Vlasov (1961): Principles of Classifying Granite Pegmatites, and Their Textural-Paragenetic Types

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Introduction

The field campaign of mapping pegmatites in the United States during WWII was matched in the Soviet Union, and for the same reason: the Soviets understood the importance of strategic mineral commodities found in pegmatites to their national defense. The Soviet effort did not result in the publication of the detailed maps and descriptions of many specific pegmatites; geologic maps were generalized, presented without detailed locations and even spatial scale, presumably as a matter of secrecy. There were, however, numerous summary publications that arose from the Soviet field studies. The article by Kuz'ma A. Vlasov (1961) was notable for several reasons, and it was one of those important papers that conveyed to me some insights that would have taken years to learn firsthand.

The wartime study in the U.S. that resulted in the summary publication by Cameron et al. (1949)(see essays #1-4 in this series) delineated the internal units of zoned pegmatites based on their position (border, wall, intermediate, and core zones) and the mineralogy of successive zones within pegmatites. Textures were mentioned sporadically throughout the monograph, but mineral habits and rock texture or fabric were not central to the classification scheme. This might seem to be an unusual oversight because pegmatites are defined by their textures, not by their composition (except that their compositions are those of the more ordinary igneous rocks: London, 2008). In his exhaustive review of pegmatite studies, Jahns (1955)(see essay #6 in this series) scarcely mentioned texture except in relation to short statements about giant crystals and graphic granite. Yet in most outcrops of pegmatite, the eye is first drawn to contrasts that are apparent in the textural fabric of the rock, not so much to its mineralogical composition (Fig. 1).

Figure 1. Surface outcrop at the San Diego mine, Mesa Grande district, San Diego County, California

The works of Cameron et al. (1949), Jahns (1953a,b), and Jahns (1955) treated pegmatites as individual bodies. The relations among them were largely ignored or simply unknown. Heinrich (1953), however, was among the first petrologists to take up the matter of district-wide zonation among pegmatite bodies. He first had to make that case that there are systematic patterns of pegmatite zonation across what Černý (1991a) termed a pegmatite group – pegmatites that are genetically and temporally related to one another and to a common granitic source. Heinrich (1953) concluded mostly on evidence provided by others that the more chemically evolved pegmatites migrate farther from their source than do the many pegmatites of simple granitic composition. He hypothesized that the extraction of pegmatite-forming dikes from granite was sequential. The withdrawal of pegmatite-forming melts early in the history of granite crystallization produced the common pegmatites, while the rare-element pegmatites originated later, from a more extensively crystallized granite body and more chemically fractionated residual melt. Heinrich (1953) speculated that the higher volatile content of the late-stage melts would impart a lower viscosity to their liquids, and thereby facilitate their migration farther from source. In the West, the regional zonation of pegmatites of a group was largely ignored after that, until Černý (e.g., Trueman and Černý, 1982) revitalized it based on field studies of pegmatites in Manitoba and Northwest Territories of Canada.

The Textural-Paragenetic Relations
Vlasov's (1961) summary was very largely descriptive. It contained little of the subjective interpretation that became the focus of writers like Jahns (1955), except that like Jahns (1955), Vlasov (1961) saw an important role for replacement processes in pegmatites. Like Jahns, Vlasov (1961) identified replacement bodies based on inferences drawn from texture and mineralogy that were founded upon the understanding, or lack of it, of what could and could not have been crystallized directly from a silicate liquid or an aqueous solution at natural pegmatite-forming conditions. Throughout the history of pegmatite study, those criteria have had little or no grounding in fact, meaning unequivocal, unambiguous evidence.

Vlasov's (1961) classification based on texture veered off course at the end, when his last pegmatite type was defined mostly by its mineralogy, not its overall textural development. However, his attention to the detail of textures was unprecedented at the time. To me, his classification of these pegmatite types is actually less important than his depictions of them in figures. These convey the spatial relations of textural zones to one another within pegmatites and the variations of zones among pegmatites with distance from source.

Pegmatite Types
Vlasov (1961) proposed five pegmatite types:

- Type I: even-grained to graphic
- Type II: block
- Type III: fully differentiated
- Type IV: rare-metal replacement
- Type V: albite-spodumene

Type I, even-grained to graphic pegmatite, is synonymous with the apical pegmatitic granite of plutons and the immediately adjacent pegmatite bodies that emanate from it. Large crystals of K-feldspar in graphic intergrowth with quartz are prevalent.

Type II, block pegmatite, refers to the development of essentially monominerallic core zones of coarse, blocky microcline within pegmatite of Type I. Cameron et al. (1949) noted that a very large number of the pegmatites studied consisted of granitic border and wall zones with cores of very coarse blocky microcline.

Type III, fully differentiated pegmatite, possesses the same outer zones of granitic to graphic pegmatite, followed inward by a zone of blocky microcline that surrounds a "*block*" zone of massive quartz. In this classification, the pegmatites of Type III may contain high concentrations of rare-element minerals:

"The content of rare-metal minerals in Type III pegmatites is commonly high: for each pegmatite field it is, as a rule, higher than in the preceding types. A number of veins of Type III, in some pegmatite fields, are a commercial source of beryl and spodumene (Brazilian pegmatites, etc.)." (p. 10)

This, by Vlasov's (1961) classification, is the full development of the igneous stage of pegmatite formation. It includes the development of rare-element mineral zones as a continuation of the magmatic process, as was proposed by Cameron et al. (1949). It also includes the incipient formation of what Vlasov (1961) regarded as replacement assemblages:

"Replacement processes are better developed here than in the preceding type. The assemblage of replacement minerals occupies larger areas but does not form individual zones, unlike Type IV. These areas are made up of albite, younger quartz, and muscovite with rare-metal minerals, garnet, etc. among them. As a rule, the replacement proceeds along the interior part of the microcline zone and in individual microcline crystals in quartz; it also affects the periphery of that zone, helped by faults along which the replacing solutions penetrate various segments of the pegmatite body." (p. 10)

The "*replacement*" assemblages lie along what Cameron et al. (1949) referred to as the core margin, and Vlasov (1961) stated that "...*as a rule, they are younger than the quartz.*" (p. 10) In the Cameron classification, massive quartz was the last primary zone to form. Norton (1983) revised that, making albite-mica units that contain abundant rare-element minerals the last-formed primary zone.

Type IV: rare-metal replacement pegmatite alludes to what have been termed "complex pegmatites" by various workers (e.g., Landes, 1933; Černý, 1991a).

"In best developed bodies of this type, often in individual fields of rare-metal pegmatites with considerable lithium content, an independent quartz-spodumene zone appears along with the above-named principal zone; it follows the monomineral microcline zone and gradually changes into a quartz core. Present in this zone, in many pegmatite fields, are amblygonite, lithiophyllite, and other lithium minerals. In its turn, the replacement zone can be differentiated into several

sub-zones, on the basis of mineral composition and texture: quartz-muscovite-beryl, lepidolite-albite, quartz-albite, clevelandite, sugary albite, etc." (p. 10)

Albite and micas comprise the bulk of the "*replacement zone*" along the core margin between block microcline and block quartz, or between microcline and the spodumene-quartz zone. The list of rare-element minerals includes "*beryl... often pink, niobo-tantalates, cassiterite, pollucite in bodies over 1 m³..., lepidolite, petalite, phosphates of lithium and manganese, bismuth minerals, and relicts of the early-stage minerals (such as spodumene)."* (p. 10)

Vlasov (1961) included miarolitic cavities, which Ginsburg (1984) identified as a pegmatite class separate from the rare-element class, in the grouping of Type IV pegmatite.

"Cavities of various sizes, common in bodies of Type IV and occupied by crystals of quartz, polychrome tourmaline, lepidolite, kunzite, clevelandite, and muscovite, in an argillaceous matrix, indicate a comparatively high content of highly volatile compounds in the original pegmatite solutions, as well as the presence of a high concentration of these compounds during the process of differentiation. These features also suggest the importance of later replacement solutions, partly condensed out of the volatiles, in the formation of these pegmatites... This type is characterized by the most complex mineral composition of all pegmatites." (p. 11)

Type V, albite-spodumene pegmatite, proved to be as enigmatic to Vlasov (1961) as it was for Černý (1991a) decades later. In contrast to the pegmatites of Type IV, which Vlasov (1961) described as thick, columnar, and generally ovoid in shape,

"Pegmatites of Type V are most commonly tabular, from a fraction of a meter to tens of meters thick, traceable for about a kilometer, occasionally for 1.5 or 2 km, along the trend, and often for over one kilometer along the dip.

"Zonation is not as well expressed here as in the other types; the graphic pegmatite zone is virtually missing, and so are, as a rule, the monomineral microcline zones and individual zones or large kernels of quartz."

"Albite-spodumene pegmatites have a rare-metal paragenesis of their own. The are characterized by a high spodumene content, by a comparatively high and consistent beryl content, and by the presence of cassiterite, amblygonite, etc; niobotantalates are represented largely by the columbite group. On the other hand, lepidolite pollucite, and vorob'yevite [read: alkali-rich beryl] *are virtually missing; this indicates, along with other factors, a relatively poor and incomplete differentiation.*

Pegmatite bodies of Type V are finer-grained than the preceding types, with spodumene crystals measured in fractions of a centimeter or centimeters, rarely as large as one meter. Beryl occurs in crystals, often barely discernible by the naked eye, measured in millimeters and even in fractions of a millimeter. At the same time these pegmatite show a general and uniform coarsening of grain toward the middle of the vein.

"Replacement processes are extremely important in Type V pegmatites. Minerals of the replacement complex are common throughout the pegmatite bodies."

"These features of the composition of albite-spodumene pegmatites, along with their structure and texture, suggest that these pegmatites should be regarded as special bodies representing an independent line parallel to pegmatites in general. Indeed, in their extreme form, they are quite different from the common non-rare-metal pegmatites which are 99.9% feldspar, quartz, and mica and are represented by rock with granitic to graphic textures. However, these two sharply different pegmatites are connected by intermediate links of all possible gradual transitions." (p. 14)

The albite-spodumene pegmatites, whose representatives include Kings Mountain, North Carolina (Swanson, 2012) and Jiajika, Kangding pegmatite field, Sichuan, China (Li and Chou, 2016), are among the largest hard-rock sources of lithium. If, as Vlasov (1961) proposed, their origins lie outside of the now-conventional model of the zoned pegmatite district, then new criteria will be needed to explore for them.

The Key Insights of Vlasov (1961)
Through illustrations, Vlasov (1961) portrayed zonation as a continuum from granitic source to the most distal bodies. Later depictions of the regional zonation of pegmatites (Černý, 1991a) originated here, but unlike the later representations, Vlasov (1961) presented pegmatites in full, not just in terms of their rare-element mineralogy. The general features of the textural variations among cogenetic pegmatites across a group were presented for the first time.

I read Vlasov (1961) as I was beginning my studies of pegmatites in the White Picacho district, Arizona (Jahns, 1952). My knowledge at that time was limited mostly to collecting minerals from mine dumps at pegmatites in Connecticut. As I explored the region, Vlasov's (1961) regional picture was clearly evident: the Hieroglyphic Mountains, a granitic mass so named for its abundance of graphic granite, fanned into a group of increasingly zoned pegmatites consisting of "*99.9% feldspar, quartz, and mica*" extending to the northwest. All of the spodumene-rich pegmatites of the district lay at the distal edge of that group, as isolated bodies here and there that lacked the obvious regional structural control of the more proximal pegmatites.

An important insight for me was Vlasov's (1961) observation that each pegmatite of a group inherits the earlier outer zones of less fractionated bodies closer to source, with the progressive addition of coarser, more segregated, and more fractionated units within the thickest parts of the pegmatite dikes. The existence of the common granitic outer zones even around the most evolved pegmatites implied a commonality of the pegmatite-forming process that did not hinge upon special conditions or special compositions. An examination of the distribution of zones in the summary by Cameron et al. (1949) showed the same features (the commonality of their zones (1) and (3) at the margins of almost all pegmatites), but only through mineralogy, not texture. The fact that the outer zones of pegmatites are more or less the same in texture and mineralogy has hindered the exploration for pegmatites that contain hidden, rare-element rich inner zones.

Vlasov (1961) also recognized what Norton (1983) noted much later, that massive quartz is not the last-formed zone in the chemically evolved Li-rich pegmatites. Norton (1983), however,

regarded the albite-lepidolite zones to be primary in origin, not a replacement of pre-existing pegmatite. The albite-lepidolite bodies with pollucite, petalite or spodumene, Ta oxides, etc. lie along the margins, not within, the quartz masses. Jahns (1953b) construed the albite-lepidolite body at the center of the Pidlite dike, New Mexico, to be a primary unit, not a replacement body. Petr Černý remarked to me that he brought the Soviet view of widespread replacement in pegmatites when he arrived in Manitoba, but that after some time underground at Tanco, he came to regard much of what had been called replacement as primary in the sense that it was deposited in the space occupied by a fluid medium, not that of a prior mineral or rock assemblage.

There are nuances of these old publications whose significance comes much later, after much cogitation, and in my case, as a result of careful re-reading of manuscripts that I could scarcely grasp at first reading. Most likely, some of those important nuances escaped the authors as well. Cameron et al. (1949) is full of veiled insights in the form of Tables 2-5 and as illustrations of pegmatites both generalized and mapped in detail. So, too, is Vlasov's (1961) work. His Figure 1 is the depiction of the gradual changes in texture and mineral zones with distance from source granite to most distal pegmatite. The page of Figure 1 (p. 6) is printed in what would be landscape orientation. In the original publication, the zonation was viewed such that the complexity of pegmatite zonation increased vertically on the page. The upward fractionation was clearly intended and emphasized by the orientation. Figure 2 (p. 11) is a magnificent three-dimensional block diagram of a *"rare-metal replacement pegmatite."* It may be a generalized illustration or a true depiction of a pegmatite that, like most Soviet publications, lacked a name, location, or map scale. A thick bulge of the pegmatite contains a more or less concentric sequence of intermediate zones and, as Vlasov (1961) would have them, replacement bodies. The thick pegmatite is fed by thinner dike segments. Those feeder dikes possess only the granitic, graphic, and block microcline zones that are the outer units of the much more voluminous intermediate zones of the thick bulge. Similar renditions appear as Figures 8-2 and 8-3 of my book (London, 2008). It was not until London (2018, Figure 15c), after I had re-read Uebel (1977), that I realized the significance of pegmatite dike thickness in relation to zoning:

➢ the outer zones of thick dikes constitute the entirety of the thinner dikes that are their feeders, regardless of orientation (up, down, sideways) from the thicker body, because crystallization from the margins toward center proceeds simultaneously and in the same proportion from the walls of thin and thick segments alike. Consequently, and as Uebel (1977) illustrated it, pegmatite bodies do not necessary become more chemically fractionated in the up-dip direction. Without even mentioning the unidirectional texture of solidification, this distribution of zones validates the model of Cameron et al. (1949) for the sequential development of zones from margins to center.

➢ By the point that the thin feeder dikes have completely solidified, the thick portions still contain an appreciable quantity of melt. Thus, the complexly zoned pegmatites crystallize as essentially closed systems, as Cameron et al. (1949) concluded, sealed by the solidification of their feeders.

➢ The internal evolution in thin versus thick dike segments, evidenced as sequences of zones, necessitates that zone refining is the principal mechanism for the internal

differentiation of pegmatite bodies, not Rayleigh-type fractionation (see Figure 22 of London, 2018, and associated text). That conclusion is demonstrated quantitatively in London (2021). The thicker portions of dikes fractionate to a greater degree than do their thin feeders simply because there is more melt from which to extract and concentrate rare elements through zone refining.

Regional Zonation within a Pegmatite Group
As recently as 1988, after giving a talk at Yale University, Karl Turekian, a professor of geochemistry at Yale, asked me "is zoning in pegmatite districts real?" The regional relations among pegmatites had received so little attention, and even where evident was so difficult to explain, that few geoscientists were even aware of it. These observations make Vlasov's (1961) paper all the more remarkable for its insights in its time.

Heinrich's (1953) hypothesis that the extraction of pegmatites from a crystallizing granite is sequential in nature has not been borne out in field studies. With sequential extraction over a protracted history of cooling (10s to 100s of thousands of years), a succession of dikes would have cross-cutting relations among many of them, except those that are the farthest from source. Though cross-cutting relations of dikes and aplites are sometimes present along the upper facies of pegmatitic granites and their immediately adjacent pegmatites (Type I of Vlasov, 1961), they are rare among the thousands of dikes that lie beyond the margins. In addition, Rubin (1995) has argued that melt cannot escape from granitic plutons until late in their crystallization, when much of their heat has been dissipated into the cooler host rocks, and at a stage where only a small fraction of evolved melt would persist.

Vlasov (1961) portrayed the regional zonation across a group of pegmatites as a vertical continuum. If there was any lingering doubt of that continuum, it was laid to rest by Lev Rossovskiy's examination of pegmatites over vast, continuous vertical outcrops in the Hindu Kush of Afghanistan (Rossovskiy and Shmakin, 1978). I have seen that continuum along single dikes stretching for nearly a kilometer:

➢ in the Middletown district at Portland, Connecticut, from the beryl-bearing Hale pegmatite southward to the Apple Orchard pegmatite in which tourmaline and spessartine became abundant, to the Gotta-Walden prospect that produced spodumene, lepidolite, and pollucite;

➢ in the White Rocks quarry, Middletown, Connecticut, where continuous quarry outcrops from pegmatitic granite to "*block*" pegmatite with columbite-tantalite, to "*fully differentiated*" pegmatite containing small domains of beryl, lepidolite, and microlite were exposed;

➢ in the southeast corner of the exposed Lawler Peak granite, near Bagdad, Arizona, where pegmatitic segregations and associated aplites within the roof of the granite evolved into discrete intrusive dikes that could be traced for a kilometer upward and outward into "*fully differentiated*" pegmatites in which beryl and columbite appeared at the most distal exposures.

The implications, therefore, are that pegmatite-forming dikes inherit their systematically fractionated melt compositions directly from their granitic source. The system of pegmatite dikes taps the residual melt in granite reservoirs from the top down, which preserves a vertical chemical gradient that is likely to be more fractionated toward the roof because of a greater extent of crystallization along the cooler contacts. How the last residual melts are extracted from a crystal mush is a matter of ongoing debate with little definitive evidence. Most of the discussion is in the field of volcanology, which does not consider the petrology or textures found in the roof zones of granite plutons. As noted here and in prior essays, pegmatites arise as interconnected segregations within granite right up to the contacts with host rocks. There is little or no intervening interval of previously-crystallized granite through which the pegmatitic magmas have traversed as cross-cutting dikes. In this case, the upper facies of pegmatitic granites are liquids, perhaps pools within crystal mushes, but not fully solidified. This is an area in which pegmatite geology could contribute to the debate in volcanology.

In schistose host rocks, individual dikes pinch down into pods, "*like beads on a string*" as Jahns (1952, p. 18) characterized them in the White Picacho district, Arizona. In Vlasov's (1961) depictions, each pegmatite body then undergoes its own internal evolution, starting with the same border sequences, and adding more texturally and mineralogically complex inner zones with distance from the granitic source. That mechanism is consistent with the observations of the many (43) geologists who contributed to the study and summary by Cameron et al. (1949): individual pegmatite bodies crystallize as essentially closed systems, not as open "*thoroughfares*" (Jahns, 1953a) for the continuous movement of pegmatite-forming melt.

Following summaries of field studies like Vlasov (1961), Soviet research on pegmatites turned more toward the chemistry of minerals and to investigations of fluid inclusions. The regional picture of zonation within a cogenetic suite of pegmatites did not reappear until Petr Černý's (1991a,b) contributions. Even so, Černý's classification was purely mineralogical, and entirely focused on rare-element mineralogy. Vlasov's (1961) classification was all-inclusive; it combined regional zonation, mineralogy, and the distinctive textures of pegmatite zones into a single concept, which is as novel today as it was then.

Vlasov went on to write the definitive encyclopedia of the rare-element mineralogy and the geology of the Lovozero alkaline massif in the Kola Pennisula, Russia (Vlasov et al., 1966, English translation). Vlasovite, monoclinic $Na_2ZrSi_4O_{11}$, was named in his honor in 1961 (Tikhonenkova and Kazakova, 1961).

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