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REGIONAL ZONING OF PEGMATITE POPULATIONS AND ITS INTERPRETATION

by

Petr Černý[+]

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Zonal distribution of different types of granitic pegmatites within their regional populations was commented on already 150 years ago. In his classic descriptive review of the subject, HEINRICH (1953) quotes authorities such as De Beaumont, Brögger, Van Hise and Emmons who either provided information on individual cases or generalized contemporary views. The present understanding of regional pegmatite zoning is based on numerous studies conducted by, e.g., HUTCHINSON (1955), BEUS (1960), KRETZ (1968), SOLODOV (1971), VARLAMOFF (1972) and ROSSOVSKYI (1974). Recent additions to the literature include GINSBURG et al. (1979), ČERNÝ et al. (1981), MEINTZER (1987) and TRUMBULL (1990), to name a few.

Thus the fact of regional pegmatite zoning has been well established by countless observations over the past 150 years. Explanations of its origin were largely intuitive, but in some cases they anticipated quite correctly the present-day interpretation based on theoretical considerations and experimental evidence.

Characteristics of regional zoning

The focus of a regionally zoned pegmatite population is a granitic intrusion parental to the pegmatites, a magmatic body from which the residual pegmatite melts differentiated and eventually intruded into their final location (ČERNÝ & MEINTZER, 1988). The pegmatites constituting such a cogenetic group may range from interior bodies (within the granite) through marginal intrusions (along the granite/country rock contacts) to exterior dikes (outside and away from the parent granite, usually at distances of less than ~2 km).

[+] Prof.Dr. Petr Černý
Department of Geological Sciences
University of Manitoba
240 Wallace Building
Winnipeg, Mainitoba, Canada R3T 2N2

Fig. 1: Concentric pattern of regional zoning in the Jiajika area, western Sichuan Province, China (modified from Yang et al., 1990; scale not given). Crosses - the parent two-mica granite; A - muscovite-microcline-albite pegmatites I, B - muscovite - microcline-albite pegmatites II, C - muscovite-albite pegmatites, D - muscovite-albite-spodumene pegmatites, E - muscovite-lepidolite-spodumene-albite pegmatites.

The pegmatites form a halo above the parent granite and around its sloping flanks. This 3d feature can normally be observed only in planar subhorizontal sections given by the current level of erosion, but the vertical dimension is occasionally exposed in mountainous terrains (e.g., TEMNIKOV, 1971, ROSSOVSKYI et al., 1975, ROSSOVSKYI & SHMAKIN, 1978, PUSHKO & SADOVSKYI, 1981). A well-expressed concentric zoning (Fig. 1) is rather exceptional, as the shape of any pegmatite group is strongly affected by the general structural style of the broader host environment (GINSBURG et al., 1979), by the shape of the parent granite intrusion (particularly its apex; BEUS, 1960), and by the distribution and attitude of potential pre-intrusion host structures (KRETZ, 1968). Consequently, strongly unidirectional groups are rather common, constrained by regional structures (Fig. 2), or possibly by asymmetric differentiation within the parent granites (GASTIL et al., 1991; Fig. 3). The geologically most rational 3d setting of regional structures and of the parent granite must always be taken into account when interpreting the zoning patterns, particularly in cases of irregular morphologies of granitic cupolas (Fig. 4; VARLAMOFF, 1972; cf. also BEUS, 1960, and Fig. 5 in ČERNÝ, 1989).

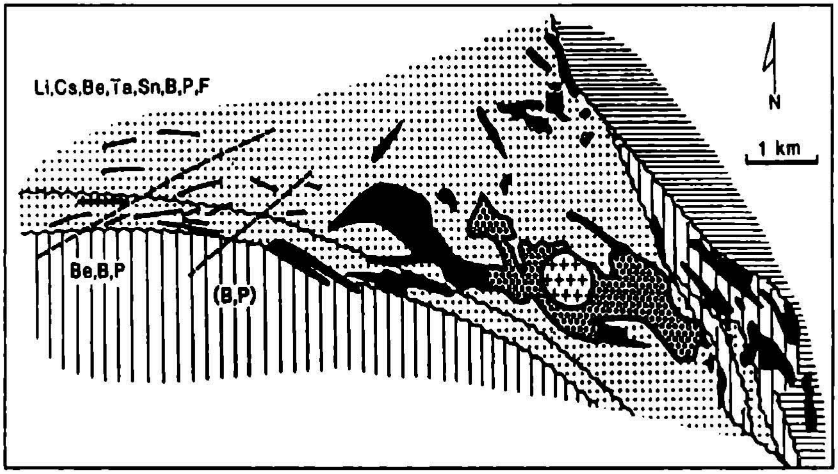

Fig. 2: An asymmetrically zoned pegmatite group at Osis Lake, Manitoba, intruded along regional faults (modified from ČERNÝ, 1989). Fractionation of the pegmatites increases westward from the internally zoned parent granite with fine-grained biotite-bearing core (crosses), coarse-grained garnet + muscovite facies (circles) and pegmatitic garnet + muscovite + tourmaline outskirts.

The total of observations by researchers quoted above (and many others) leads to the following generalized sequence, from the granitic source outward (see ČERNÝ, 1991a for terminology of pegmatite classification):

1) barren,
2) (rare-earth type),
3) beryl-columbite subtype,
4) beryl-columbite-phosphate subtype,
5) spodumene and/or petalite, ± amblygonite subtypes,
6) lepidolite subtype,
7) albite-spodumene type,
8) albite type.

This is, of course, a composite sequence assembled from segments documented in diverse fields. Among the most common deviations from this idealized scheme is the rather frequent absence of zone (2), and the variable representation of zones (5), (6) and (7). It is quite common that only one of the three latter zones is developed, with a very restricted proportion of the other two categories. This evidently depends on the chemistry of the parent melts (activities of F, P) and on the regime of pegmatite crystallization (homogeneous, stress-affected albite-spodumene type). The albite type sub (8) is difficult to rank, as it is rather scarce and its position is poorly defined even in specific individual groups. It can be actually found associated with any of the zones (5) to (7).

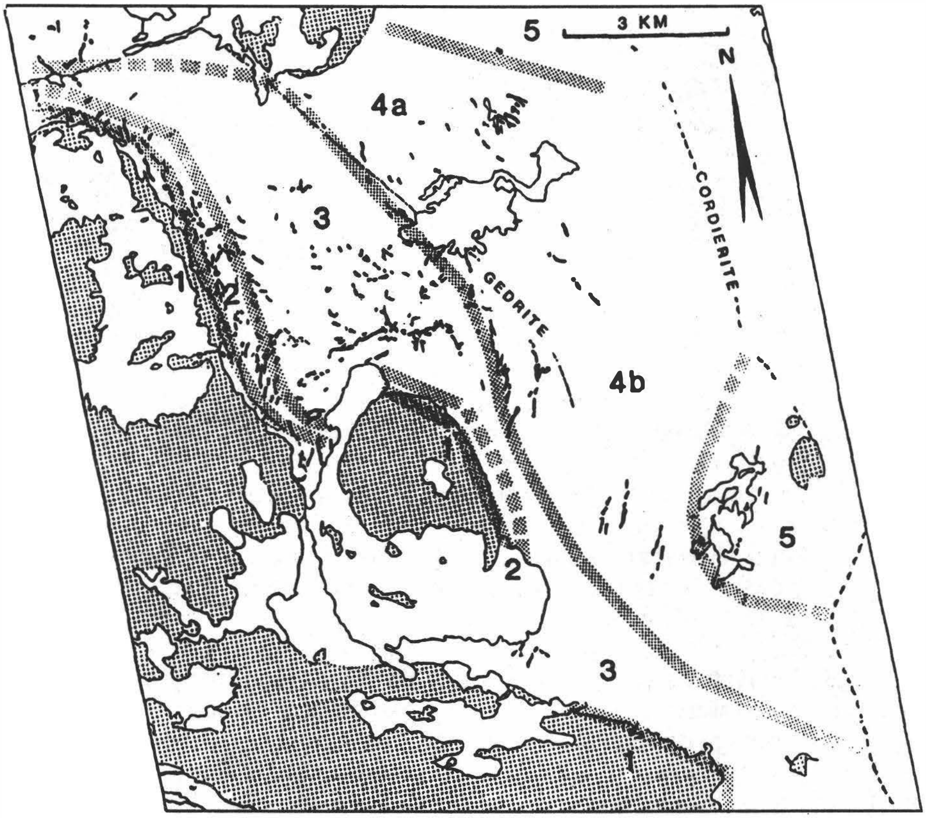

Fig. 3: Regional zoning of the Sparrow-Thomson-Hidden lake group in the Yellowknife field, Northwest Territories (after MEINTZER, 1987). 1 - beryl-columbite pegmatites, 2 - barren zone, 3 - beryl-columbite (± phosphate) pegmatites, 4a - zoned spodumene pegmatites with Be, Nb $\gtrless$ Ta, 4b - albite-spodumene pegmatites, 5 - zoned spodumene pegmatites with Be, Nb $\gtrless$ Ta,Sn.

Discussion

Paragenesis and geochemistry of zoned pegmatite groups (Fig. 5) show a marked increase of volatile components - Li, Rb, Cs, B, P, F - from the inner to the outer zones. The contents of these elements can attain as much as 1 wt.% Li, 1.4 wt.% Rb, 2 wt.% Cs, 0.5 wt.% B, 1 wt.% P and 1.3 wt.% F in the bulk composition of solidified pegmatites (ČERNÝ, 1991a). Some of the above components could have been significantly higher in the pegmatite melts, as indicated by holmquistite, tourmaline and Li, Rb, Cs, F-enriched biotite in exocontact aureoles.

The progressive increase in the volatile components is particularly strong in the upward direction, above the parent granite intrusions, as shown by well-exposed vertical profiles. This is also supported by the fact that granites parental to the most fractionated pegmatites with extreme accumulation of rare elements (e.g., Tanco, Bikita, Greenbushes) are not exposed by erosion.

The outward enrichment in Li, Rb, Cs, B, P and F provides the principal clue for understanding the origin of regional zoning. Increased concentrations of these elements strongly influence some properties of pegmatite melts, namely the H_2O content, viscosity, density and thermal stability, and consequently their mobility.

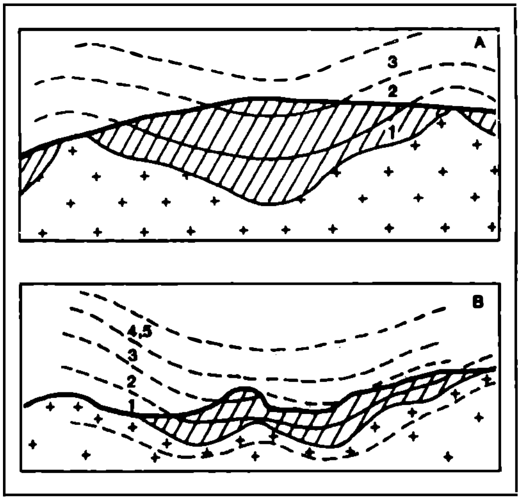

Fig. 4: Vertical zoning in the Berere (A) and Sahatany (B) pegmatite groups, Madagascar (modified from VARLAMOFF, 1972). Schists overlying parent granites (ruled over crosses, respectively) host 1 - homogeneous biotite pegmatites, 2 - zoned muscovite- biotite-tourmaline pegmatites, 3 - zoned pegmatites with beryl and muscovite, 4,5 - Li-bearing pegmatites.

Li, B and P increase the solubility of H_2O in pegmatite melts. Experiments conducted with the highly fractionated Li, Rb, Cs, B, P, F-enriched Macusani glass show that 75-85% crystallization of an initially H_2O-undersaturated melt generates a homogeneous residual magma containing 15-20 wt.% of dissolved H_2O (LONDON et al., 1989).

One of the effects of increased H_2O content is the lowering of the liquidus and solidus temperatures of pegmatite melts. This effect is considerably enhanced by Li (STEWART, 1978), Cs (HENDERSON & MANNING, 1984, HENDERSON & MARTIN, 1985), B (MANNING & PICHAVANT, 1988), P and F (LONDON, 1990). Experiments indicate a crystallization span from ~620° to ~450°C for H_2O, Li, Rb, Cs, B, P, F-rich melts of Macusani glass at 2.5 kbar, much lower than ~730° to ~650°C for hydrous haplogranite magmas (LONDON et al., 1989).

Another significant effect of the discussed components is the reduction of viscosity. Increased substitution of OH^- and F^- for O^{2-}, the presence of tetrahedral B^{3+} and P^{5+}, and excess of Al in peraluminous magmas all promote depolymerization of quartzo-feldspathic melts, and consequently increase their fluidity (LONDON, 1991, 1992; DINGWELL, 1988, DINGWELL et al., 1992).

Density of pegmatite magmas is also affected. Enrichment of the melts in B, P and F was experimentally shown to decrease density (DINGWELL et al., 1992). Li and H_2O should have, of course, the same effect.

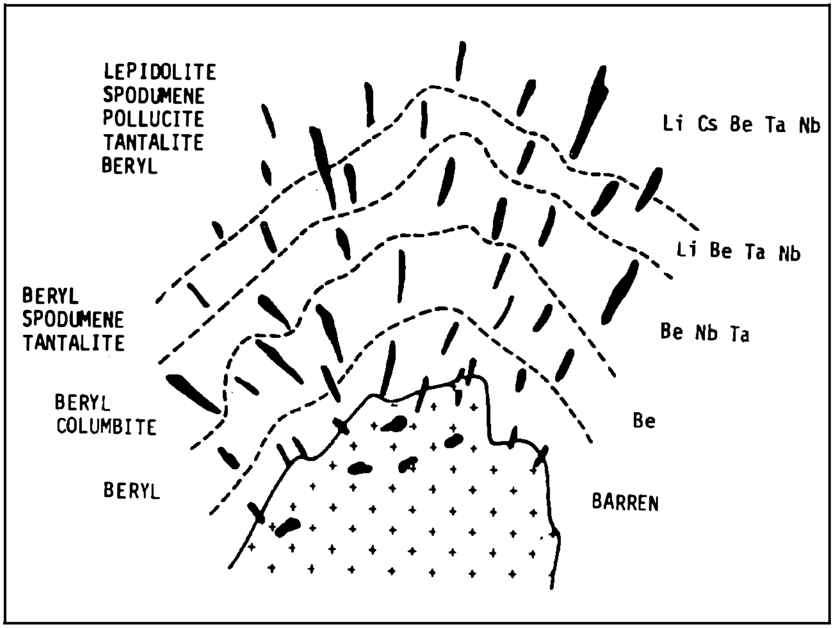

Fig. 5: Schematic view of regional zoning in a cogenetic granite-pegmatite group (modified from ČERNÝ, 1991b). Besides the elements (and minerals) indicated, the contents of B, P and F (tourmaline, phosphates, lepidolite) also increase outwards but not necessarily in a simple quantitative correlation with the others.

The combined effects of the above factors translate into increased mobility and thermal stability of pegmatite melts enriched in H_2O, Li, Rb, Cs, B, P and F. Such melts acquire an intrinsic capacity to migrate farther away (and particularly upward) from their pluton-sized parent intrusions relative to geochemically more primitive magmas. Thus, the distance of any pegmatite type from its source is proportional to the relative thermal stability and fluidity of its particular melt composition (ČERNÝ, 1982, 1991b; ČERNÝ & MEINTZER, 1988). The viscous melts crystallizing as barren to beryl-columbite-pegmatites should be arrested in their sluggish migration close to their parent plutons, solidifying at relatively high temperatures. In contrast, the rather fluid melts generating e.g. pegmatites of the lepidolite subtype should travel much farther down the thermal gradient surrounding their parent plutons, before they reach liquidus temperature.

It is obvious from the proceeding discussion that pronounced regional zoning can be expected, and is found, mainly in the most widespread family of granitic pegmatites - the peraluminous association concentrating Li, Rb, Cs, Be, Ga, Sn, Nb, Ta, B, P and F. In contrast, subaluminous to metaluminous magmas generating pegmatites enriched in Nb, Ti, Y, REE, Zr, Th, U and F are generally poorer in the liquidus- and viscosity-depressing components. Consequently, these pegmatites are commonly formed within, or in close vicinity of their granitic parents, and regional zoning is developed only in a rudimentary manner, if at all.

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