Dick Jahns at the Tanco pegmatite mine, Bernic Lake, Manitoba, in May of 1982. The field trip was held in conjunction with the MAC short course on Granitic Pegmatites in Science and Industry. (photograph courtesy of B. C. Chakoumakos)

Dick Jahns carried across stream on the Seward Peninsula, 1971, by devoted colleague, C. L. "Pete" Sainsbury. Dick never liked to get his tennis shoes wet. (photograph courtesy of R. C. Ewing)

Dick Jahns at Serpentine Hot Springs on the Seward Peninsula in Alaska, 1971, with C. L. "Pete" Sainsbury. (photograph courtesy of R. C. Ewing)

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Introduction to the Jahns Memorial Issue

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ABSTRACT

The Jahns Memorial Issue of the *American Mineralogist* honors the fundamental contributions of Richard H. Jahns to the study of granitic pegmatites and related rocks. This introduction summarizes some of the general features of granitic pegmatites and provides background and a literature guide to work already published about these rocks. It draws heavily from some of the classic studies by Jahns as well as from recent reviews. An overview of the contributions made by Jahns to the study of granitic pegmatites is also presented. Each of the 30 contributions to the Jahns Memorial Issue is identified and grouped into one of four subdivisions. Some of the major unanswered questions concerning granitic pegmatites are discussed.

GENERAL BACKGROUND

Granitic pegmatites have been the subject of much study and controversy, particularly with regard to their origins. These holocrystalline rocks are typically characterized by extreme variations in grain size, ranging from very coarse "giant" crystals (Jahns, 1953a) to fine groundmass crystals, and have as their major constituents minerals commonly found in ordinary igneous rocks (Jahns, 1955a). Minor constituents of granitic pegmatites can include a variety of unusual minerals; some of the latter are of economic importance, and these provided much of the impetus for the early study of pegmatites in the United States (see, e.g., Jahns, 1951). The estimated bulk composition of many granitic pegmatites corresponds to thermally low parts of the quaternary haplogranite system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O (Jahns, 1982).

The most comprehensive, recent review of granitic pegmatites is the collection of papers edited by Černý (1982b). These papers discuss numerous examples of granitic pegmatites and illustrate their diversity with regard to age, distribution among different rock types, depth of formation, size, shape, texture, internal zonation, bulk composition, and mineralogy. The generalizations made below come from the study by Ginsburg et al. (1979) and the overview by Černý (1982a). These rocks have a wide age distribution, occurring in host rocks ranging in age from 3900 Ma (metamorphosed Precambrian Greenland shield rocks) to 20 Ma (rocks of the Alpine orogenic belts). As examples, the pegmatites in the Black Hills of South Dakota and most of the pegmatites of Colorado and New Mexico are of Precambrian age (1800–1600 Ma), whereas the well-known southern California pegmatites are hosted by Mesozoic (190–100 Ma) granitic to gabbroic rocks of the Southern California batholith. Granitic pegmatites are associated with many different rock types, including migmatites, metamorphic rocks ranging from granulites to greenschists, and igneous rocks ranging from gabbros to granites. Variation in the estimated depth of formation of granitic pegmatites has been used by Ginsburg et al. (1979) as the basis for a simple but useful, fourfold classification: greater than 11 km (pegmatites associated with granulites of shield areas); between 7 and 11 km (mica-bearing pegmatites commonly associated with metamorphic rocks of the almandine-amphibolite facies); between 3.5 and 7 km ("rare-element" pegmatites commonly associated with metamorphic rocks of the cordierite-amphibolite facies); and between 1.5 and 3.5 km (pegmatites that contain miarolitic cavities or "pockets" and that are commonly associated with granites or low-grade metamorphic rocks). Granitic pegmatites occur in a variety of shapes and sizes, ranging from veins several centimeters across to large tabular bodies tens of square kilometers in outcrop area. Jahns (1974, pers. comm.) often stated that the average shape of granitic pegmatites is "about like a lima bean."

Many granitic pegmatite bodies are internally zoned, either symmetrically or asymmetrically, with respect to mineralogy, texture, and element distribution (see, e.g., Cameron et al., 1949). Figure 1, taken from Jahns and Burnham (1969), illustrates three examples of this vertical zonation, including concentric or symmetric zoning (Fig. 1A) and asymmetric zoning (Figs. 1B and C). Figure 1B is a diagrammatic illustration of a zoned pegmatite that presumably formed from a hydrous silicate melt in the presence of a free aqueous phase at shallow depth; the lower portion or "footwall" represents a fine-grained, soda-rich aplite (sometimes referred to as "line rock" if it appears banded or layered). The middle portion shows the quartz-rich core with open "pockets" that may contain gem-quality tourmaline and beryl, quartz, alkali feldspars, and a variety of accessory minerals. The upper portion above the quartz core—the "hanging wall"—is rich in

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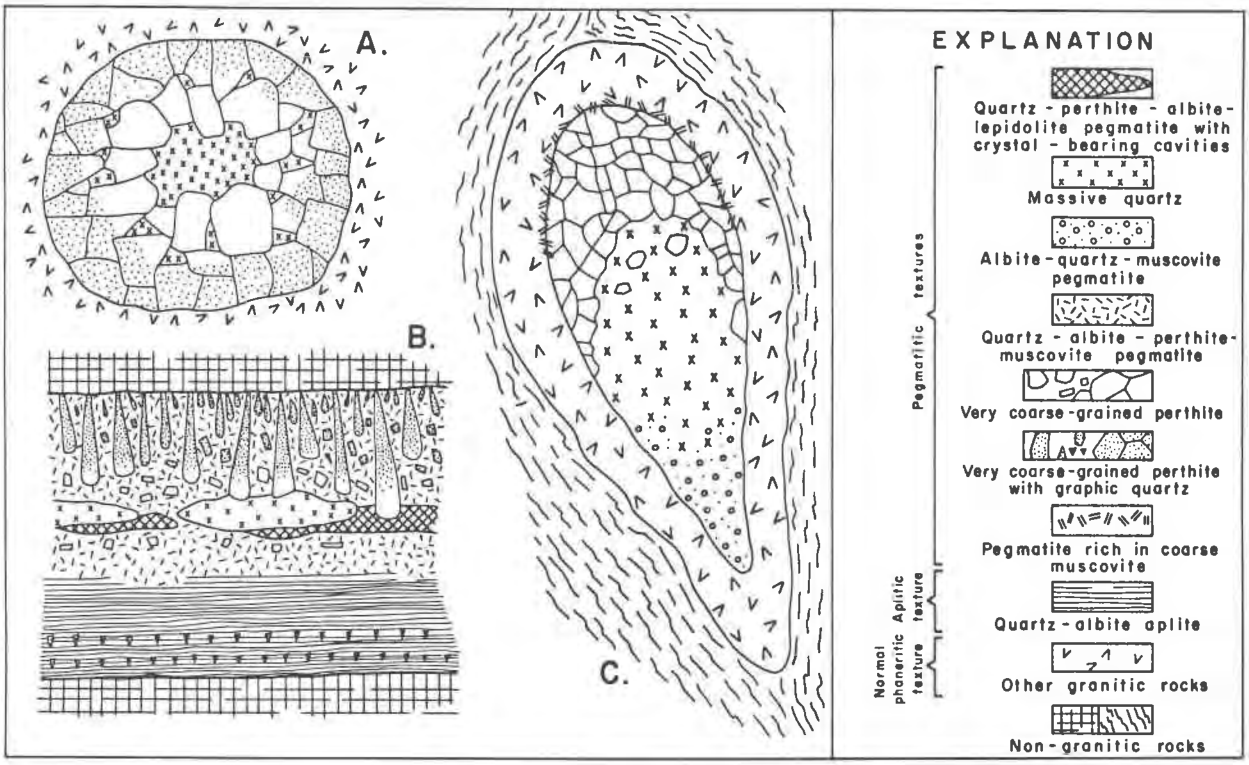

Fig. 1. Diagrammatic vertical sections of three types of zoned granitic pegmatite bodies. Fig. 1A represents a symmetrically zoned miarolitic pod in a granite; the diameter is several centimeters. Fig. 1B represents an asymmetrically zoned pegmatite dike with aplitic footwall portion; the thickness is several tens of centimeters. Fig. 1C represents an asymmetrically zoned pod-like body of pegmatite with granitoid outer portion; the thickness is several meters. From Jahns and Burnham (1969, fig. 5).

potassium feldspar, shown as the large, lath-shaped crystals. Figure 1C also shows vertical asymmetry, but represents a zoned granitic pegmatite that formed from a hydrous silicate melt in the absence of a free aqueous phase at moderate depth; it also displays the general tendency of these zoned bodies for potassium enrichment upwards and sodium enrichment downwards. It is the internal segregation of granitic pegmatites that has stimulated much of the pegmatite research since 1960, including that of Dick Jahns.

A brief account of some of the theories of pegmatite formation is given in Smirnov (1976) and includes a discussion of the major differences between the genetic models of the Russian schools of Fersman and Zavaritsky and the American school of Jahns, Cameron, Landes, and others (see, e.g., Cameron et al., 1949). A more recent summary of the different hypotheses for pegmatite petrogenesis is given by Černý (1982c). The most important genetic controversy has involved igneous versus metamorphic origins for some of the deeper-seated pegmatites, that grade into migmatites. Most of the North American pegmatite specialists belong to the igneous camp; however, in certain cases, metamorphic origins, involving recrystallization, anatexis, or replacement, are clearly indicated by field relations and compositional data. Refinements of these genetic models (see, e.g., Brown, 1982) have been primarily based on experimental work involving volatile-containing silicate melts (e.g., Jahns and Burnham, 1969; Burnham and Davis, 1974); development and application of equilibrium thermodynamic models derived from these experimental results (e.g., Burnham, 1981; Burnham and Nekvasil, 1986); analytical studies of element-zonation patterns within and around pegmatite bodies (e.g., Shearer et al., 1984; Walker et al., 1986); and the application of phase equilibria (e.g., Stewart, 1978; London and Burt, 1982) and mineral, fluid-inclusion, and stable isotope geothermometry and geobarometry (e.g., Taylor et al., 1979). Some of these advances are represented by papers in this issue.

THE JAHNS YEARS

Jahns' studies of granites and granitic pegmatites began before World War II with his field investigations of granite quarries in New England, particularly the Fletcher quarry in northeastern Massachusetts (Jahns, 1942; Jahns and Currier, 1952). During the war, Dick's energies were focused on the assessment of domestic sources of strategic materials (mica, lithium, tantalum, and beryllium) needed for the war effort (Jahns, 1951). These field investigations took him to the mineral deposits of Iron Mountain in the Sierra Cuchillo of south-central New Mexico (Jahns, 1944; Glass et al., 1944; Jahns, 1955b) and to the pegmatites of the White Picacho district of west-central Arizona (Jahns, 1952) and those of northern New Mexico. Most important among the latter were the lithium-beryllium-tantalum-rich Harding pegmatite (Jahns, 1953a; Jahns and Ewing, 1976, 1977), the mica-bearing pegmatites of the Petaca district (Jahns, 1946, 1974), and the Pidlite dike (Jahns, 1953b). In the case of the Harding pegmatite, over 10 000 kg of microlite concentrate (68 wt% Ta_2O_5 and 7 wt% Nb_2O_5) were produced between 1942 and 1947 to meet the critical wartime needs. Dick also played an important part in extensive field investigations by the U.S. Geological Survey of mica deposits in the southeastern U.S. Piedmont (Jahns and Lancaster, 1950; Griffitts et al., 1953) and had a career-long love affair with the gem-bearing pegmatites of southern California (Jahns and Wright, 1951; Jahns et al., 1974; Jahns, 1953a, 1954, 1979; Stern et al., 1986).

Dick's success in much of his field work can be attributed in part to the long-term friendships he formed with the owners, operators, and "high-graders" of every pegmatite mine he visited; on more than one occasion, he was alerted to the discovery of a new "gem pocket" by the miner and rushed to the site to help excavate and carefully document its contents. These field studies provided Dick with a unique perspective about the mineralogy and internal structure of pegmatites that led to a series of classic papers (Cameron et al., 1949; Jahns, 1953a, 1953b). "The study of pegmatites" (Jahns, 1955a) contained a summary of his observations and ideas and established him as an international authority on granitic pegmatites and the leading proponent for their magmatic origin.

The unusual chemical zoning patterns that Dick observed and documented in his work on complex granitic pegmatites—as schematically illustrated on the relatively small scale of Figure 1B (the "logo pegmatite" on the cover of this issue)—led him to the first experimental studies of pegmatite systems in collaboration with C. Wayne Burnham (Jahns and Burnham, 1957, 1958, 1969; Burnham and Jahns, 1961, 1962). These landmark studies demonstrated the importance of an exsolved aqueous fluid phase in the transport and segregation of major elements like K and Na and led to the formulation of the well-known and often-quoted "Jahns-Burnham" model for the evolution of granitic pegmatites (Jahns and Burnham, 1969). The basic postulates of this model involve crystallization of pegmatite minerals in the presence, successively, of a hydrous silicate melt, of melt and coexisting aqueous fluid, and finally, for relatively shallow pegmatites, of the supercritical fluid phase alone. The final-stage development of pegmatite "pockets"—some of which are lined with striking and highly valued crystals of tourmaline, beryl, and topaz, in addition to quartz, micas, and feldspar—can be qualitatively understood, in large part, by using this model (Jahns, 1982). However, the origin of the quartz core in such pegmatites remains incompletely understood (Burnham and Nekvasil, 1986).

Other important experimental work that Dick participated in during this period included several studies of crystallization in the granite-water system (Luth et al., 1964; Steiner et al., 1975). Field observations remained central to Dick's work on pegmatites as shown by his many years of study at the Harding pegmatite in New Mexico (Jahns and Wright, 1944; Jahns, 1953a; Jahns and Ewing, 1976, 1977) and in the Pala district in southern California (Jahns and Wright, 1951; Jahns, 1979; Stern et al., 1986). The most complete and recent summary of Dick's ideas and observations on the genesis of complexly zoned granitic pegmatites was presented in a symposium on granitic pegmatites in Winnipeg, Canada (Jahns, 1982). In characteristic fashion and with his usual keen insights, this paper ends with 16 unanswered questions about the genesis of pegmatites. We hope that some of these questions are answered, in part, by papers in this special issue.

Organization and contents of the Jahns Memorial Issue

The papers composing this special issue are divided into four sections: experimental studies; petrology, mineralogy, and geochemistry; structural, spectroscopic, and calorimetric studies of pegmatite minerals; and studies on related granitic rocks. Many of the contributors to this issue are former colleagues and students who were first introduced to granitic rocks, including pegmatites, by Dick. It is certainly due to Dick's influence that pegmatites of New Mexico and southern California figure prominently in this issue.

Because of the close collaboration between Dick and C. Wayne Burnham over a quarter century, it is fitting that the Jahns Memorial Issue begins with the paper by Burnham and Nekvasil on equilibrium properties of granite pegmatite magmas. This paper is a detailed account of Burnham's "quasi-crystalline" model of hydrous aluminosilicate melts that can be used to predict equilibrium melt properties, particularly for volatile-containing systems. In some respects it represents a quantitative extension of the "Jahns-Burnham" model for pegmatite evolution. R. Luth and Boettcher extend the discussion of volatile components in silicate melts to include H_2, on the basis of their experimental studies of albite, diopside, and quartz melting in the presence of H_2O-H_2 vapors, and consider its effect on melting relations. The effect of the BeO component on the phase equilibria in a hydrous aluminosilicate melt is documented by Barton; these phase relations provide constraints on the temperatures and activities of silica and alumina during the formation of Be-containing pegmatites and greisens. Huang and Wyllie have contributed an experimental study of the gabbro-tonalite-granite-water system in which they evaluate fractionation trends of hydrous magmas responsible for the formation of the calc-alkaline rock series. Constraints on the origin of A-type granites are provided by the experimental study of Clemens et al. Crystal-growth experiments in simplified, hydrous, granitic pegmatite systems are presented in studies of graphic granite by Fenn, quartz morphologies by Swanson and Fenn, intergrown ternary feldspars by Petersen and Lofgren, and phosphates by Shigley and Brown. These studies are useful for placing constraints of temperature, pressure, and water contents on crystal growth in pegmatites. The final paper in this section by Long and W. Luth models Ba zoning during the crystallization of K-feldspar megacrysts in granitic rocks.

The second section of the Jahns Memorial Issue is devoted to the petrology, mineralogy, and geochemistry of granitic pegmatites, with special emphasis on the petrogenesis of particular pegmatite bodies. London uses fluid-inclusion data and phase relations to trace the transition from magmatic to hydrothermal conditions in the Tanco mine, Manitoba, Canada. In a second paper, London considers the effect of tourmaline crystallization on pocket formation and suggests that the appearance of tourmaline governs the timing and extent of H_2O exsolution from pegmatitic melts. Stern et al. document the mineralogy of the pocket zone of the Little Three pegmatite, Ramona, California, and present a solution-mineral equilibrium thermodynamic model for the geochemical evolution of the major pegmatite-aplite mineral assemblages. Foord et al. provide the first detailed description of the mineralogy of "pocket" clays from the pegmatites of San Diego County, California. The internal evolution of the Tin Mountain pegmatite, Black Hills, South Dakota, is documented by Walker et al. in their study of major and trace elements and oxygen isotopes. Nabelek presents a trace-element fractionation model for the granophyres and aplites of the Notch Peak granitic stock, Utah, which demonstrates that rocks resulting from fractionation of anhydrous melts can be distinguished from those crystallized in the presence of aqueous fluids. Jolliff et al. use compositional variations of tourmalines to determine the crystallization sequence and differentiation mechanism of the Bob Ingersoll pegmatite, Black Hills, South Dakota. In a similar study, Černý et al. use Nb- and Ta-bearing oxides to determine the fractionation trends in the Greer Lake pegmatitic granite, southeastern Manitoba, Canada, and show that the concentrations of Ti and Sc in the contact aureole are due to internal fractionation rather than assimilation. In contrast, Shearer et al. found extensive element-dispersion halos around several Black Hills, South Dakota, pegmatites caused by fluid transport out of the pegmatite system.

The third section presents compositional, structural, spectroscopic, and calorimetric data for selected major and accessory pegmatite minerals. Moore, in a new look at quartz and structurally related minerals such as steenstrupine, cerite, and rhabdophane, demonstrates that "there will always arise a need for another paper on quartz." Lumpkin et al. demonstrate in a detailed analysis of the compositional variations and radiation damage of microlite from the Harding pegmatite, New Mexico, that "there will never be the need for another paper on microlite" (Jahns, 1985, pers. comm.). In a high-temperature crystal-structure study, Brown and Mills present the results of an investigation of the high-temperature crystal chemistry and structural expansion of a hydrous, Cs-rich beryl from the Harding pegmatite, New Mexico. The heat capacities and derived entropies and free energies of formation of the Be-containing pegmatite minerals beryl, phenakite, euclase, bertrandite, and chrysoberyl are given in a paper by Hemingway et al. The causes of color in smoky quartz (Partlow and Cohen) and an unusual Mn-rich, yellow tourmaline (Rossman and Mattson) are explained by optical absorption spectroscopy. This section concludes with a mineralogical description of a new mineral, minasgeraisite, named after the famous Brazilian pegmatite province, Minas Gerais (Foord et al.).

The Jahns Memorial Issue concludes with several papers on the petrology and textural variations of granitic rocks and one paper on the structural setting of pegmatites. O'Brient documents an example of arrested plutonic development in a shallow volcanic complex in Rabb Park, New Mexico, with rock types ranging from tuff to pegmatite. McMillan uses the Jahns-Burnham model for the evolution of pegmatites to explain the development of miaroles in the albite porphyry of Cuchillo Mountain, New Mexico. On a larger scale, Barker et al. describe petrologic variations across the Coast batholith from Haines, Alaska, to Tutchi Lake, British Columbia, and suggest that this complex is part of a broad and long-lived magmatic arc formed above subducting plates of the Pacific basin. Brisbin describes the shape and orientation of pegmatite bodies as a function of fluid pressure, rheological state of the host rocks, lithostatic and directed stresses, pore-water pressures, strength and ductility anisotropies, and dilational directions.

FUTURE PROSPECTS

It should be clear from the papers in this issue that the subject of pegmatites and their genesis is still an active and diverse field of research with important economic consequences. Pegmatites may become a principal source of metals for high-technology materials, such as glass-ceramics (Li), electronic photomultipliers (Rb and Cs), high-strength alloys (Be, Nb, Ta), and cutting tools and filaments in electronic devices (W).The diversity of pegmatite research includes field, analytical, and experimental approaches, all of which were employed by Dick Jahns in his long-term study of pegmatites and related rocks. Recent work has also included modeling of mineral-melt fractionation and equilibria, as well as the thermodynamic properties of pegmatitic melts. In spite of the numerous studies of pegmatites, including those appearing in this issue, there are many basic questions concerning pegmatite genesis that remain unanswered or only partially answered (Jahns, 1982). The more important of these include the causes of the asymmetry of the zonal structure of pegmatite bodies, the profound segregation of constituents resulting in nearly monomineralic zones of giant crystals, the enormous differences in grain size of the same or contemporary minerals in the same pegmatite zone, and the origin and composition of pegmatitic melts. In November of 1985, as we conclude this introduction to the Jahns Memorial Issue, we hope that answers to some of these questions will be presented and new questions will be asked during the Symposium on Granites, Pegmatites, and Skarns at the 14th General Meeting of the International Mineralogical Association to be held on July 13–14, 1986, at Stanford University.

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Although saddened by the loss of a close friend, colleague, mentor, fellow practical joker, and teller of the best jokes and anecdotes, we are honored to have this opportunity to pay tribute to the late Richard H. Jahns, who introduced both of us to the subject of pegmatites. Some of the best times either of us can remember were had on field trips led by Dick to the pegmatites of southern California and New Mexico. We also wish to acknowledge the efforts and patience of the contributors to this volume and thank many referees who responded to our requests for rapid reviews in a positive fashion. Brown wishes to thank Laura Stern for a quick and helpful review of this manuscript and the School of Earth Sciences at Stanford for providing financial support to cover the costs of preparing this manuscript as well as xeroxing and postage costs. Ewing expresses a special thanks to B. C. Chakoumakos and G. R. Lumpkin who kept the research going while he edited manuscripts for this volume. Thanks are also due former Editor of the *American Mineralogist,* Mike Holdaway, for his support, advice, and hard work during most of the preparation of this issue. Jim Munoz took over the Editorship during the final stages of organization of the issue and is also thanked for his help and advice. Finally, the Mineralogical Society of America is acknowledged for providing endowment support for the production of the Jahns Memorial Issue.

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