necessary, for which the abundant feldspars from quartz–feldspatic rock surrounding the Mn<sup>3+</sup>-rich andalusite rock may have been

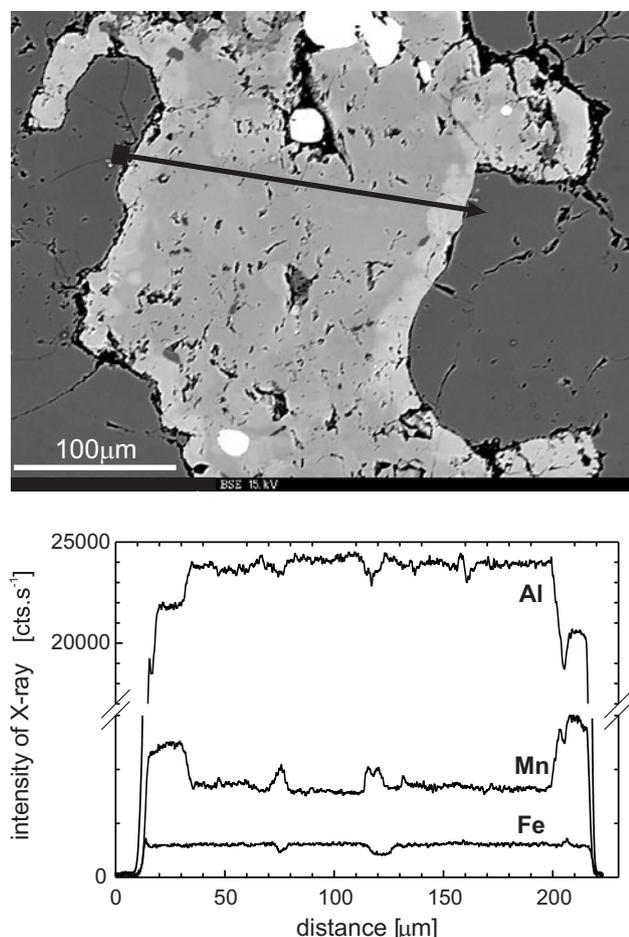
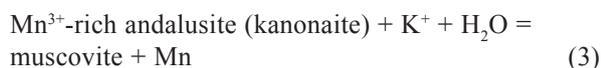


Fig. 5 Profile across zoned  $\text{Mn}^{3+}$ -rich andalusite (core) to kanonaite (rim); a) BSE image; b) variation of major elements.

the appropriate source. Subsequent replacement of both  $\text{Mn}^{3+}$ -rich andalusite and kanonaite by late muscovite is compatible with the simplified mineral reaction:



This reaction requires influx of K (Na) and water but also output of Mn, having a retrograde character. The ultimate sink for Mn is unknown because secondary muscovite is Mn-poor and no other secondary minerals of Mn were found in association with muscovite.

## 7. Conclusions

Zoned  $\text{Mn}^{3+}$ -rich andalusite to kanonaite from Kojetice is very similar to the other localities in its chemical composition and style of zoning (Schreyer et al. 2001; Kugimiya et al. 2004). The main differences include: (i) abundance of feldspars (albite, K- and Ba-feldspars), (ii) total absence of pure  $\text{Al}_2\text{SiO}_5$  polymorphs (sillimanite, andalusite or kyanite), and (iii) some specific accessory

minerals (tephroite, pyrophanite, chernovite-(Y) and Sb-rich rutile). The early metamorphic event producing  $\text{Mn}^{3+}$ -rich andalusite to kanonaite was characterized by high  $f\text{O}_2$  at about pyrolusite/partridgeite buffer ( $\log f\text{O}_2 \sim -3$  to 2; for  $P = 400$  kbar,  $T = 600$  °C; Abs-Wurmbach and Peters 1999). However, the P–T conditions remained unconstrained due to the very high stability of  $\text{Mn}^{3+}$ -rich andalusite to kanonaite (Abs-Wurmbach et al. 1983). They may have been close to the P–T data given above for the estimated  $f\text{O}_2$ . The formation of spessartine (+albite/paragonite) was accompanied by markedly decreasing oxygen fugacity ( $\log f\text{O}_2 < 2$ ; for  $P = 400$  kbar,  $T = 600$  °C; see Abs-Wurmbach and Peters 1999). Such a metamorphic evolution is distinct from that at Banid Hamir, where an increase of  $\text{Mn}^{3+}$  contents in late  $\text{Mn}^{3+}$ -rich andalusite and, more commonly, kanonaite are characteristic of the replacement process. The retrograde stage (alteration) in Kojetice is manifested by formation of muscovite and output of Mn. Such a behavior is also distinct from the other localities of  $\text{Mn}^{3+}$ -rich andalusite to kanonaite (Schreyer et al. 2001, 2004; Kugimiya et al. 2004).

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## Andalusit bohatý Mn<sup>3+</sup> až kanonait a produkty jejich rozpadu z Kojetic u Třebíče, moldanubikum

Kvarcitická hornina z v Kojetic u Třebíče místy obsahuje partie různých texturních a mineralogických typů metamanganolitů (relativně hojně, braunitem bohaté nepravidelné partie, vzácné polohy s Mn<sup>3+</sup> bohatým andalusitem, úlomky spessartinem bohatých hornin a vzácné úlomky masivního rhodonitu s celsianem a spessartinem). Zonální andalusit bohatý Mn<sup>3+</sup> až kanonait tvoří černozeleň, krátce prismatické krystaly až 2 mm velké zarostlé v křemenné matrix. Vedle dominantního křemene a andalusitu obsahuje hornina ve vedlejším množství braunit, K-živce, albit, hyalofan, spessartin, paragonit a růžový sekundární muskovit. Jako akcesorické minerály byly zjištěny tefroit, chernovit-(Y), monazit-(Ce), pyrofanit, rutil bohatý Sb, cobaltin, srůsty magnetitu a rutilu a pseudobrookit(?). Zonální hypidiomorfně omezená zrna andalusitu bohatého Mn<sup>3+</sup> místy s lemy kanonaitu mají silný pleochroismus: X = žlutá, Y = zelená, Z = tmavě zelená, lemy kanonaitu ukazují mírně intenzivnější zbarvení. Studium na elektronové mikrosondě potvrdilo zonální složení, kdy středy zrn mají relativně nižší obsah Mn<sub>2</sub>O<sub>3</sub> vzhledem k leům kanonaitu. Složení kolísá od andalusitu s 0,21 apfu Mn<sup>3+</sup> (9,72 váh. % Mn<sub>2</sub>O<sub>3</sub>) ke kanonaitu s 0,60 apfu Mn<sup>3+</sup> (26,09 váh. % Mn<sub>2</sub>O<sub>3</sub>). Dále byl zjištěn zvýšený obsah Fe<sub>2</sub>O<sub>3</sub> od 0,07 do 0,14 apfu Fe<sup>3+</sup> (6,12 váh. % Fe<sub>2</sub>O<sub>3</sub>). Andalusit až kanonait je místy zatlačován nebo obrůstán spessartinem v asociaci s albitem nebo paragonitem a později zatlačován muskovitem. Nebyl zjištěn rozdíl ve stupni muskovitizace mezi andalusitem bohatým Mn<sup>3+</sup> a kanonaitem. Nově tvořený spessartin vyžaduje snížení  $f\text{O}_2$ , které je indikováno také přítomností akcesorického tefroitu. Tento process je odlišný od ostatních lokalit kanonaitu, kde je naopak typické zvyšování  $f\text{O}_2$  během zatlačování kanonaitu. Poměrně hojně živce, absence Al<sub>2</sub>SiO<sub>5</sub> minerálů a přítomnost některých akcesorických minerálů také odlišují Kojetice od jiných lokalit kanonaitu ve světě.