The boron (F-Li) rich Capo Bianco aplite (Elba Island, Italy): a snapshot of fluid separation processes during subvolcanic emplacement of a pegmatite-like magma

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One of the main open questions about cristallization processes in aplite-pegmatite systems concerns the growing medium from which pegmatite minerals form: is it a single fluid that evolve continuously from an early silicate melt to a late aqueous fluid, or is it, at some stage, a composite fluid made up by silicate melt, hydrosaline fluid and aquous-rich fluids linked each other by immiscibility processes? Several authors addressed this problem directly by studying fluid inclusions and experimental runs as well as indirectly developing theoretical discussions based on petrographic and geochemical data. The original controversy is well figure out by the "Jahn's" and "London's" models, and it has been liven up by the recent experimental and fluid inclusion data produced by the Potsdam's group as well as by the new experimental data on boundary layers provided by London.
The aim of this contribution is to rouse the discussion about this topic by presenting some petrographic and geochemical data on a peculiar rock cropping out at Elba Island: the Capo Bianco aplite. This rock displays such unusual features that it was noted and described by the ancient people that hung around the Mediterannean Sea and it was finally included into the Argonauts Myth by Apollonios Rhodios (III century B.C.).
The Capo Bianco aplite is a white porphyritic rock with alkali feldspar granite composition. Its isotopic age is constrained by dates between 7.91-7.95 (muscovite–whole rock Rb-Sr) and 8.5 Ma (Li-rich mica ^{39}Ar-^{40}Ar). This rock occurs in two tabular bodies, both largely intruded by younger granite porphyries: the deeper layer occurs in western Elba within metaophiolites and pelitic hornfels, while the upper layer is exposed in central Elba, near Portoferraio, and it was originally hosted by pelitic-siliciclastic sequences. This contribution is focused on the upper layer: a sill about 3.5 km in length, $\geq$ 120 m thick and originally emplaced at a depth of 2.6 km. Thermometamorphic and hydrothermal effects on the host rocks are negligible.
Both layers of Capo Bianco aplite have a porphyritic trachitoid texture made up of small phenocrysts (1-5 vol %; 2-5 mm in size) of brownish-grey muscovite-phengite, K-feldspar, oligoclase and quartz, set in a very fine-grained groundmass characterized by a fluidal distribution of albite laths (100-250 µm) and an equigranular K-feldspar-quartz aggregate (5-50 µm). The fluidal orientation of albite laths is a pervasive character of the whole rock and it is roughly parallel to the sill boundaries. The lower layer is entirely made up of this rock type; on the contrary, the upper layer shows major textural and mineralogical variations with a strong zonation from the bottom to the top of the intrusive body. The bottom is constituted by porphyritic aplite but moving towards the top of the sill millimetric tourmaline spots appear and their amount and size rapidly increase. In parallel with tourmaline increasing, a pervasive layering become more and more visible as outlined by the alternance of pinkish mica-rich layers, white mica-poor ones and layers containing several tourmaline orbicules. At the micro scale the albite laths are oriented parallel to the meso scale layering. The upper part of the sill is characterized by a large number of tourmaline orbicules with variable diameter (1 to 15 cm) frequently associated with rounded cauliflower aggregates (up to 2 cm) of a pinkish-grey Li-F-rich mica and globular quartz. The Li-F-rich mica has been also observed as overgrowths on early muscovite-phengite phenocrysts. The blue-black tourmaline orbicules are made up of a tourmaline-quartz assemblage, with radiating, very fine-grained fibrous tourmaline and interstitial microgranular quartz. No voids or miarolitic cavities have been observed. The orbicules often include phenocrysts of quartz and feldspars comparable in size and shape with those set in the main groundmass. The included feldspars phenocrysts are frequently replaced by tourmaline. On the other hand, the orbicules rarely contain the lath-shaped albite microlites of the groundmass.

Additionally, the albite laths, flow-aligned parallel to the main rock layering, sometimes have been observed to wrap around the orbicules. Quartz-tourmaline aggregates display numerous and highly variable inclusions: 1) vapor-liquid inclusions; 2) vapor-liquid-halite inclusions; 3) mineral-rich fluid inclusions and 4) potentially recrystallised melt inclusions. A third type of rounded mineral aggregate is made up of small globular quartz crystals embedded in a matrix of kaolin and illite-smectite. The original interstitial phase has never been observed; note that the rock around such aggregates is not altered. Finally, accessory minerals are represented by euhedral fluorapatite, zircon, monazite-Ce, xenotime-Y and late interstitial cassiterite, and Ti-Nb-Ta-W-Sn oxides.
The basal facies of the Capo Bianco aplite is characterised by very high silica content (73-75 wt%) and a strong peraluminous signature (Alumina Saturation Index in the range 1.3-1.5). It exhibit very low contents of TiO_2, FeO_{tot}, MgO and CaO leading to a leucocratic aspect and an absence of mafic minerals. Trace element distribution is characterised by relatively high Be, Cs, Rb, Nb and Ta, coupled with very low Sr, Ba, Zr and Th. Rare earth element chondrite-normalised patterns are flat (La_N/Yb_N=1.3-2.2) and bear a deep Eu negative anomaly. The high $^{87}Sr/^{86}Sr$ (0.712-0.714), the low $^{143}Nd/^{144}Nd$ (0.51213-0.51214), and the $\delta^{11}B$ of its tourmaline (-7.2/-7.6 ‰), coupled with geochemical data point to an origin from an upper crustal, metapelitic source, possibly via a muscovite dehydration melting processes (Dini et al., 2002). The boron content is low (10-50 ppm) in the true tourmaline-free portions but the occurrence of some millimetric tourmaline spots usually rise the B content to a typical average of 100-150 ppm. Li and F are respectively in the ranges 400-600 ppm and 1300-1800 ppm. The layered and orbicule-rich uppermost zone doesn't show any significant variation of major and trace elements. Boron (on a minor extent also Li and F) is the only element to increase noticeably reaching very high values (average range 400-700 ppm; values up to 3000 ppm) in the tourmaline-rich zone at the top of the intrusive layer.
Tourmaline orbicules of the Capo Bianco aplite were interpreted in the past to result from a subsolidus autometasomatic process induced by a late circulation of hydrothermal fluids. However, the lack in the aplite of both pervasive tourmalinization and a quartz-tourmaline vein network connecting the orbicules, indicates that the orbicules, once formed, behaved as an almost closed system in the course of their crystallization. A closed system like this cannot have a pure hydrothermal nature, because it would result in miarolitic cavities as commonly observed in most intrusions. Instead, this requires a relatively fast crystallization from a volatile-rich silicate melt ("hydrosaline melt" ?) as supported by (i) the presence of numerous halite-rich and crystal-rich inclusions (ii) the complete filling of orbicules, (iii) the outward crystal growth of radiating tourmaline fibres, (iv) the homogeneous, core to rim, composition of tourmalines (F-rich schorl-elbaite solid solution), all in contrast with the extremely zoned (oscillatory, patchy) tourmalines that usually crystallize from aqueous fluids.
More recently, tourmaline orbicules have been frequently described in plutonic acidic rocks around the world and are commonly interpreted as results of exsolution of late-magmatic volatile-rich phases that did not escape the intrusive system. However, the Capo Bianco aplite did not crystallize in a deep plutonic environment that typically leads to concentration of volatiles in residual interstitial melt ("2nd boiling" process). Indeed, the low amount of phenocrysts (1-10 % in volume) and textural evidence indicate rapid groundmass crystallization excluding the formation of tourmaline orbicules from volatiles concentrated in the residual interstitial melt. On the other hand, textural features such as (i) the perfectly rounded shape of the orbicules, (ii) their physical separation from the groundmass highlighted by both wrapping by groundmass albite laths and the limited intergrowth with the groundmass, and (iii) the occurrence of grabbed phenocrysts in the orbicules are evidence for the separation of B-rich silicate melt bubbles in a very early stage when most of the system was still melt.
A possible explanation of such an event and the formation of tourmaline orbicules in Capo Bianco aplite is here summarized: 1) the Capo Bianco magma is transferred from the source to

the emplacement level via-dyke; 2) the rapid decompression along the conduit induce a strong liquidus undercooling of the granite system and promote the nucleation of albite laths; 3) the massive and fast nucleation/crystallization of albite induce a concentration of fluxing elements (in particular B, but also F, Li and H_2O) in discrete microdomains (micro boundary layers?) that reach compositions susceptible of liquid immiscibility; 4) immiscible B-rich hydrosaline melt drops formed into the microdomains are accreted by the flow along the conduit and as the clusters increase in size (they are the precursor of tourmaline spots and orbicules) their lower density induce a vertical separation along the magma column; 5) the magma enriched in fluxed elements emplace first into a structural trap and it is followed by the emplacement of flux-poor magma at the base; 6) during the emplacement the final layering and albite laths orientation is acquired; 7) at this stage the fast crystallization produce the fibrous-radiating texture of the orbicules and the very fine-grained groundmass.

Capo Bianco aplite can thus be regarded as a serendipitous occurrence of a B-rich magma that escaped from the plutonic levels (or directly from the deep source) and stopped in a subvolcanic setting just at the right depth for maintaining a snapshot of separation processes involving B-rich fluids and coexisting silicic magma. In conclusion this study suggests that pressure drop should be considered as a major factor controlling liquid phase separation and crystallization processes in pegmatite-like magmas.

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