Jahns (1953a,b): The Genesis of Pegmatites

David London (dlondon1@memphis.edu)
November 8, 2020

Following the summary publication by Cameron et al. (1949), each of the various regional groups of geologists published the detailed maps of the pegmatites studied in these districts: New England (Cameron et al. 1954), the central Appalachians (e.g., Kesler and Olson, 1942, Olson et al., 1968) and southern Piedmont (Heinrich et al., 1953), South Dakota (Page et al., 1953), Idaho and Montana (Stoll, 1950), and Colorado (Hanley et al., 1950), all as part of a series of publications through the U.S. Geological Survey. James J. "Jim" Norton continued to publish many detailed investigations of the pegmatites and their relations to Harney Peak granite in the Black Hills, SD, mostly through the U.S. Geological Survey (1964, 1966, 1994, Norton and Redden, 1990, Norton et al., 1962, 1964). All of the USGS publications and their detailed maps as plates are freely available online in PDF at https://pubs.er.usgs.gov/. The three articles discussed here (Jahns, 1953a,b and Heinrich, 1953) are posted along with this essay by permission of editors of The American Mineralogist.

Richard H. "Dick" Jahns was a coauthor on some of these publications, and first author on one (Jahns et al., 1952). However, most of his early published works appeared outside of the venue of the Federal survey, first on the Petaca district, New Mexico (Jahns, 1946), then the Pala district, California (Jahns and Wright, 1951), and the White Picacho district, Arizona (Jahns, 1952), where I conducted the research for my Master's thesis. Jahns' (1952) detailed maps of pegmatites in the White Picacho district included the locations of mineral ore piles, which were exactly as he rendered them when I began my studies there.

Jahns continued to publish apart from the USGS contingent with his first articles to a professional journal, *The American Mineralogist*, in 1953. Eberhardt W. "Abe" Heinrich also published a break-out article on pegmatites in *The American Mineralogist* in 1953, entitled "Zoning in Pegmatite Districts." Heinrich's article was a concept piece on the nature and origins of regional zonation among pegmatites of a group. As such, it was a departure from the field geologic studies of the wartime effort: it presented no new data, but rather an opined assessment of previously reported work. Heinrich's principal conclusions were that (1) pegmatites are igneous rocks that inherit their chemical attributes from their source granites, (2) chemical zonation within a pegmatite group is real, with the most chemically evolved members farthest from their "*pegmatitic hearth*", (3) the amount of pegmatite formed by replacement is small, generally < 1% by volume (p. 80), and (4) pegmatite-forming melts likely escape from their parent magma over the course of crystallization of the pluton, such that the most differentiated pegmatite-forming melts are derived from the last remaining fraction of melt fraction.

Jahns (1953a) The genesis of pegmatites. I. Occurrence and origin of giant crystals.

Jahns' first paper, "The Genesis of Pegmatites. I. Occurrence and Origin of Giant Crystals" (Jahns, 1953a) was similarly a departure from purely field geology, as it veered toward an emphasis on internal processes within pegmatites. Like Heinrich's paper, Jahns' work was meant to convey authority on the subject. The title, "The Genesis of Pegmatites", and the serial number

"I", signified that this was to be the first of a series of works that could define a discipline and a career. The audience for these publications was academic, and they were therefore a departure from the resource-driven mission of the USGS.

For those who read and publish in professional journals today, the style of these early articles on pegmatites would seem strangely florid and voluble. For instance, Heinrich (1953) muses:

"The idea that a general relation exists between wall rock composition and pegmatite composition is an old wives' tale that, despite numerous decapitations, continues to sprout in hydra fashion under succeeding generations of pegmatite investigators." (p. 81)

Jahns (1953a) opens with a similarly colloquial paragraph that speaks to his reputation as a great teller of stories:

"*The writer's personal experience with giant crystals dates from a springtime day in 1932* [Jahns was 17 years old]*, when he spent several hours in collecting a well-faced 284-pount individual of potash feldspar from a mass of pegmatite in northwestern Riverside County, California. He clearly recollects his chagrin in discovering, a few weeks later, that this was by no means the largest known crystal of feldspar!*" (p 565)

Like Heinrich (1953), Jahns (1953a) then set about to detail occurrences that framed his topic and provided the basic data of his thesis. Like Heinrich, these included both old and new references to specific case studies. The remarkable addition to Jahns (1953a), however, was his Figure 12, which showed the average changes in crystal size of individual minerals and all minerals overall from margin to center of pegmatite dikes in the Hualapai district near Bagdad, AZ, and the White Picacho district east of Wickenburg, AZ. The dikes were large, as "*none of these bodies is less than 40 feet in maximum outcrop breadth.*" (p. 580) The sizes of crystals increased non-linearly by more than an order of magnitude, but notably the rate of increase in size was the same for all mineral species, and the size increased as a continuum from margin to center.

Figure 12 contributed to Jahns' (1953a) thesis that systematic relationships of crystal size and orientation add to the known features of pegmatites in support of an igneous origin for crystallization. He alluded to Cameron et al. (1949):

"*Many investigators have concluded that pegmatite zones were formed by fractional crystallization of magma, with incomplete reaction between successive crops of crystals and rest-liquid. The giant crystals in pegmatites are here considered to be primary constituents of those zones, mainly on the basis of their systematic distribution, age relations, textural and structural relations, and variations in composition. They are thought to have crystallized directly from pegmatite liquid that was rich in hyperfusible components, probably under restricted-system conditions involving a rather delicate thermal and chemical balance..."* (p. 564)

Jahns (1953a) backed up this systematic relationship with the observation that minerals formed by replacement are "*much finer-grained*" (p. 585) than the giant crystals that define the zonation of pegmatites, and that the minerals that line miarolitic cavities are generally finer-grained than those same individuals in the massive pegmatite (p. 577).

The bulk of Jahns' (1953) discussion pitted the magmatic model of Cameron et al. (1949) against the metasomatic replacement model that was most notably promoted by Landes (1933). Consequently, much of the discussion in Jahns (1953a) is reflexive, in that it refers back to prior ideas about the origins of pegmatites. This includes a lengthy segment on the problem of support for giant crystals in a melt of presumed low viscosity, wherein he specifically comments on the evidence presented by Landes (1933). Like Heinrich (1953), Jahns (1953a) observed that replacement phenomena are common in pegmatites but negligible in total volume. Jahns (1953a), however, proposed that the fluid that is responsible for hydrothermal replacement originates within pegmatites, such that the crystalline pegmatite would "*stew in its own juice*" (p. 582).

In the section entitled "Origin of the Pegmatite Framework, Jahns (1953a) presented a list of observations on the zonation and textures within pegmatite bodies after Cameron et al. (1949), and so concluded:

"All known features of pegmatite zones seem reasonably explainable on the basis of crystallization from a melt of low viscosity, with or without end-stage deuteric or hydrothermal activity. Many of these features also suggest that masses of pegmatite crystallized inward from the walls of an original chamber... rather than in some sort of channelway or thoroughfare under more open-system conditions..." (p. 581)

This, which is Jahns' conclusion, precedes his evidentiary discussion of magmatic versus metasomatic origins of pegmatites and their giant crystals. As such, it is not the norm of publications today.

In the preface to this series of essays, I noted that I would review some articles that were obscure, but which have figured prominently in my thinking about pegmatites and the people who have studied them. Jahns (1953a) is surely one of those papers on both counts. By the time I found it (pre-WWW), I had already read Jahns and Burnham (1969), which took a dramatically different turn from the model of Cameron et al. (1949). Jahns (1953a) was not an easy article to find by inspection of the lists of citations: except for one paper (Jahns, 1955), Jahns never again cited this article. I was surprised that Jahns had originally embraced the igneous fractionation model of Cameron et al. (1949), but had abandoned it. However, Jahns was the second author on the monograph by Cameron et al. (1949), and so he would have had a prominent role in writing it. The copy of Cameron et al. (1949) that I own was given to Andy McNair, a co-author, by Jahns, which conveys Jahns' sense of authorship. In that light, Jahns' (1953a) embrace of the igneous fractionation model makes sense, as he may have been claiming the idea as his own.

Jahns reused some of the line drawings in his later articles. Figure 13, showing a tapered perthite crystal from the Mack mine, Rincon district, CA, appeared again in Jahns (1982) but with the addition of chemical analyses along its length. Figure 12, evidently a unique study of crystal size distribution in pegmatites, never appeared again. Neither the methods nor the actual data were presented. The individual points plotted are averages, but with no indication of the deviation from the mean. In reference to the occurrence of giant crystals, Jahns (1953a) explained that single crystals commonly originate at a point near the margins of a pegmatite and become wider as they advance inward (his Figures 13 and 19). In such a case, it is not evident what measurement was recorded as the value of the crystal "size" with location from margin to center. Jahns later made references to other crucial data that were never published. This lack of evidence, and the transparency that is mandated in current scientific publications, makes an assessment of his contributions all the more difficult.

Jahns (1953a) ends with this conclusion:

"*Available evidence, in the writer's opinion, indicates that nearly all the giant crystals were formed during what has been designated by most investigators the primary, or magmatic, stage of pegmatite development, and hence by crystallization form liquid under conditions that permitted remarkable growth of a relatively few individuals. These conditions will be discussed in some detail in a forthcoming paper* [a literary device used more than once by Jahns]. *Suffice it to say here that the typical pegmatitic magma that yielded these enormous crystals must have been rich in hyperfusible constituents* [by which Jahns, following the usage by Cameron et al. (1949), meant fluxing components] *and probably had a very low viscosity. The crystals are thought to have formed rapidly under restricted-system conditions involving a rather delicate thermal and chemical balance. Temperatures almost certainly were below 600 °C., and the confining pressures were sufficiently great to prevent major escape of volatile constituents during the period of giant crystal development.*"

Herein, Jahns (1953a) recants Cameron et al. (1949) yet again by invoking melts of low viscosity as the result of high concentrations of hyperfusible constituents. These are fascinating comments because up to this time, the experimental work that would demonstrate the fluxing effects of components of H_2O, B, P, F, and excess alkalis were unknown, as were the viscosities of granitic liquids; hence, there are no citations to these hypotheses. The granitic bulk compositions of pegmatites were not known with confidence, and much of the subsequent work done by members of the USGS and by Jahns that aimed at establishing the bulk compositions of pegmatites came later. No evidence was presented that temperatures "*almost certainly were below 600 °C".* Jahns was likely aware of the earliest experiments on melting relations in the system granite-H_2O that were being conducted by O.F. Tuttle and N.L. Bowen; however, no works were cited. Jahns' proposed upper limit on temperature, however, is nearly 100°C below the solidus of the hydrous granite system (Tuttle and Bowen, 1958). Jahns' (1953) suggestion that the giant crystals grew rapidly seems to be an original insight, and one that ran counter to any expectations at the time. He may have considered that as thin dikes intruded into host rocks along brittle fractures, pegmatites must cool quickly. Pegmatites have long been regarded as the products of crystallization over millions of years in order to explain the giant size of their crystals (see Chapter 2 of London, 2008). With regard to "*major escape of volatile constituents*", it is not clear if Jahns (1953a) was referring to the escape of those volatile components from the pegmatite-forming melt, or out of the pegmatite system entirely. That becomes a point of distinction in his later publications.

It is apparent that Jahns used this publication to make his place in the study of pegmatites. Through it, he aligned himself with the model of Cameron et al. (1949), or identified the model with himself, and added insights such as those above that were meant to guide thinking about pegmatites. Pointing out the growth habits and orientations of giant crystals as additional evidence to the igneous model is useful science, but not landmark work. The real story of Jahns (1953a) appears to be his adoption of the igneous fractionation model, down to the same points and counterpoints made in Cameron et al. (1949), much of it taken verbatim from Cameron et al. (1949). What remains unusual about Jahns (1953a) is how drastically and quickly he left that model behind. There is little doubt that experimental studies of the granite system at this time caught Jahns' attention (Bowen and Tuttle, 1951). Not long afterward Jahns teamed up with experimentalists O.F. Tuttle and C.W. Burnham, both then at Pennsylvania State University and cited as good friends of Jahns at the time (Wright, 1985). Jahns' new direction of thinking appeared in his article, "The Study of Pegmatites" (1955).

Jahns (1953b) The genesis of pegmatites. II. Quantitative analysis of lithium bearing pegmatite, Mora County, New Mexico.

Most of Jahns' field work during WWII took place in New Mexico and Arizona. This paper presented a detailed mapping study of a lepidolite-rich pegmatite, the Pidlite dike, in northeastern New Mexico. In this work, Jahns' explanations of the methodology by which the body was mapped and a bulk composition calculated were meticulously detailed. Quantitative modal analysis of pegmatites figured into the wartime study in almost every district, partly for scientific reasons and partly for resource assessment.

Jahns (1953b) identified four primary zones including a quartz core that did not lie in the center of the body. Instead, the central unit is a mass that consisted mostly of lepidolite and lesser albite. Three replacement bodies were termed "*composite units*" because they were "*plainly composite, in the sense that they contain two well defined generations of minerals*" (p. 1081): primary crystals as relict masses or pseudomorphs in an assemblage dominated by much finer-grained lepidolite and albite. His Figure 3 is a fence diagram of the geology of the pegmatite as it was revealed by surface and underground mining. His Figure 4 is in two parts: I, the pegmatite zones as they might have appeared on a surface plan map prior to replacement, and II, the superposition of replacement bodies on the primary zones.

Jahns' (1953b) modal analysis (volumetric percentage) reported in Table 4 is:

Quartz	35.4
Perthite	21.4
Albite	20.3
Muscovite	5.7
Lepidolite	16.8
Spodumene	0.3
Topaz	0.1

The corresponding chemical analysis, calculated on the basis of mineral compositions, was given in Table 6 as:

SiO_2	74.5
Al_2O_3	14.8

CaO	0.2
Na_2O	3.3
K_2O	5.4
Li_2O	0.7
H_2O	0.6
F	0.9

Jahns (1953b) observed that the compositions of the Pidlite dike, the Harding pegmatite, NM, and the Stewart pegmatite, CA, were those of the average of iron-poor granites, except for their higher contents of Li and F. He noted that tourmaline is abundant in the host rocks adjacent to the Pidlite dike but absent in the pegmatite. The boron contained by that tourmaline was not included in his bulk composition, but it would likely have been negligible as a weight percentage.

"*It has been emphasized that, although evidences of mineral replacement are widespread in the dike, the* ***amount*** [emphasis by Jahns] *of demonstrable replacement material is relatively small as compared to the bulk of the pegmatite*." (p. 1109)

Jahns (1953b) then began a lengthy assessment (p. 1104-1108) of the chemical mass balance that would have been required to convert the primary material of two outer zones to the replacement assemblage of the composite units. The third composite zone, the lepidolite-rich body at the core of the pegmatite, was included as a composite unit, though not as a replacement of solid rock.

"*There is no positive evidence to indicate that the central part of the dike, now occupied mainly by lepidolite, was composed largely of solid material prior to the development of lepidolite and other minerals by replacement of still earlier minerals*." (p. 1110)

The net change in composition of the composite units, including the lepidolite body, was principally a large reduction in silica (SiO_2). Jahns concluded that large-scale transport out of the pegmatite was unlikely: "*There is little evidence for the expulsion of silica at a late stage in the development of the Pidlite dike*." Jahns remarked that the most prevalent alteration of host rocks was the conversion of hornblende to biotite, "*and this almost certainly involves no increase in silica*" (p. 1109). Jahns also rejected the hypothesis that the net gain of some components in the composite units arose from outside of the pegmatite. His argument was conjectural, that the mass of fluid required to transport that much solute would have been large, and the effects would have been too obvious to occur without a visible trace.

In conclusion, Jahns (1953b) proposed that 75-85% of the pegmatite had crystallized from melt prior to the onset of replacement phenomena (p. 1109). Most of the remaining volume was occupied by what was mapped as the central body of massive lepidolite, for which evidence of replacement was lacking. For this reason, Jahns proposed that the lepidolite body was deposited mostly from residual liquid of unspecified properties except that it was solute-rich:

"*The quantitative analysis of pegmatite units and of replacement features in the dike indicate that all the observed relations can be accounted for if the zones were developed by fractional crystallization of a pegmatite magma, and if the composite units were developed in part by* *replacement of earlier-formed zonal material and in larger part by direct crystallization from residual fluid or fluids…*" (p. 1110)

This conclusion harkens back to the discussion of replacement bodies in Cameron et al. (1949), wherein they recognized fracture fillings and replacements that could be traced back to primary inner zones. In essence, the lepidolite-rich zone at the Pidlite dike is one of these, and it was a giant step forward by Jahns to conclude that the lepidolite body was essentially a primary unit of the pegmatite. The non-granitic composition of such units fostered the hydrothermal replacement model of Landes (1933) and others. A mechanistic explanation was lacking, but Jahns' ground observations were astute.

I offer these points in comment: (1) Norton (1983) later revised the mineralogical zonation of Cameron et al. (1949) to include quartz-poor lepidolite-albite bodies as the last of the primary units. At the time of his study of the Pidlite dike, Jahns likely would have concurred. (2) In experimental studies with similar bulk compositions, the final melt composition is notably aluminous but sharply depleted in silica though quartz-saturated, and that liquid coexists with an assemblage of nearly pure quartz and minor topaz (Figure 4b and sample PEG 46 in Table 8 of London and Morgan, 2017). (3) The crystallization of that liquid produces a quartz-absent assemblage of lepidolite + albite after the deposition of pure quartz (Figure 3c of London and Morgan, 2017). (4) Jahns (1953b) offers three illustrations, two photos and one line drawing (his Figures 6, 7, and 8), as illustrations of the textural evidence of replacement. In these, large irregular masses of quartz or of topaz are surrounded by fine-grained aggregates of albite and lepidolite. The uniqueness of that interpretation, however, is debatable. Figure 1 below is from London (1999). It shows several large irregular masses of quartz, surrounded by much finer grained material dominated by potassic feldspar (bright) and albite plus quartz (dark), which in places forms oscillating bands that deflected around the quartz mass. As a macroscopic occurrence within pegmatite, a "*casual observer*" (p. 1101) would likely interpret these textural relations as a replacement of early and very coarse quartz by the fine-grained assemblage. Here, all were igneous and simultaneously formed, at least in relation to a protracted episode of crystallization.

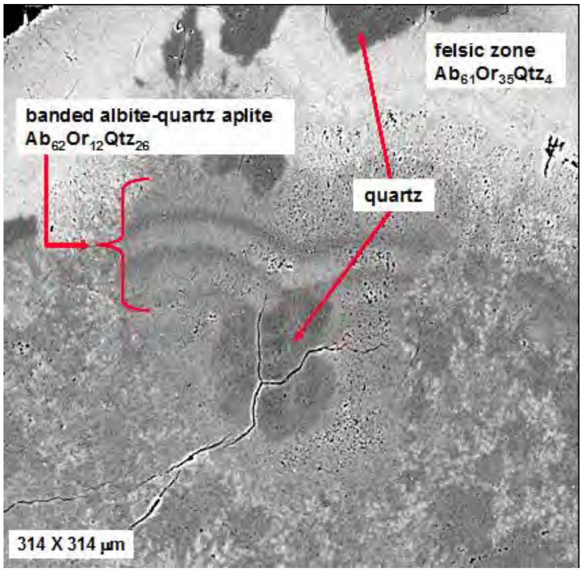

Figure 1, from London (1999)

Jahns (1953b) counseled with this opinion:

"*It is not the purpose of this paper to discuss the implication of the figures in the table* [Table 8], *but it seems worth while to emphasize the essentially normal granitic composition, in terms of all major constituents of the pegmatite that are not likely to appear "normal" to the casual observer in the field. In particular, large masses of quartz in these and many other pegmatite bodies give an understandably exaggerated impression of the* SiO_2 *content of such bodies, and the occurrence of large crystals or crystal aggregates of the less common minerals often give a similar impression. Further, there has been a tendency of a few geologists to consider the genesis of pegmatites, and especially of zoned pegmatites, solely in terms of the composition of individual minerals or of restricted mineral groups. This approach can be misleading, especially if it is used as a measure of the composition of presumed fluids from which the minerals were formed. It would seem to be much more desirable first to approach the problem in terms of the composition of pegmatite zones and other units, as well as the bulk composition of entire pegmatite bodies.*" (p. 1101),

to which passage I say, Amen. The careful field analyses like Jahns (1953b) and others have established the essentially granitic compositions and the essentially igneous origins of pegmatites beyond any doubt. This includes the Li-rich pegmatites such as the Pidlite dike, which is exactly Jahns' point. It may be that Jahns viewed the bulk composition of the Pidlite dike as "*rich in hyperfusible constituents*", but it is only so in terms of a couple of weight percent of its overall composition, and Jahns (1953b), like Cameron et al. (1949), concluded that little to nothing had entered or left the pegmatite following its emplacement. However, his admonition to others about drawing great conclusions from the study of one or a few selected mineral constituents is of utmost importance, and it distinguished Jahns' holistic approach to the study of pegmatites. Jahns (1953b) was advocating petrology to understand pegmatites over mineralogy in the absence of petrologic context. The whole is a better representation than any one of its parts can be.

References

Bowen, N.L. and Tuttle, O.F. (1951) Synthetic granites and their melting behavior under high H_2O pressures. *Geological Society of America Bulletin*, **62**, 1425.

Cameron, E.N., Larrabee, D.M., McNair, A.H., Page, J.J., Stewart, G.W., and Shainin, V.E. (1954) Pegmatite investigations, 1942-45, New England. *U.S. Geological Survey Professional Paper*, **255**, 352 p.

Hanley, J.B., Heinrich, E.W., and Page, L.R. (1950) Pegmatite investigations in Colorado, Wyoming, and Utah, 1942-1944. *U. S. Geological Survey Professional Paper*, **227**, 125 pp.

Heinrich, E.W. (1953) Zoning in pegmatite districts. *American Mineralogist*, **38**, 68-87.

Heinrich, E.W., Klepper, M.R., and Jahns, R.H. (1953) Mica deposits of the southeastern Piedmont. Part 9, Thomaston-Barnesville district, Georgia; part 10, Outlying deposits in Georgia. *U. S. Geological Survey Professional Paper*, **248-F**, 327-400.

Jahns, R.H. (1946) Mica deposits of the Petaca District, Rio Arriba County, New Mexico, with brief descriptions of the Ojo Caliente District, Rio Arriba County, and the Elk Mountain District, San Miguel County. *New Mexico Bureau of Mines & Mineral Resources Bulletin*, **57**, 289 p.

Jahns, R.H. (1952) Pegmatite deposits of the White Picacho district, Maricopa and Yavapai Counties, Arizona. *Arizona Bureau of Mines Bulletin*, **162**, 105 p.

Jahns, R.H. (1953a) The genesis of pegmatites. I. Occurrence and origin of giant crystals. *American Mineralogist*, **38**, 563-598.

Jahns, R.H. (1953b) The genesis of pegmatites. II. Quantitative analysis of lithium bearing pegmatite, Mora County, New Mexico. *American Mineralogist*, **38**, 1078-1112.

Jahns, R.H. (1955) The study of pegmatites. *Economic Geology, 50th Anniversary Volume*, 1025-1130.

Jahns, R.H. (1982) Internal evolution of pegmatite bodies. In: Černý, P. (Ed.) Granitic Pegmatites in Science and Industry. *Mineralogical Association of Canada Short Course Handbook*, **8**, 293-327.

Jahns, R.H., Griffitts, S.W., and Heinrich, E.W. (1952) Mica deposits of the southeastern Piedmont. Part I. General features. *U. S. Geological Survey Professional Paper*, **248-A**, 1-10.

Jahns, R.H. and Wright, L.A. (1951) Gem- and lithium-bearing pegmatites of the Pala District, San Diego County, California. *California Division of Mines and Geology Special Report*, **7-A**, 1-72.

Kesler, T.L., and Olson, J.C. (1942) Muscovite in the Spruce Pine District, North Carolina. *U. S. Geological Survey Bulletin*, **B 0936-A**, 1-38.

Landes, K.K. (1933) Origin and classification of pegmatites. *American Mineralogist*, **l8**, 33-56 and 95-103.

London, D. (1999) Melt boundary layers and the growth of pegmatitic textures. (abstr.) *Canadian Mineralogist*, **37**, 826-827.

Norton, J.J. (1964) Geology and mineral deposits of some pegmatites in the southern Black Hills, South Dakota. *U. S. Geological Survey Professional Paper*, **297-E**, 293-341.

Norton, J.J. (1966) Ternary diagrams of the quartz-feldspar content of pegmatites in Colorado. *U.S. Geological Survey Bulletin*. **1241**, D1-D16.

Norton, J.J. (1994) Structure and bulk composition of the Tin Mountain Pegmatite, Black Hills, South Dakota. *Economic Geology and the Bulletin of the Society of Economic Geologists*, **89**, 1167-1175.

Norton, J.J., and others (1964) Geology and mineral deposits of some pegmatites in the southern Black Hills, South Dakota. *U.S. Geological Survey Professional Paper*, **297-E**, 293-341.

Norton, J.J., Page, L.R., and Brobst, D.A. (1962) Geology of the Hugo pegmatite, Keystone, South Dakota. *U.S. Geological survey Professional Paper,* **297-B**, 127 p plus plates.

Norton, J.J. and Redden, J.A. (1990) Relations of zoned pegmatites to other pegmatites, granite, and metamorphic rocks, in the southern Black Hills, South Dakota. *American Mineralogist*, **75**, 631-655.

Olsen, J.C., Griffitts, W.R., Heinrich, E.W., Jahns, R.H., Parker, J.M. III, Amos, D.H., Bergman, S.A., Taylor, A.R., and Teague, , K.H. (1968) Mica deposits of the Blue Ridge in North Carolina. *U.S. Geological Survey Professional Paper*, **577**, 124 p.

Page, L.R., Norton, J.J., Stoll, W.C., Hanley, J.B., Adams, J.W., Pray, L.C., Steven, T.A., Erickson, M.P., Joralemon, P., Stopper, R.F., and Hall, W.E. (1953) Pegmatite investigations, 1942-1945, Black Hills, South Dakota. *U.S. Geological Survey Professional Paper,* **247**, 228 p.

Stoll, W.C. (1950) Mica and beryl pegmatites in Idaho and Montana. *U. S. Geological Survey Professional Paper*, **229**, 64 pp.

Tuttle, O.F. and Bowen, N.L. (1958) Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. *Geological Society of America Memoir*, **74**, 153 p.

Wright, L.A. (1985) Memorial to Richard H. Jahns, 1915-1983. *Memorials, Geological Society of America*, **15**, 1-10.