FOITITE: FORMATION DURING LATE STAGES OF EVOLUTION OF COMPLEX GRANITIC PEGMATICITES AT DOBRÁ VODA, CZECH REPUBLIC, AND PALA, CALIFORNIA, U.S.A.

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ABSTRACT

Zoned crystals of tourmaline (elbaite–foitite) were found in pockets of the lepidolite-subtype granitic pegmatites at Dobrá Voda, western Moravia, Czech Republic, and the White Queen mine, Pala, San Diego County, California. Zoned crystals consist of pale pink, colorless and greenish Fe-poor elbaite, blue, violet or green Fe-rich elbaite, and dark violet to black foitite. Elbaite–foitite is associated with quartz, cookeite, albite and apatite at Dobrá Voda, and with albite, quartz, K-feldspar, beryl, and muscovite at the White Queen mine. Chemical compositions of foitite and associated Fe-poor to Fe-rich elbaite are similar at both localities, and exhibit an X-site vacancy (0.75 apfu, in foitite), and variable amounts of Ca (0.05 apfu), Mn (0.47 apfu) and F (0.75 apfu, in elbaite), in contrast to foitite that in many cases is F-free. Two distinct stages of late Fe-enrichment in tourmaline were recognized, in contrast to Fe-depletion, noted in many granitic pegmatites. The first stage is generally characterized by increasing Fe and Na, and decreasing Al and Li contents; three substages show the following substitutions: (i) $\text{R}_2\text{(LiAl)}_2$, $\text{NaR}_2\text{(OH)}_2$ ($\text{AlO}_2\text{[Li(OH)_2]}$ and (OH) F $^{-1}$) for elbaite containing <0.3 Fe apfu at Dobrá Voda ($R = Fe_{\text{tot}} + Mn + Mg + Zn$); (ii) Na $R_2$ (OH) ($\text{AlO}_2\text{[Li(OH)_2]}$ or Na $\text{AlO}_2\text{[Li(OH)_2]}$ and F (OH) $^{-1}$), for Fe-rich elbaite with 0.5–1.0 Fe apfu; (iii) $\text{Al}_2\text{[Li(OH)_2]}$ and (OH) F $^{-1}$, perhaps combined with $\text{R}_2\text{(LiAl)}_2$, for Fe-rich elbaite with 1.0–1.3 Fe apfu at the White Queen mine. The second stage involves formation of foitite via the $\text{R}[\text{NaLi}]_2$ exchange and, at White Queen, also the substitution (OH) F $^{-1}$). Foitite at Dobrá Voda crystallized from Fe-rich fluids at temperatures below ~400 °C (as low as 300 °C), on the basis of observed mineral assemblages, textural relations and results of experimental studies. Iron enrichment during the late stages of pegmatite crystallization recorded in Fe-rich elbaite, foitite, schorl and other minerals [micas, (Nb,Ta)-oxides] appears to be a widespread but volumetrically negligible process in complex granitic pegmatites. However, the source of Fe has not been sufficiently explained.

Keywords: tourmaline, foitite, elbaite, electron microprobe, compositional evolution, paragenesis, Fe-enrichment, complex granitic pegmatite, Dobrá Voda, Czech Republic, White Queen mine, California.

SOMMAIRE

Nous décrivons des cristaux zonés de tourmaline (elbaite–foitite) prélevés de poches dans des pegmatites granitiques à lepidolite à Dobrá Voda, en Moravie occidentale, en République Tchèque, et à la mine White Queen, à Pala, comté de San Diego, en Californie. Les cristaux zonés contiennent une elbaite rose pâle, incolore ou verdâtre à faible teneur en fer, une elbaite bleue, violacée ou verte riche en fer, et une foitite violette foncée ou noire. Les cristaux d’elbaite–foitite montrent une association avec quartz, cookeite, albite et apatite à Dobrá Voda, et avec albite, quartz, feldspath potassique, beryl, et muscovite à la mine White Queen. Les compositions chimiques de la foitite et de l’elbaïte contenant moins de 0.3 Fe apfu, dans la foitite, et de teneurs variables en Ca (0.05 apfu), Mn (0.47 apfu) et F (0.75 apfu, dans l’elbaïte), ce qui contraste avec la foitite, qui dans plusieurs cas est sans fluor. Nous distinguons deux stades distincts d’enrichissement tardif en fer, ce qui contraste avec l’appauvrissement en fer qui est signalé dans plusieurs massifs de pegmatite granitique. Le premier stade se distingue par une augmentation en Fe et Na, et une diminution en Al et Li; trois subdivisions de ce stade montrent les substitutions suivantes: (i) $\text{R}_2\text{(LiAl)}_2$, $\text{NaR}_2\text{(OH) AlO}_2\text{[Li(OH)_2]}$ et (OH) F $^{-1}$ dans le cas de l’elbaïte contenant moins de 0.3 Fe apfu à Dobrá Voda ($R = Fe_{\text{tot}} + Mn + Mg + Zn$); (ii) Na $R_2\text{(OH)[AlO}_2\text{[Li(OH)_2]}$ ou NaR $\text{AlO}_2\text{[Li(OH)_2]}$ et F (OH) $^{-1}$, dans le cas de l’elbaïte riche en fer avec entre 0.5 et 1.0 Fe apfu; (iii) $\text{Al}_2\text{[Li(OH)_2]}$ et (OH) F $^{-1}$, possiblement en combinaison avec $\text{R}_2\text{(LiAl)}_2$, dans le cas de l’elbaïte riche en fer contenant entre 1.0 et 1.3 Fe apfu à la mine White Queen. Le deuxième stade implique la formation de la foitite via le mécanisme d’échange $\text{R}[\text{NaLi}]_2$ et, à la mine White Queen, la substitution (OH) F $^{-1}$ en plus. La foitite à Dobrá Voda a cristallisé à partir d’une phase fluide riche en fer à une température...
INTRODUCTION

The physical and optical properties, chemical composition and crystal structure of foitite, \( \text{Hf}_2\text{Al}_{6}\text{Si}_6\text{O}_{18}\text{(BO}_3\text{)}_3\text{(OH)}_4 \), are well described, but the type locality is known only as “southern California” (MacDonald et al. 1993; redescribed by Hawthorne & Henry 1999). Although the holotype specimen of foitite is a single crystal removed from its matrix, one can assume that the type locality is one of southern California’s many complex rare-element granitic pegmatites. Since the initial description, foitite has been found at a number of localities and in various rocks, chiefly granitic pegmatites (Dutrow & Henry 2000, and references therein). Foitite was found in pockets from several pegmatite dikes from Elba, Italy (Aurisicchio et al. 1999) as dark violet to black terminations on zoned crystals of elbaite. It also occurs there as gray, hair-like clusters within small vugs spatially associated with sekaninaite aggregates from the Filone Rosina dike, San Piero in Campo, Elba (Pezzotta et al. 1996). Dutrow & Henry (2000) described complexly zoned fibrous tourmaline (foitite – Fe-rich elbaite – Li-rich schorl – “fluor-elbaite”) hosted by elbaite from the Cruzeiro mine, Minas Gerais, Brazil. Black tourmaline from less fractionated, outer units of lepidolite- and petalite-subtype pegmatites also locally exhibit a slight predominance of the foitite component over schorl (Novák & Selway 1997, Selway et al. 1999, 2000). Foitite was also found in pseudomorphs after sekaninaite associated with cookeite, albite and muscovite at pegmatite from Dolní Bory (unpubl. data of MN).

GEOLOGICAL SETTING AND INTERNAL STRUCTURE OF PEGMATITES

Dobrá Voda

This pegmatite is a symmetrically zoned, steeply dipping dike, up to 6 m in width and about 100 m in length, emplaced in amphibolite and gneiss (Staněk 1965, Černý et al. 1995, Novák & Staněk 1999). It consists of (1) a volumetrically dominant marginal granitic unit, (2) a graphic unit, (3) a coarse-grained albite unit with blocks of K-feldspar, which is subdivided into three subunits: (3a) muscovite–albite, (3b) outer lepidolite–albite, and (3c) inner lepidolite–albite. Subunit 3c is adjacent to (4) a lepidolite unit in the central part of the dike. Amblygonite–montebrasite and pseudomorphs of spodumene + quartz intergrowths after petalite occur in subunits (3b) and (3c). Typical accessory minerals include andalusite, dumortierite, (Nb,Ta)-oxide minerals (manganocolumbite, stibiotantalite, microlite, manganottantalite), apatite, zircon and cassiterite (Novák & Staněk 1999).

Three types of pockets, each with a distinctive location in the dike and distinct mineral assemblages, were found (Novák & Staněk 1999; see Table 1). (5) Pink elbaite-bearing pockets in the lepidolite unit (4) are up to 10 cm across, equidimensional in shape, and lined with crystals of smoky quartz, homogeneous Fe-free, X-site-deficient elbaite, and lepidolite. (6) Green elbaite-bearing pockets are similar in shape and size, and occur in the inner lepidolite–albite subunit (3c). Elbaite is zoned from (pink) Fe-free elbaite to (dark green) Fe-rich elbaite to rare (bluish black) foitite. (7) Cookeite-
bearing pockets are more common; they are elongate, flat pockets, up to 20 cm in length and 5 cm in width, and occur in the outer albite–lepidolite subunit (3b) close to the contact with, or locally in, subunit (3c) and unit (4). The host rock of the cookeite-bearing pockets consists primarily of albite, quartz, lepidolite and (pink) elbaite, and locally massive pale gray to colorless lepidolite with subordinate elbaite. Those pockets are lined with crystals of quartz, tourmaline longitudinally zoned from (pink) Fe-free elbaite to (green) Fe-rich elbaite to (bluish black) foitite, albite, late apatite, and cookeite. No textural or paragenetic evidence was found to indicate pocket rupture in any pocket.

White Queen mine

Although gem-quality pink beryl ("morganite") was mined at this locality for many years, few data on the internal structure and mineralogy of the pegmatite were published (cf. Jahns & Wright 1951, Foor et al. 1991). The pegmatite is an asymmetrically zoned dike, up to 5 m in thickness and several hundreds m in length, emplaced in gabbro. The dike exhibits a zonal pattern typical of the more fractionated pegmatites in the Pala pegmatite district: (1) a fine-grained, layered aplite footwall, (2) a graphic hanging wall unit, and centrally located (3) blocky K-feldspar + quartz unit, (4) bladed albite, and (5) massive fine-grained lepidolite units. Pockets occur near the center within the units (4) and (5), and are lined with crystals of quartz, albite, K-feldspar, muscovite, and minor beryl and tourmaline. Typical accessory minerals include almandine–spessartine, spodumene, lithiophilite, beryl and manganocolumbite.

TOURMALINE DESCRIPTION AND PARAGENESIS

Dobrá Voda

Tourmaline typically is subordinate to minor in all units and subunits. It varies in composition from (black) foitite–schorl to schorl–foitite in the outer units through (black) schorl to (blue and green) Fe-rich elbaite in the subunit (3a), (commonly pink) Fe-free elbaite and very rare (pink) rossmanite in units and subunits (3b, 3c, 4) (Selway et al. 1999, Novák & Staněk 1999). In general, the sequence of tourmaline crystallization and its compositional evolution in massive pegmatite units (tourmalines from pockets are discussed in the next paragraph) are comparable with those described in other complex pegmatites, particularly those of the lepidolite subtype (e.g., Jolliff et al. 1986, Novák & Povondra 1995, Selway et al. 1999).

Elbaite–foitite occurs as elongate columnar crystals, subparallel intergrowths, with striated prisms, up to 15 × 5 mm in size in the green elbaite-bearing and cookeite-bearing pockets (Table 1). Early-formed pale green to pink or nearly colorless elbaite grades to semifibrous bluish black foitite at crystal terminations ≤ 0.1 mm thick. The change of color in elbaite is continuous, with small oscillations in early stages, but a sharp boundary separates pale green elbaite from light violet Fe-rich elbaite and violet Fe-rich elbaite from bluish black foitite (Fig. 1a) (see also Staněk 1963). Dark violet Fe-rich elbaite and bluish black foitite exhibit strong pleochroism: O blue, E pale pink and O deep blue, E pale violet, respectively.

White Queen mine

Tourmaline is a minor constituent of the pegmatite, and black schorl apparently predominates in massive units. Foitite occurs as terminations and rarely as a rim on solitary, striated columnar crystals of (dark blue to green) elbaite to Fe-rich elbaite, up to 25 × 5 mm in

Fig. 1. Back-scattered electron image of elbaite–foitite crystals. a) Foitite termination of the crystal; note some oscillatory zoning in the intermediate zone between elbaite (dark) and foitite (bright), sectorial zoning of elbaite and semifibrous termination, Dobrá Voda. b) Foitite termination of the crystal; note porous and semifibrous texture of foitite and zoning between homogeneous elbaite (dark) and foitite, White Queen mine.
size. The prisms are associated with tabular crystals of beryl, albite, microcline, ordered orthoclase, muscovite and rare elbaite to Fe-rich elbaite exclusively in pockets. A sharp boundary between the early-crystallized (dark violet) Fe-rich elbaite and (bluish black) foitite terminations of crystals is typical. Foitite also forms porous semi-fibrous terminations, up to 0.5 mm thick, on Fe-rich elbaite crystals (Fig. 1b); elbaite–foitite crystals show local sector zoning.

**Analytical Methods**

Three solitary crystals of elbaite–foitite from the green elbaite- and cookeite-bearing pockets at Dobrá Voda and two solitary crystals from pockets at White Queen were studied with an electron microprobe; the total amount of spot analyses is 29 at Dobrá Voda and 58 at White Queen.

Electron-microprobe analysis was performed in wavelength-dispersion mode on a Cameca Camebax SX–50 instrument with a beam diameter of 4–5 μm and an accelerating potential of 15 kV. A sample current of 20 nA measured on a Faraday cup was used for Si, Al, Ti, Fe, Mn, Mg, Ca, Na and K, and a current of 40 nA was used for Zn, F and P. Counting time for all elements was 20 seconds. The following standards were used (Kα X-ray lines): diopside (Si, Ca), kyanite (Al), fayalite (Fe), rutile (Ti), pyrope (Mg), spessartine (Mn), albite (Na), orthoclase (K), fluorapatite (P, F) and gahnite (Zn). Data were reduced on-line using the PAP routine (Pouchou & Pichoir 1984, 1985).

Chemical formulae were calculated from stoichiometry constraints (e.g., Hawthorne 1996) using the method of Dutrow & Henry (2000), on the basis of the following assumptions: (i) Si = 6 apfu (atoms per formula unit), (ii) B = 3 apfu, (iii) Li = 3 – Al – Fe<sub>tot</sub> – Mn – Mg – Zn, (iv) Fe<sub>tot</sub> is assumed to be essentially Fe<sup>2+</sup>; see the discussion in Dutrow & Henry (2000) and Henry & Dutrow (1996).

**Results**

**Chemical Composition**

The chemical compositions of elbaite–foitite from both localities are similar (Tables 2, 3). Apart from the major elements (Si, Al, Fe and Na), minor elements include Mn (<0.15 and <0.47 apfu), Ca (<0.05 and <0.03 apfu, commonly in elbaite), and F (<0.70 and <0.75 apfu, in elbaite) at the Dobrá Voda and White Queen pegmatites, respectively. Low Zn contents (<0.06 apfu) were found in elbaite at the White Queen mine. Magnesium is below or close to the detection limit in all cases at both localities. Calculated cation charges are less than 58 in all cases (Table 2, 3) and indicate presence of Fe<sup>3+</sup>, which is also supported by the wet-chemical analytical data on elbaite (Table 2) from a green elbaite-bearing pocket at Dobrá Voda (Povondra et al. 1985), polarized absorption spectra (Platonov et al. 1995), and the strong pleochroism of foitite.

Foitite from southern California (MacDonald et al. 1993), foitite from the Elban localities (Pezzotta et al. 1996, Aurisicchio et al. 1999) and foitite from the Cruzeiro mine, Minas Gerais, Brazil (Dutrow & Henry 2000) show very similar compositions relative to the foitite studied here, but they also contain higher Mg contents [≤0.23 apfu; locality Grotta d’Oggi, San Piero in Campo: Aurisicchio et al. (1999)] and traces of Ti [≤0.02 apfu].

**Compositional variations in the elbaite–foitite series from pockets**

Distinct compositional trends were found in the early-crystallized elbaite and late foitite, respectively (Figs. 2, 3, 4). The chemical composition of very early elbaite has a significant deficiency in the X site, up to
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...about 0.45 apfu (Fig. 2a). Elbaite to Fe-rich elbaite from Dobrá Voda and the White Queen mine show generally an increase in Fe and Na, a decrease in Al and Li (Figs. 2, 3, and 4, Table 2), and evident oscillatory behavior of F with progressive crystallization (Fig. 2c). However, the behavior of Mn differs at each locality; in the White Queen mine, Mn increases from early to late stages of the elbaite–foitite series, whereas in the Dobrá Voda foitite, Mn shows oscillatory zoning and lower concentrations (Table 3).

Late foitite is characterized by an entirely different compositional trend relative to the Fe-enrichment in elbaite; moreover, there is a distinct compositional gap between early-crystallized Fe-rich elbaite and late foitite (Fig. 2), particularly at Dobrá Voda. The compositional evolution of foitite is very similar at both localities: each has relatively constant Al content, increasing Fe, and decreasing Na, Li, and F. Elbaite from the White Queen pegmatite is apparently Mn-enriched (Figs. 2, 3, 4, Table 3).

The compositional evolution from elbaite to foitite exhibits two distinct stages (Figs. 2, 3, 4, Tables 2, 3), which can be expressed using complex exchange-operators (Burt 1989), where $R = \text{Fe}_{\text{tot}} + \text{Mn} + \text{Mg} + \text{Zn}$.

#### DISCUSSION

**P–T conditions of the foitite formation at Dobrá Voda**

The overgrowth of foitite on elbaite is a late pocket mineral associated with quartz and commonly with cookeite, albite and apatite at Dobrá Voda. Textural relations indicate cookeite to be later than elbaite and foitite. On the basis of the experimental data of Vidal & Goffé (1991), the assemblage cookeite + quartz, commonly present in the cookeite-bearing pockets at the Dobrá Voda pegmatite, is stable between 380 and 280°C at P(H_{2}O) = 2 kbar. This is a reasonable pressure for this locality, in view of the presence of primary petalite, now replaced by the spodumene + quartz intergrowths (Novák & Staněk 1999). The shape and appearance of the cookeite-bearing pockets (elongate, flat pockets developed through different textural and paragenetic units) indicate them to be products of a subsolidus reaction. Therefore, a temperature of formation below ~450°C (London et al. 1989, London 1992) seems likely. On the basis of observed mineral assemblages, textural relations and results of experimental studies (Vidal & Goffé 1991, London et al. 1989), we conclude that foitite and associated minerals (elbaite, cookeite, quartz, albite, apatite) precipitated from a hydrothermal fluid medium below ~450°C, possibly as low as 300°C.

Cookeite was not found in the foitite-bearing pockets at the White Queen mine. In view of the recent find of petalite in the Pala district (Taylor & Wise 1998), the P–T conditions of consolidation of the Pala and related pegmatites (including overall conditions of pocket formation) were inferred from the experimental data of Vidal & Goffé (1991), the assemblage cookeite + quartz, commonly present in the cookeite-bearing pockets at the Dobrá Voda pegmatite, is stable between 380 and 280°C at P(H_{2}O) = 2 kbar. This is a reasonable pressure for this locality, in view of the presence of primary petalite, now replaced by the spodumene + quartz intergrowths (Novák & Staněk 1999). The shape and appearance of the cookeite-bearing pockets (elongate, flat pockets developed through different textural and paragenetic units) indicate them to be products of a subsolidus reaction. Therefore, a temperature of formation below ~450°C (London et al. 1989, London 1992) seems likely. On the basis of observed mineral assemblages, textural relations and results of experimental studies (Vidal & Goffé, 1991, London et al. 1989), we conclude that foitite and associated minerals (elbaite, cookeite, quartz, albite, apatite) precipitated from a hydrothermal fluid medium below ~450°C, possibly as low as 300°C.

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formation at the White Queen mine) could have been similar to those outlined for the Dobrá Voda.

Fe-enrichment during crystallization in complex granitic pegmatites

Iron depletion (e.g., in tourmaline and other minerals) is generally developed in the late stages of pegmatite crystallization in complex pegmatites (e.g., Černý & Ercit 1985, Jolliff et al. 1986, Federico et al. 1998); however, Fe-enrichment of tourmaline in the late stages of pegmatite crystallization also is documented. The Fe-enrichment has two distinct stages. (i) The formation of Fe-rich elbaite (green, blue, violet) characterizes the first stage, and such a rather weak Fe-enrichment in tourmaline has been documented at many localities in so-called “watermelon” elbaite (e.g., Foord 1976, Althaus 1979, Dietrich 1985, Zagorskyi & Peretiazko 1992, Selway 1999). (ii) This stage is followed by the formation of foitite via Na- and F-depletion and strong Fe-enrichment; it occurs almost exclusively in pockets, and is known from several localities (e.g., Pezzotta et al. 1996, Novák & Taylor 1996, Dutrow & Henry 2000). The distinct compositional gap between early Fe-rich elbaite and late foitite found in all localities (Fig. 2; see also Aurisicchio et al. 1999, Dutrow & Henry 2000) may be an indication of different conditions of crystallization during early and late stages of the tourmaline precipitation in pockets (e.g., decreased temperature or decreased activity of F and Na), although high activities of Fe and B are maintained throughout the process. However, a crystal-chemical control may also be responsible for such a compositional gap; Fe cannot enter the O(1) (V site) site, and the X site is expected to be vacant if three Y sites are occupied by 2M2+ + 1M3+ and produce a seven-charge environment in foitite (Hawthorne 1996, Robert et al. 1997), whereas Fe-rich elbaite with 1M2+ + 1M2+ + 1M3+ in the Y site produces a six-charge envi-

![Fig. 2.](image)

Na+ – R2+, Al – R2+ and F – R2+ plots of elbaite–foitite series from pockets at Dobrá Voda and White Queen mine. Arrows labeled with the exchange vectors represent directions of the vector but not the magnitude; R2+ = Fe_{ox} + Mn + Mg + Zn. a) Na+ versus R2+. Note three rather distinct substages in the elbaite – Fe-rich elbaite series. b) Al versus R2+. Dispersions of the data within Fe-rich elbaite with 1.0–1.3 Fe apfu at White Queen is roughly parallel with the exchange vector AlO2[Li(OH)2]−1. c) F versus R2+. Note oscillatory behavior of F. Symbols used for Figures 2, 3 and 4: square: early elbaite (<0.3 Fe apfu), triangle: Fe-rich elbaite (>0.5 Fe apfu), circle: foitite; Dobrá Voda: solid symbols; White Queen: open symbols; cross: Fe-rich elbaite from Dobrá Voda (Povondra et al. 1985).
environment suitable for incorporation of F and Na into the structure (Table 2, anal. 475 and WQ435).

In addition to the trend displayed by late Fe-rich elbaite, schorl and foitite (e.g., Tonarini et al. 1998, Aurisicchio et al. 1999, Selway 1999, Dutrow & Henry 2000, Novák et al. 2000), several other examples of late Fe-enrichment are known in complex pegmatites: late Fe-enrichment in some (Nb,Ta)-oxide minerals (Ercit 1986, Novák & Černý 1998a, 2001), and Fe-rich elbaite + Fe-rich lepidolite to zinnwaldite subsolidus reaction-rims around Mn-rich garnet (Němec 1983, Novák & Černý 1998b).

Pocket rupture, which may be associated with an influx of Fe-rich fluids from the host rock and the formation of Fe-rich tourmaline overgrowths, is the frequently cited cause of the Fe-enrichment during late stages of pegmatite evolution (e.g., Foord 1976, Tonarini et al. 1998, Aurisicchio et al. 1999, Selway 1999). Magnesium is commonly below the detection limit of the electron microprobe in late foitite (or schorl) at the localities studied and other occurrences (e.g., Aurisicchio et al. 1999, Dutrow & Henry 2000, Novák et al. 2000). As some of the above-mentioned pegmatite dikes are located in Mg-rich rocks (e.g., serpentinite, dolomitic marble), Fe is unlikely to have infiltrated into the pegmatite from host rocks, unless Mg is totally immobile. It does not appear that infiltration from the host rocks can explain the enrichment in Fe.

Aurisicchio et al. (1999) described two distinct parageneses of late Fe-rich tourmalines from pockets in the pegmatites on Elba. (i) In the foitite-bearing pockets, replacement of biotite and sekaninaite by white mica and circulation of Fe-enriched fluids through the pegmatite are considered to make Fe available for incorporation into foitite, but the system (pocket environment) is closed relative to the host rock (Aurisicchio et al. 1999). As both biotite and sekaninaite carry subordinate amounts of Mg (Orlandi & Pezzotta 1993), such process would increase the availability of Mg, but foitite is commonly Mg-free. (ii) In the schorl-bearing pockets on Elba, Fe-rich fluids were probably expelled during a hydrothermal pulse related to the latest stages of the Mt. Capanne pluton, and the system (pocket environment) is open relative to the host rock. The only example of apparent late Mg-enrichment was found in foitite from the Grotta d’Oggi, San Piero in Campo, with up to 0.23 apfu Mg (Aurisicchio et al. 1999).

The Fe-enrichment in the late stages of the pegmatite crystallization seems to be a relatively widespread but volumetrically negligible process in complex gra-

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**Fig. 4.** Na – F plot of the elbaite–foitite series. Same symbols as in Figure 2.
nitic pegmatites, although its details differ in individual pegmatites. An external source of Fe seems improbable in the case where the host rocks are Mg-rich (amphibolite, gabbro, dolomitic marble), and Mg is below the limit of detection in late Fe-rich tourmaline and in other late Fe-rich minerals [micas, (Nb,Ta)-oxides]. Thus an internal source of Fe must be sought; the origin of Fe in late stages of such complex granitic pegmatites remains unknown.

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