Cameron et al. (1949): Overview

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In 1988, Brian J. Skinner (1928-2019), then Yale professor and chief editor of *Economic Geology*, contacted me with the suggestion that I write a book on pegmatites. His rationale was that the most important published work on pegmatites was long out of print, and the field needed an update. That "most important published work" was:

Cameron, E.N., Jahns, R.H., McNair, A.H., and Page, L.R. (1949) Internal structure of granitic pegmatites. *Economic Geology Monograph* **2**, 115 p.

The monograph is now available for purchase in PDF from the bookstore of the Society of Economic Geologists[1]. Skinner may have been more right than he knew about the importance of that publication. In my subsequent book (London, 2008), I said:

"If I were going to advise any serious reader where to go (after reading this monograph) to learn more about pegmatites from the literature, I would direct him or her to Cameron et al. (1949), and to the many subsequent publications on specific pegmatites and districts that followed the WWII efforts in the U.S. …"

Despite its age, Cameron et al. (1949) is the most succinct yet thorough description of what pegmatites are. It is also the most unusual and authoritative publication on the geology of pegmatites. It is unusual in that none of the principal authors had a prior research focus on granitic pegmatites. They all came from other fields: E.N. "Gene" Cameron worked on layered gabbroic intrusions. A.H. "Andy" McNair and L.R. "Linc" Page had just completed theses on regional geology in New England. Harold M. Bannerman, not an author but a key member of the New England group, had field experience in base-metal deposits of Ontario. Another leader, W.C. "Campbell" Smith, worked for the U.S. Geologic Survey in field study of metallic ore deposits. R.H. "Dick" Jahns, who subsequently took the lead on pegmatite studies, was finishing his dissertation entitled:

Stratigraphy of the easternmost Ventura Basin, California, with a description of a new lower Miocene mammalian fauna from the Tick Canyon Formation (California Institute of Technology, 1943)

Pressed into service to produce a war-time guide to exploration for and exploitation of granitic pegmatites for their economic commodities (then feldspar, sheet muscovite, beryl, and tantalite), the lead group came without strongly held or preconceived notions of what pegmatites represent. That was then, and remains, rare in a field where authors mostly present their opinions on how pegmatites form, sometimes without reference or connection to the actual petrology of the rocks.

The work was uniquely authoritative in terms of the numbers of participants, the vastness of their field investigations, and the extent of cooperation among them. The study began in 1939, but was mostly conducted between fall 1942 and spring 1945. They describe the effort as "68 man-years of work" by 43 contributors (if I counted correctly). Each principal pegmatite district that was known at the time (which did not include the gem-bearing pegmatites of Southern California) in the U.S. had a project leader (Cameron, Page, McNair, Bannerman, Smith, and Jahns).

By the term "internal structure", Cameron et al. (1949) meant lithologic units. Lithologic units are distinctive bodies of rock, as defined by their petrology and their position within the pegmatite bodies. In turn, petrology encompasses the minerals present, their proportions, the habits of crystals (e.g., equant, euhedral, elongate, flaring, radiating, skeletal), and their arrangement, in what is referred to as texture or fabric of the rock (e.g., massive, layered, equigranular, oriented). They grouped these lithologic units into three categories, which conveyed their interpretations of the origins of each category, as:

(1) primary zones,
(2) replacement bodies, and
(3) fracture fillings.

Each category is described in relation to specific examples from mapped pegmatites. If one hoped to fact check these examples, one would need at hand the geologic data that found their way into many subsequent publications by the U.S. Geological Survey (see citations in London, 2008).

As far as was possible, Cameron et al. (1949) tried to limit the amount of interpretive or genetic inferences in their classification of internal structure. They summarize their approach this way:

"The structural and lithologic units within some pegmatites are much better known than those within others, because in some pegmatites the relations between units are more clearly exposed, the units themselves are more completely exposed, or the units have been studied in greater detail. It therefore seems desirable to classify and define such units as simply as possible, hence chiefly on the basis of structure. A genetic classification is not feasible, as there is no general agreement on the origin of pegmatites, and certainly no one theory of origin seems applicable to all. It has proven impossible, however, to divorce the classification from genetic considerations, hence a compromise has been adopted. It is suggested that pegmatite bodies be analyzed primarily according to their structural features, but with the recognition that some of these features have obvious genetic implications." (p. 14)

It was questionable then, as now, what is "*obvious*" about many aspects of pegmatite geology. Subjective interpretation is particularly evident in their discussion of replacement bodies. The extent of replacement (formed from or in the space of pre-existing rock or minerals) versus primary crystallization (rock and mineral assemblages that occupy the space of the melt or aqueous solution from which they crystallized) has been an arguing point from the start of pegmatite studies to the present day. However, the WWII field study was almost purely observational, without much in the way of mineral or whole-rock chemistry that might have influenced the interpretations[2].

It quickly became apparent to the leaders that they needed to devise a systematic approach to viewing, recording, and depicting what they observed. That procedure is described in detail in the Appendix (p. 107-111). All of the detailed maps from this effort were drafted by hand, using technical India-ink drafting pens. Topographic contours were mapped by plane table, alidade, and staff. The detailed renderings of scores of maps exemplify the magnitude and exactitude of the tasks, down to the final but exceedingly important task of representing what they saw as accurately as possible. Forever after, the internal structure of granitic pegmatites has been represented by line and stipple, or color, patterns. These imply sharply discernable boundaries where they may or may not exist. They imply uniformity of the rock within the boundaries of their lines, which might or might not be accurate. The Appendix to the monograph is a lengthy accounting of the complications in rendition, the schemes employed, and the trade-offs made. Good as they are, however, inevitably a lot is lost – mineral habits, textures, orientations, color, size, and distribution – when a visual inspection is reduced to a line-and-pattern rendering. To understand what pegmatites are as represented by maps, such as those produced from the WWII study, it is necessary to develop a visual imagery that translates the maps into depictions of real rocks. One can develop this knowledge by taking these maps in the field and attempting to see the units and boundaries in the rock as they are presented on the maps. I've done this many times, starting with my first field trip to a pegmatite locality (Hale quarry, Portland, Connecticut, in 1972). Usually the zonal boundaries are evident at the scale of an outcrop or mine wall, but sometimes not. One commonly sees variations within a mapped zone at scales too small to delineate on the meter-scale of most maps.

An important aspect of geologic map legends, which is common practice among geological surveys, is to list minerals present in their decreasing order of abundance. Cameron et al. (1949) do this, with additions in parentheses of minor mineral constituents that may be negligible in volume but economically significant (e.g., beryl or tantalite). The sequence of minerals in the map legends, therefore, is as necessary for mental visualization of pegmatites as is the general sequence of their zones. For unfamiliar readers, it is usually the first two, maybe three minerals listed that are volumetrically significant in each zone. Nonetheless, a perthite-quartz zone might be 90% perthite-10% quartz, or 60% perthite-40% quartz. A very few published studies are notable for the laboriousness of the effort to determine the proportions of minerals in each zone of a pegmatite, and with respective zonal volumes, to compute a whole-rock composition[3]. The spatial heterogeneity of pegmatites precludes a meaningful chemical analysis of a single hand sample, or even several samples, which is commonly sufficient for the other common igneous rocks.

The lasting contribution of Cameron et al. (1949) is their system for describing the internal parts of pegmatites by position and by mineralogy. I will comment on these in the ensuing essays. They do not explicitly include rock texture as a basis of classification, though throughout their text, they describe texture using terms that include grain size and rarely crystal habit (e.g., "perthite euhedra") in association with specific structural units of pegmatites.

The final section of Cameron et al. (1949) offers their opinions on the fundamental significance of zones in relation to the internal evolution of pegmatite bodies:

"*Zones represent crops of crystals deposited as successive layers upon the walls of the chamber enclosing a body of pegmatitic liquid, and hence are due primarily to fractional crystallization… Inward coarsening of texture probably is due to lower viscosity, which in turn is due to progressive enrichment of the rest-liquid in hyperfusibles* (p. 105)."

They viewed pegmatites, therefore, as a textbook example of Bowen's (1928) principles of fractional crystallization of silicate melts: sequential crystallization, with concomitant fractionation of melt and mineral assemblages, segregation of early formed crystals from the residual melt as crystallization advanced inwardly from the margins, and accompanying changes in texture due to compositional changes of the residual melt. The interpretation was main stream at the time. The only surprising outcome was how quickly it was abandoned.

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FOOTNOTES

[1] Order from Monographs at: https://www.segweb.org/store/

[2] One important observation of mineral composition made its way into Cameron et al. (1949): the compositional variation in plagioclase from margin to core (p. 100). Later publications, some of which began during the WWII study, aimed at delineating the bulk compositions of pegmatites. See the references to footnote 3 below.

[3] Examples include:

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