Lembin

RELATIVE DISTANCE FROM SOURCE INTRUSIVE AS A FACTOR IN PEGMATITE VARIATION

John Jesse Hayes

59

A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Geology of the University of Michigan. May, 1948

Contents

Abstract

Pegmatites are grouped in three divisions on the basis of their location with respect to the source intrusive: Interior, Marginal, and Exterior. Interior pegmatites are within the intrusive, simple, and usually barren of rarer minerals. Marginal pegmatites are complex and occur along the zone of contact between the intrusive and the invaded country rock, but still on the intrusive side of the contact. Exterior pegmatites occur in the country rock, are simple to complex, and may have several advanced hydrothermal phases.

Five districts that show all three types are discussed. Namaqualand in South Africa, Erongo in South-West Africa and Eight Mile Park, Colorado, are treated in detail. Spruce Pine in North Carolina and the Preissac-La Corne area, Quebec, are discussed briefly.

The five districts have similar features of structure, mineralogy, and distribution among the pegmatites that support the criteria used in the spatial classification.

MASTER'S THESIS

RELATIVE DISTANCE FROM SOURCE INTRUSIVE AS A FACTOR IN PEGMATITE VARIATION

John Jesse Hayes

Introduction

Purpose

This paper discusses pegmatites related to batholithic intrusions and attempts to demonstrate that the internal structure and mineral content of the pegmatites of any one district are functions of their relative distance from the batholith.

The pegmatites are grouped in three divisions on the basis of their location with respect to the source intrusive: Interior, Marginal, and Exterior. This nomenclature follows the terminology of Gevers (1936, p. 339) and suggestions by Dr. E. Wm. Heinrich of the Department of Mineralogy, University of Michigan. The Interior pegmatites are within the intrusive and are comparatively simple and barren of the rarer minerals; the marginal ones are complex and lie along the zone of contact between the intrusive and the invaded country rock, but on the intrusive side of the contact; the exterior pegmatites occur in the country rock at varying distances from the intrusive, are simple to complex, and may have an advanced series of hydrothermal phases.

Districts which show all three types associated with a single source intrusive are described.

Previous Work

The division of pegmatites associated with a single source intrusive into three groups, interior, marginal, and exterior was proposed by Gevers (1936, p. 339) in describing the pegmatites of Namaqualand. Emmons (1933, p. 331) in describing the events attending and following the intrusion of a batholith emphasizes the restriction of pegmatites to the core (interior), hood (interior and marginal), and roof (exterior). Balk (1937, p. 106) mentions marginal pegmatites which occur along the contacts of an igneous mass near Bornholm, Sweden. In discussing the effect of structure on pegmatite intrusion, Landes (1942) divides pegmatites into two groups: 1) those found in crystalline foliates and 2) those occurring in massive rocks.

This paper was written under the supervision and guidance of Dr. E. Wm. Heinrich of the Department of Mineralogy, University of Michigan. The author also wishes to acknowledge the helpful suggestions and criticisms of Dr. K.K. Landes and Dr. F.S. Turneaure during the preparation of the manuscript.

General Features of Pegmatites

There are many problems concerning the relationships of pegmatites to batholith crystallization, hydrothermal solutions, structural control and method of emplacement, which this paper does not attempt to discuss in detail. However, it may be well to consider briefly the current concepts concerning origin, nature, and emplacement of pegmatites for the purpose of defining the emphasis which will be placed on certain of these principles as they apply to the spatial and mineralogical distribution of pegmatites with relation to the parent igneous body.

The development of the theories on pegmatite origin, which was thoroughly reviewed by Landes (1933), has progressed through the now largely discarded hypothesis of lateral secretion to the widely accepted concept of formation of the pegmatites that contain the rarer constituents. The formation of the complex pegmatites involves two distinct processes:

1) A primary period of magma crystallization followed by

2) A hydrothermal period. The hydrothermal period may consist of several phases of alteration of the primary pegmatite minerals by chemically different solutions that react with the earlier minerals in a more or less well-defined sequence.

The importance of hydrothermal replacement in the formation of some pegmatites was emphasized in 1925 by the independently published investigations of Schaller, Mullbauer, Landes, Cook, and Hess. The evidence, evaluated by Landes (1933), indicates that the primary period of crystallization takes place from a volatile-rich and highly mobile residual portion left over from the consolidation of the batholith. This residual portion crystallizes after the fashion of the source intrusive but with a lower freezing point and with larger crystals. This magmatic period, which forms the "essential" pegmatite minerals, such as microcline, beta-quartz, and primary mica, may be accompanied by a certain amount of reaction of the earlier minerals with the uncrystallized liquid in which they form. The "deuteric" perthites described by Alling (1932, p. 54) and the graphic granites may be cited as possible examples of this early magmatic alteration.

In the majority of pegmatites the magmatic period marks the end of the process of formation. Mineralization is carried no further and the remaining volatiles in solution escape into other channels. There are no later alterations and the deposits may be sealed off from renewed reaction with later solutions by complete consolidation of the pegmatite. These are the simple pegmatites, and unless they are re-opened to hydrothermal activity, they remain essentially similar in composition to the parent intrusive.

The second, or hydrothermal period of pegmatite formation occurs in an extremely small number of pegmatites as compared with the total number of known occurrences. These may be simple pegmatites in channels that were re-opened to a later flow of solutions by fracturing caused by differential movements of the surrounding rocks, or pegmatites that have never been completely cut off from the residual magma chamber. The replacement minerals developed in this way contain much higher amounts of water, boron, fluorine and other mineralizers than do the primary minerals of the parent body or the essential minerals of the simple pegmatites.

These are the complex pegmatites which contain most of the minerals of economic importance.

The source of the altering solutions has not yet been satisfactorily explained. They may represent material which is being rejected by the still crystallizing portions of the batholith, or further residuals from pegmatites being formed at greater depth, or possibly, in the case of the largest pegmatites, from material contained within the pegmatite itself and representing an ultimate residual left over from crystallization. It is also possible that the source of solutions may be different in one pegmatite locality from that in another.

Relation to Batholith Crystallization

Pegmatites are found associated with intrusive bodies of nearly all types of igneous rocks, but the vast majority occur within or peripheral to granite batholiths. Emmons (1940, p. 189) has postulated the sequence of events in the emplacement of a typical batholith during which solidification takes place from the top downward to result in a capping shell or "hood" enclosing a still liquid interior. As the interior cools, certain characteristic minerals crystallize early, and thereby remove the more basic constituents from the magma, leaving it progressively enriched in alkalies and volatiles. Vapor pressure in the residual magma rises, fracturing of the hood takes place, and there is a resulting injection of the residual material into the hood and the adjacent roof rock where it begins the primary or magmatic period of pegmatite crystallization.

As fluids high in volatiles and, in some cases, possibly containing metallic sulphides, continue to rise from the interior they follow whatever channels of escape are available. If they originate as vapors they become liquid as they move into a cooler environment.

If this order of events is the case, it is not difficult to conceive that these fluids will preferentially follow channels through established zones of fracture that have already been travelled by pegmatitic fluids and, in those places where they have access to previously emplaced pegmatites, become the hydrothermal replacement solutions of the complex pegmatites. If pegmatite crystallization closes these original injection channels, or if new openings are formed by the pressure of the fluids or movements of the hood, the solutions escape elsewhere, the pegmatites are unaffected and remain simple in composition. The gases and liquids may then function in the general sequence of vein formation and replacement deposition, and if high in the metallic constituents, as the ore solutions. Such a combination of events at this stage of batholith consolidation might account for the presence of both simple and complex pegmatites in restricted areas in the marginal and exterior portions of some granitic bodies.

The absence of complex minerals in the deep interior of batholiths, according to Emmons (1940, p. 189), suggests that the core was the only source of the high-volatile materials and that these were gradually eliminated during crystallization of the main mass. This idea is supported by the mineralogy of pegmatites found in the deepest interior portions. They are usually of the simplest quartz-feldspar type and probably represented the rejected material that crystallized last. These pegmatites, situated at random wherever they were enclosed by the general consolidation of the core, are the segregation pegmatites such as those described by Williams (1895, p. 675) in Maryland, the riebeckite-aegerite pegmatites of the Quincy Granite, Massachusetts (Warren and Palache, 1911), and possibly the sanidine pegmatites of Grant County, New Mexico (Kelley and Branson, 1947).

Relation between Pegmatites and Hydrothermal Veins

As investigations continue, it is becoming apparent that there is a close relationship between the source material for pegmatites and that for hydrothermal veins. An examination of deeply-eroded, pegmatite-producing granite batholiths shows that some of them have in association, hydrothermal vein deposits rich in metallic elements. Other batholiths have none or the veins are present to a limited degree. Yet both types of intrusives may have produced large numbers of simple to complex pegmatites. This would indicate that batholithic magmas, similar in all other respects, may vary markedly in their content of metallic constituents in quantity as well as in kind. In certain metal-producing batholiths, pegmatites subjected to hydrothermal replacement by post-pegmatite solutions contain appreciable quantities of the metals characteristic of the ore deposits in the area, as for example, the tin-bearing pegmatites of northern Bolivia (Ahlfeld, 1936, p. 59), which are associated with the cupola regions of a quartz monzonite or granodiorite batholith, genetically related to the source intrusive of the tin deposits of the Cordillera Real. In these pegmatites, cassiterite ores, locally of commercial grade, occur with molybdenite and tourmaline as later fillings of fractures and pockets within the pegmatites (Turneaure, 1947, p. 53). Numerous other examples of post-pegmatite metallization of this type have been described, such as the tin-bearing pegmatites of the Erongo region, South West Africa (Gevers and Frommurze, 1929), the common occurrence of tungsten, also in Bolivian pegmatites (Ahlfeld, 1936, p. 59), and the consistent occurrence of molybdenite in many pegmatite localities. Landes (1937, p. 559) divides the pegmatite-producing magmas into two groups:

1. Granitic magmas that produce abundant pegmatites and have later hydrothermal solutions that precipitate tin, tungsten and molybdenum minerals in the pegmatites, as well as in veins near and for some distance around the pegmatites.

2. Intermediate magmas (granodiorite, monzonite, diorite, etc.) that have greater variety and volume of metallic ore minerals and that produce a minor pegmatite phase before entering the hydrothermal phase.

A significant variation from Landes' second group is the occurrence of abundant tin associated with an intermediate magma in the Cordillera Real of Bolivia. Lindgren (1926, p. 140) describes the parent rock at Caracoles as quartz monzonite similar in nature to the quartz monzonites at Leadville and Telluride, Colorado and to parts of the Boulder Batholith in Montana.

It is generally considered that the pegmatite fluid is one of an aqueo-igneous fusion, rich in volatiles, yet not nearly so mobile as the ore solution which is capable of penetrating minute cracks and pore spaces. The dilute character and high water content of the ore solution enable it to cause extensive wall rock alteration, impossible for the less active pegmatite fluid. Again, it is generally agreed that the starting point for both is the silicate, orthomagmatic solution of the parent magma.

Most authors have also agreed that crystallization of the orthomagmatic solution causes a gradual concentration of the volatiles in a residual portion. Fenner (1933, p. 73) proposes a separation of a highly mobile ore solution at an early stage in the consolidation of the magma and the formation of a residual liquid which is the pegmatite solution. He emphasizes the separation and transportation of the metallic constituents by a vapor phase with eventual condensation to form the liquid ore solution. Ingerson and Morey (1940) consider that the ore solution was produced late in the cycle, but chiefly in a liquid form.

Bowen (1933, pp. 117-118) considers the ore solution to be derived from the pegmatite residual through the separation of a vapor phase by a process of boiling to eventually become the ore liquid by condensation. Graton (1940, p. 326) is opposed to Bowen and Fenner and concludes that the ore solutions do not pass through a vapor stage. He suggests two possibilities, which are as follows:

1. The ore fluid is a residual liquid, representing a more advanced stage in differentiation of the pegmatite fluid and has a more specialized composition.

2. The ore fluid represents an immiscible separation from a residual liquid of a pegmatitic character.

Structural Control of Emplacement

In Undisturbed Sedimentary Rocks. The extent of pegmatite emplacement in the surrounding rocks and the forms that they take are largely determined by the structure of the invaded rocks. Pegmatite occurrences in unaltered sedimentary rocks are almost unknown. It is difficult to conceive of pegmatite emplacement of any extent in sediments that have not been greatly affected by the intrusion of the parent igneous body. A small pegmatite in the Lower Paleozoic sedimentary rocks of the Decaturville Dome, Missouri, has been described, but because of the complete absence of contact alteration of the surrounding rocks, it is considered by Tolman and Landes (1939) to be a former resistant feature on the old pre-Cambrian erosion surface which was later covered by sediments. Emerald and pegmatite occurrences have been described in the intensely folded Cretaceous marine shales near Muzo, Colombia (Oppenheim, 1948), that apparently are related to a deep-seated Tertiary intrusive.

More typical are the occurrences described by Gevers and Frommurze (1929) in the Erongo area of Damaraland where a few pegmatites, in a region remarkable for its vast numbers of pegmatites, intrude sedimentaries that are much altered to quartzites and marbles by granite intrusions and tectonic disturbances preceding and accompanying pegmatite emplacement.

In Non-foliated Rocks. Emplacement control in non-foliated rocks is established by the formation of fracture systems which are used as channels by the escaping magmatic solutions (Balk, 1937). The fractures may occur in the upper and earlier consolidated portions of the parent batholith (Emmons, 1940, p. 189) or, where igneous country rocks are intruded, fractures may be opened in the invaded rocks by the force of the intrusion. Bjørlykke (1937) explains the emplacement of the granite pegmatites of southern Norway on this basis.

Pegmatites may be emplaced in any openings in massive rocks, whose shapes will determine the shapes of the pegmatites. The majority of pegmatites are highly irregular in form, and no one form is characteristic of them as a whole. Where they fill cross-cutting fissures they assume the conventional dike form. Others are rudely tabular or tend to acquire a lens-like shape.

At the intersections of fracture planes they may form pipes as do the tin-bearing pegmatites of the Zaaiplaats district, South Africa (Kynaston and Mellor, 1909). Few pegmatites have been observed through any great vertical distance as compared with length.

<u>In</u> <u>Foliated</u> <u>Rocks</u>. Structural control of pegmatite emplacement is very marked in many localities where pegmatites have been intruded into schistose or gneissose rock. Gevers and Frommurze (1929) describe pegmatite dikes associated with phacolithic granite bodies intruded parallel with the bedding planes of sedimentary schists. Similar parallelism to schistosity has been noted by Anderson in Latah County, Idaho (1933), by McLaughlin in the Bridger Mountains of Wyoming (1940), and by Duncan in the Harney Peak region of the Black Hills (1913).

In the Bridger Mountains, McLaughlin states that the older pegmatites conform to the joints that parallel the foliation of the pre-Cambrian schistose country rock, and that the younger ones parallel the directions of later jointing. Broedel (1937, p. 158) is describing the gneiss domes near Baltimore, Maryland, states that pegmatites are both conformable and non-conformable. The larger ones occur in swarms following the strike of the formations, and are most abundant in the schists along the flanks of domes and folds.

Lit-par-lit injections are very common in schist and gneiss, where the pegmatites form thin tabular bodies alternating with and parallel to the original banding of the rock. In some occurrences the injected material is so abundant that it equals or exceeds the host rock.

Many notable exceptions to this idea of the parallelism of pegmatites to foliated rocks may be cited, for example, the Orange River area of Namaqualand (Gevers, Frommurze, and Partridge, 1936) where the majority of pegmatites are discordant to the schistosity.

General Sequence of Mineralization

Pegmatite crystallization begins at a time when magmatic conditions prevail. The initial consolidation is characterized by the extensive development of microcline and beta-quartz. These two minerals are often accompanied by the formation of varying amounts of perthite and graphic granite, and such early minerals as common beryl, black tourmaline, muscovite, apatite, and red garnet. If zoning is to be developed in the pegmatite it is established at this time.

The hydrothermal stage, which may initiate a series of phases each characterized by the presence of one or more of the volatile elements and the resulting deposition of a characteristic mineral suite, begins near the end of, or shortly after the magmatic stage.

The two most common replacement processes are muscovitization and albitization which are often nearly simultaneous. Muscovite widely replaces both feldspar and the early beta-quartz, while albitization results in the exchange of sodium for potassium in the feldspars. Following these, or in some cases preceeding their completion, may be some of the phases in various sequences as listed below.

1. Lithium phase with the development of minerals such as spodumene, amblygonite, and lepidolite as in the Keystone district of South Dakota (Landes, 1928), Madagascar (Gratacap, 1916), and Namaqualand (Gevers, 1936).

2. Boron phase with some lithium producing later colored tourmalines.

3. Fluorine phase like that developed in the cryolite-pegmatites of Ivigtut, Greenland (Baldauf and Beck, 1910), and in the St. Peter's Dome area of Colorado (Landes, 1935).

4. Beryllium phase producing late beryllium minerals of a rare earth and gem type, as in central Maine (Landes, 1925; Bastin, 1911), Madagascar, and Brazil.

Phosphate and rare earth and metallic element occurrences are widely known but much less common.

All of the minerals of both the magmatic and hydrothermal stages are subject to alteration by supergene processes and to reactions with post-pegmatite solutions which are in no way genetically associated with the formation of the original deposit.

General Concept of Zoning

The concept of primary zoning within pegmatites is one which has been discussed by R.H. Jahns in his studies of the mica pegmatites in the Petaca district of New Mexico (1946, p. 42). The following statements have been taken largely from his summary of the subject.

Zones are developed early in the formation of a pegmatite and consist of more or less concentric shells with a characteristic texture or composed of minerals deposited about a central core. These shells or zones are rarely developed in a complete fashion and may be extremely irregular or altogether lacking in places.

The zones have been classified as follows:

1. A border zone consisting of a selvage of fine- to medium-grain, usually only a few inches thick, which may be sharply defined or may grade into the adjacent country rock. It is apparently established by the degree of reaction between the pegmatite and the country rock.

2. A wall zone which is developed inside the border zone and is much thicker and of coarser grain. It is usually well-defined (in the Petaca district) but also may grade imperceptibly into both the border zone and

the interior of the pegmatite. The zone may be considerably modified by replacement solutions subsequent to its formation.

3. Intermediate zones lie between the core and the wall zone and may be of variable thickness and, in some pegmatites, divisible into two or three zones. Often they are completely lacking and usually are incomplete.

4. The core occurs near the center of the pegmatite and seems to be the last to form. Usually it is composed of massive quartz with subordinate and scattered amounts of feldspar. Cores are not necessarily continuous and in the elongated bodies may have a pod-like shape, or be strung out into a disconnected chain of smaller pods.

Classification of Pegmatites

The classification used in this paper is based upon the spatial distribution of pegmatites with respect to the parent intrusive. In so doing, the author has drawn freely upon the system used by Gevers (1936, p. 339) in describing the Namaqualand pegmatites, and the criteria developed by Emmons (1933) and other writers concerning the mode and sequence of pegmatite emplacement during the cooling of a batholith.

Pegmatites are divided into three groups: interior, marginal, and exterior. The interior pegmatites correspond to those Emmons allocates to the core regions of the batholith; the marginal pegmatites are located in the early consolidated hood region; the exterior ones are all those formed outside the parent body in the invaded country rock. In this paper only the granite pegmatites are considered.

The characteristic features of the pegmatites are given in the following paragraphs:

Interior. The interior pegmatites are simple in mineralogy and show little evidence of high-temperature replacements. They consist almost entirely of quartz and feldspar, with minor amounts of schorl, garnet, or muscovite, and compare closely in composition and mineral relationships with the enclosing rock. The pegmatites are irregularly distributed throughout the core of the batholith and are generally small in size, although in some cases they may grade into a pegmatite facies of considerable extent, as in the Harney Peak granite of the Black Hills (Darton and Paige, 1924). In general, they become fewer in number at depth with respect to the batholith.

Their shapes vary, ranging from a roughly pipe-like or prolate-spheroid form as in certain of the segregation pegmatites which have a boundary marked only by a change in texture and an increase in grain size inward from the enclosing rock, to intricate stockworks of irregular, narrow, anastomosing veins with sharp boundaries. Between these two extremes the interior pegmatites may assume any shape or orientation, and in some cases zoning may be developed.

Marginal. The marginal pegmatites also occur within the parent intrusive but are restricted to the outer portions corresponding to Emmons' hood region, which crystallized early in the upper part of the batholith and was later fractured by contraction due to cooling, vapor pressures, or tectonic stresses.

The mineralogy of the marginal pegmatites may be either simple or complex, depending upon whether or not the pegmatites were subjected to hydrothermal alteration subsequent to emplacement.

Their shape and size are determined by the nature of the openings into which they have been injected. Many pegmatites give indication of having maintained an open system for the passage of solutions from the time of their formation until the conclusion of igneous activity. Others may have had open systems intermittently, the channels being sealed by pegmatite crystallization, then opened again by differential movement of the surrounding rock. Still others were apparently sealed off from later emanations soon after emplacement, were never re-opened and remained as simple pegmatites with a mineralization similar to that of the deeper interior pegmatites. In general, the contacts with the enclosing rock are sharp with little development of contact metamorphism.

Exterior. Under the grouping of exterior pegmatites are included all those found outside of the igneous body in the invaded country rock. Their distribution is greatest in the roof rock above and along the upper sides of the batholith, and they may extend for a considerable distance away from it. Near the granite body they may mingle with those of the marginal group, as in the case of individual pegmatites that lie partly in country rock and partly in granite. Occurrences of this type are relatively uncommon, however.

The mineralogy is essentially similar to that of the marginal pegmatites except where it is influenced by contact with the country rock. Under this heading may be included the contact and migmatic pegmatites of Fersmann (1931) in which the pegmatite may have acquired a limited amount of material by interaction with the country rock, or there may have been a development of a mixed magma through assimilation of country rock by an extremely high-temperature pegmatite solution.

Hydrothermal alteration, in nearly all districts, has its greatest development in the exterior pegmatites and the principles of zoning may perhaps be more consistently demonstrated in these pegmatites than in those of the interior and marginal regions, with due consideration to the effects of pre-heating and the susceptibility of the country rocks to contact metamorphism.

* * * * * * * * * * *

The following areas of pegmatites will be reviewed with the application of these generalized considerations in mind.

Namaqualand Pegmatites

General Statement

The Namaqualand pegmatites, which were described by Gevers in 1936, occur in a zone extending for 150 miles along the Orange River in South Africa and are within a large area of pegmatite occurrences that extends over Namaqualand, Gordonia, and Bushmanland. The pegmatites are in the broad zone of contact between the Namaqualand batholith of pre-Cambrian gneiss and the igneous rock that it intrudes. The batholith and the intruded country rocks form part of the Old Granite-Gneiss complex of South Africa.

The pegmatites are simple to complex and muscovitization and albitization are the dominant alterations. The later series of hydrothermal phases in the complex pegmatites begins with the deposition of lithium and rare earth minerals and ends with sulphide replacements. Quartz-tourmaline veins are associated with the complex pegmatites and show the sulphide stage.

The oldest rocks of the region are the metamorphosed lavas and sedimentaries of the Kheis System of South Africa which was intruded at various times by several types of igneous rocks. The sequence of intrusion is summarized as follows:

1. Ultramafic to mafic rocks ranging composition from peridotite to hornblende diorite.

2. Normal diorite with gneissoid structure.

3. A variety of granites.

4. The Namaqualand batholith and its acid differentiates.

5. Parallel mafic dikes in swarms that are later than and that transect the general trend of the pegmatites.

These intrusions were accompanied by great tectonic stresses that produced shearing along parallel zones which, in turn, influenced the emplacement of the larger intruding bodies and resulted in their alignment in a general east-west direction. At the time of pegmatite emplacement the stresses were still active but of reduced intensity as indicated by marked deformation of minerals in the younger granites and less crystal deformation in the pegmatites.

Rock Descriptions

<u>The Invaded Rocks</u>. The subordinate Kheis rocks (Rogers, 1914) which consist of remnants of altered quartzites, schists, and massive, amygdaloidal, basic lavas, much sheared, are of little importance in the development of the pegmatites. The ultramafic and mafic rocks of the first post-Kheis intrusions include a series of diorites that contain large amounts of augite, hornblende and biotite, and in many places these grade into tonalites. The most extensively distributed rocks of the pegmatite area, however, are the biotite and hornblende granites of the third intrusive period. For the most part these are

coarse and unfoliated, commonly porphyritic in texture, and in many places grade into quartz monzonites and high-quartz granodiorites. Shearing and foliation of these granites are most pronounced along the contact with the Namaqualand batholith in the area of most abundant pegmatites.

The Intruding Body. The Namaqualand batholith is represented along its northern border in the Orange River area by a series of acid rocks, the most common of which is a red aplitic granite, that Gevers (1936, p. 337) judges to be the marginal facies of the batholith. This in turn grades southward into the typical biotite-gneiss of the main intrusive mass. Deep erosion has removed most of the original roof features of the batholith, and the exposed pegmatites are those formed along the sides and interior of the source intrusive.

Pegmatites

Interior. The interior pegmatites are numerous and consist mostly of narrow veins and veinlets that are barren of the rarer minerals and are but slightly altered. Mineralization consists almost entirely of the "essential" minerals of the early magmatic period ---- beta-quartz, microcline, some muscovite, red garnet, and scattered small crystals of black tourmaline and beryl.

Marginal. The marginal pegmatites are somewhat less numerous than the exterior ones and are confined to a zone on the intrusive side of the contact which is relatively narrow compared with the wide band occupied by the exterior pegmatites. They may be distinguished from the exterior pegmatites chiefly by their distribution and generally less extensive alteration and mineral variety.

Exterior. The exterior pegmatites occur in great abundance in a zone having a maximum width of 10 miles. They contain the great majority of the rarer minerals, the variety and abundance of which decreases away from the contact with the batholith. They are intruded into the older consolidated portions of the parent rock as are the marginal pegmatites, and are dike-like, pod-like, or completely irregular in shape. The majority of them cut across the intrusive contacts, foliation, and schistosity of the country rocks. Gevers (1937, p. 342) notes that few individual bodies have extent in depth, but the total vertical range of pegmatite exposures is over 2,000 feet with little variation in mineralogy.

Of intermittent occurrence among the exterior pegmatites are large, dike-like bodies, 100 to 150 feet wide and as much as a mile long, spaced at intervals roughly one and one-half miles apart. In the space between great numbers of smaller pegmatites form intricate stockworks that extend for hundreds of feet vertically and horizontally.

Numerous tungsten-bearing, quartz-tourmaline veins occur close to the exterior pegmatites. For the most part they are located farther out from the contact than the areas containing the largest numbers of pegmatites.

Zoning

Zoning, especially in the exterior pegmatites, is of common occurrence and has strongly influenced the distribution of the minerals of the hydrothermal stages, not only within the individual pegmatites but also in the area as a whole. Gevers states (1937, p. 342)

> All minerals found in pegmatites are associated with zones of intense alteration of the original pegmatite base. The alteration is almost without exception closely connected with bodies of later alpha-quartz.

These alpha-quartz bodies, or cores located near the center or along the margin of the pegmatites, are commonly lens- or pod-shaped and occur either as a single, continuous unit or as a series of separate bodies strung out for a considerable distance within the pegmatite. The alterations may extend for several yards outward from the relatively unaffected quartz core and apparently represent hydrothermal replacement of the intermediate zones, possibly guided by the contact of the core with the intermediate zone. Nearly all of the less common minerals of the district are restricted to these zones, with the exception of red garnet and occasional small crystals of beryl.

Paragenesis

The magmatic stage of pegmatite crystallization resulted in the formation of the "essential" minerals (microcline, orthoclase, and beta-quartz) along with minor amounts of zircon, apatite, and red garnet. Later magmatic replacements of these minerals resulted in the formation of more red garnet and muscovite.

During the following hydrothermal phases quartz was constantly deposited and occurs interstitial to even the latest formed hydrothermal minerals. Black tourmaline was formed first, followed by red garnet, common beryl, apatite, columbite-tantalite, the rare earth minerals (euxenite, monazite, xenotime, and polycrase), albite, and spodumene. Albitization, accompanied by the formation of spodumene, was the dominant alteration process during the earlier hydrothermal period, but gave way in the later stages to muscovitization accompanied by the deposition of lepidolite which replaced the feldspars, tourmaline and spodumene. In the later stages were formed lithiophyllite, scheelite, the sulphides, molybdenite, bismuthinite, and chalcopyrite, and also the quartz-tourmaline veins containing scheelite and apatite. These veins frequently have pegmatitic portions.

Evaluation

The abundance of the less common minerals in the Namaqualand pegmatites appears to vary directly with the distance of the pegmatites from the zone of contact between the batholith and the country rock. The marginal pegmatites which are located on the intrusive side of the contact, have a markedly smaller number of minerals than do the exterior ones located within the wide contact zone. Again, as the distance of the exterior pegmatites from the contact zone becomes greater, the number of minerals becomes less.

With the exception of the scheelite and apatite occurrences which are restricted to the quartz-tourmaline veins outside of the zone of abundant pegmatites, there does not appear to be a regional distribution of minerals in the area, with one group of minerals more characteristic than another in mappable units as mineral zones. Mineral distribution is more distinctly divisible upon the basis of abundance rather than variety. Gevers observes (p. 341) that the very large marginal and exterior pegmatites do not have significant amounts of the rarer minerals and that the same is true at localities where the smaller pegmatites occur in the greatest numbers.

Zoning within the pegmatites is most pronounced in and close to the contact between the batholith and the country rock and has directly influenced the kind, number, and localization of the hydrothermal minerals in the complex pegmatites of the region.

Eight Mile Park Pegmatites

General Statement

The Eight Mile Park pegmatite area is in Fremont County, Colorado, a few miles west of Canon City on the north rim of the Royal Gorge of the Arkansas River. It has an areal extent of approximately 25 square miles. The abundant pegmatites lie in the zone of contact between the Pikes Peak granite batholith of probable middle Proterozoic age (Heinrich, 1948), and the much metamorphosed Idaho Springs formation. The locality has been briefly discussed by Bastin (1910), Finlay (1916), and Landes (1935), and was visited by the author in April of 1947. The only detailed study of the pegmatites is that made by Heinrich in 1947.

The pegmatites are simple and complex. Muscovitization is the most characteristic alteration process, but during the hydrothermal phases the pre-existing minerals were locally replaced by large amounts of feldspar and abundant beryllium and lithium minerals.

The Idaho Springs formation, which is the oldest rock in the area, was intensely metamorphosed into schist and later intruded by mafic sills before intrusion of the Pikes Peak granite. Injection of dikes and sills of aplitic material took place during the final consolidation of the granite mass and preceded the intrusion of the pegmatites. The pegmatites were emplaced along fracture sets in the granite as dikes and sills, and in the schist country rock as dikes parallel to the foliation. Accompanying the emplacement of the pegmatites numerous dikes of diabase were intruded along fractures in both the granite and the schist. The pegmatite period was succeeded by distinctly later mild hydrothermal activity that resulted in the deposition of a few barren quartz veins.

Rock Descriptions

The Invaded Rocks. The Idaho Springs formation was greatly affected by the intrusion of the Pikes Peak granite and a wide band of injection gneiss was formed in it by lit-par-lit action adjacent to the contact. Both pegmatitic and aplitic material are present in the gneiss. The aplite is most abundant toward the gradational boundary between the gneiss and the schist, but toward the contact with the granite, the pegmatitic material predominates. The schist has a higher content of biotite near the granite as well as large amounts of microcline and quartz. A noteworthy feature is the presence of a relatively undisturbed belt of schist about one-half mile wide immediately adjacent to the contact with the batholith.

The Intruding Body. The Pikes Peak granite is part of a batholith some 2,500 square miles in area in the southern part of the Colorado Front Range. The granite of the Eight Mile Park area, which is separated from the main igneous mass by faulting and intrusion of the later Cripple Creek granite, is a coarse-grained, porphyritic rock containing phenocrysts of microcline in a groundmass of quartz, oligoclase, and biotite. The accessory minerals include allanite, sphene, apatite, and magnetite, but the fluorine minerals common in other parts of the batholith are absent. Primary foliation, reduced grain-size, and an absence of phenocrysts are characteristic features along the contact with the Idaho Springs formation.

Pegmatites

Interior. The majority of the interior pegmatites are of dike-like form, a few inches to two feet wide, and occur in swarms cross-cutting the surrounding rock. They consist chiefly of microcline, quartz, and muscovite, and like the interior pegmatites of the Namaqualand area, they are essentially lacking in the rarer minerals of the district.

Marginal. Most of the marginal pegmatites are poorly differentiated, sheet-like bodies that were injected along fractures perpendicular to the general trend of the flow structure in the granite. Chemically and mineralogically they are much like the surrounding rock and have had little or no reaction with it along their margins. Except for a few pegmatites in which later hydrothermal reactions produced a limited number of the less common minerals, the marginal pegmatites did not proceed beyond the magmatic stages. The "essential" minerals are quartz, and blocky microcline, with varying amounts of muscovite, oligoclase, biotite, black tourmaline and red garnet.

Exterior. The exterior pegmatites may be divided into two groups: those in the schist and those in the injection gneiss. The pegmatites in the undisturbed Idaho Springs schist are tabular to lens-like in form, and were intruded parallel to the foliation of the surrounding rock. The largest pegmatites are close to the contact with the Pikes Peak granite. The others decrease in size and increase in abundance toward the contact with the injection gneiss. The pegmatites in schist have a more extensively developed hydrothermal phase than the marginal pegmatites of the granite. The minerals most widely developed include the plagioclases (oligoclase, albite-cleavelandite), muscovite, biotite, garnet, beryl, black tourmaline, and, toward the contact with the injection gneiss, considerable amounts of euhedral magnetite. The exterior pegmatites in schist, in contrast with the marginal pegmatites, had some reaction with the surrounding rock. They formed tourmaline metacrysts and caused recrystallization of mica in the schist.

The pegmatites of the injection gneiss are of finer-grain than most of the pegmatites of the area and are extremely irregular in shape and size. The chief minerals are quartz and microcline, with magnetite crystals in considerable abundance, and subordinate amounts of muscovite, biotite, and garnet.

Zoning

The general principles of zoning as discussed earlier in this paper are well illustrated in the Eight Mile Park area.

The tabular interior pegmatites have narrow cores of massive quartz and microcline surrounded by outer zones of fine-grained quartz and microcline with accessory black tourmaline and oligoclase. The sheet-like marginal pegmatites have gradational rather than clearly defined boundaries between the zones. Cores of massive quartz and microcline are patchily distributed in the central part of these pegmatites and are surrounded by the intermediate zone which is composed of quartz, microcline, and muscovite, with occasional euhedral crystals of graphic granite. A wall zone of variable thickness is commonly present and consists of fine-grained quartz, microcline, and mica (biotite or muscovite).

The exterior pegmatites in schist have cores of massive quartz with variable amounts of pure microcline occurring in large crystals. The intermediate zone may consist of two phases (Heinrich, 1947), one of which is composed of quartz grains and muscovite flakes in parallel arrangement, and the other consists of microcline and quartz in graphic intergrowth. The wall zones are well-developed in some of the exterior pegmatites and, as in the marginal pegmatites, are made up of fine-grained microcline, quartz, and muscovite. Border zones are sometimes present and are narrow, irregular selvages of mica flakes deposited perpendicular to the walls of the pegmatite along with variable amounts of quartz.

Paragenesis

During the magmatic stage the zones within the pegmatites were developed, and crystallization took place inward from the margins. The quartz-muscovite border zones were the first to form and were followed by the deposition of oligoclase, black tourmaline and garnet in the intermediate zones. The magmatic stage ended with consolidation of the cores.

Heinrich (1947) divides the hydrothermal stage into two major phases. The first phase developed great quantities of muscovite, large amounts of feldspars (chiefly oligoclase and albite), and minor amounts of biotite, garnet, beryl, black tourmaline, apatite, triplite, columbite, chalcocite, and, in the pegmatites near the injection gneiss, considerable magnetite. The second phase was marked by the deposition of lepidolite, sericite, and cleavelandite, and minor amounts of beryl, lithium, tourmalines, fremontite, torbernite, and several sulphides.

The hydrothermal solutions were guided by fractures in the pegmatites, and the greatest number of the rarer minerals were deposited along the footwall of the core.

Evaluation

The pegmatites have marked differences in characteristics as their distance from the granite source body increases, and some show indications of having had a chemical and mineralogical influence upon the rock they intrude. Some wall rock contamination is suggested by the presence of andesine instead of oligoclase in those interior pegmatites that cut across bodies of gabbro.

The exterior pegmatites in schist have a much more extensive degree of hydrothermal mineralization than do the marginal pegmatites, while the exterior pegmatites in the injection gneiss are nearly as simple in composition as the interior pegmatites. This condition suggests that the degree of hydrothermal mineralization was in part controlled by the structure of the injected country rock, and that the foliation of the schist provided the best channelways for the pegmatite solutions.

Zoning in the Eight Mile Park pegmatites is simply but clearly developed in the interior tabular pegmatites, present but gradational in the marginal pegmatites, highly developed in the exterior pegmatites in schist and apparently non-existent in the exterior pegmatites of the injection gneiss.

Regional distribution of minerals is characterized by the development of magnetite in pegmatites near and in the injection gneiss, and its absence in the pegmatites in and near the granite. This suggests that the magnetite was derived by the reaction of the intruding granite upon the Idaho Springs schist, and that it was not an abundant original constituent of the Pikes Peak magma in the Eight Mile Park locality.

Erongo Pegmatites

General Statement

The tin-bearing pegmatites of the Erongo district are located in the vicinity of the Erongo Mountains, northwestern Damaraland in South-West Africa (Gevers and Frommurze, 1929b). They are distributed in three well-defined, parallel belts, 25, 60, and 80 miles long, each ranging in width from three to ten miles.

The exposed complex pegmatites are associated with small granite bodies of phacolithic shape intruded into intensely folded schists around the margins of still larger granite bodies. Tourmalinization with the development of greisen and extensive deposition of cassiterite where tourmaline is not present are the most characteristic mineralogical features of the district.

The ancient Archean sedimentary Schist Formation of South-West Africa is the oldest rock unit in the district (Gevers and Frommurze, 1929a, p. 37). The schist was much disturbed by at least two periods of major folding and was intruded at several times by a wide variety of igneous rocks. The sequence of major events is as follows:

1. Sedimentation terminated by folding and metamorphism.
2. Discordant intrusion of gneissose granite during folding.
3. Concordant intrusion of the Salem magma series and its

pegmatite-producing differentiates during the close of the Archean.

4. Erosion and deposition of sediments followed by more folding.
5. Intrusion of the non-pegmatitic Erongo igneous series accompanied by various extrusives.

The resulting regional geology is very complex and probably represents the root zone of an Appalachian type orogenic belt (Gevers, 1942, p. 138). The pegmatite-producing Salem granites were concordantly intruded under tectonic control in close accord with the structural features of the country rock.

Rock Descriptions

The Invaded Rocks. The Schist Formation may be divided into three rock units: a lower quartzite, a middle marble series, and an upper mica schist. The quartzite is phyllitic, well-bedded, and grades downward into massive arkose that has acquired a gneissose character through metamorphism. The marble series consists of a main band of thoroughly recrystallized limestone about 1,000 feet thick overlying the quartzite, and many smaller units intercalated with the quartzites and the overlying mica schist. The marbles and quartzites are very resistant rocks and rarely contain pegmatites.

The thick series of schists make up most of the country rock and contain the greatest number of pegmatites. The schists are predominately biotitic in composition, but contain variable amounts of muscovite, quartz, hornblende, and chlorite. Where alteration has been less intense, they are represented by phyllites, slates, and shales.

The Intruding Body. The igneous rocks of the Salem granite magma series crop out in roughly oval-shaped to elongate bodies with extremely irregular borders. The pegmatite-producing rock is characteristically a porphyritic, coarse-grained, biotite granite with phenocrysts of orthoclase and microcline, and accessory muscovite, zircon, apatite, and topaz. Primary flow structure has been developed along the contacts with the country rocks. Gevers and Frommurze (1929a, p. 38) have divided the granite into a series of differentiates in which each successive type is more acid and intrudes the preceding ones. The later granites contain greater amounts of quartz, microcline, muscovite, and black tourmaline, and are finer-grained and non-porphyritic in texture.

Pegmatites

Interior. Erosion has not progressed deep enough to expose the small, tabular simple pegmatites of the deep interior of the igneous mass. However, their composition may be reflected in the large, dike-like masses of late-differentiated, pegmatitic granite that is emplaced near the contacts of the earlier granite masses, and that is, in turn, intruded by true pegmatites. The pegmatitic granite, which in places also grades into true pegmatite, contains large quantities of muscovite and replacements of quartz by black tourmaline. Garnets are abundant in the pegmatite granite and wherever present reflect the chemical nature of the intruded country rock. The majority are the iron (almandite) or manganese (spessartite) varieties, but where the pegmatitic granite invades marble, calcium (grossularite) garnets are developed.

Marginals. The marginal pegmatites are very distince in mineralogy and general relationships from the exterior pegmatites. They are generally of dike-like form and occupy joint planes that parallel the general strike of the country rock outside the granite. The "essential" minerals are potassium feldspar, beta-quartz, and early tourmaline. Albite and microcline occur in perthitic intergrowth and graphic granite is common. Black tourmaline is also the most characteristic mineral of the hydrothermal stage, replaces both feldspar and quartz, and may be accompanied by minor amounts of muscovite or biotite and variable amounts of red garnet. In the marginal pegmatites there are extremely rare occurrences of black cassiterite intimately intergrown with tourmaline, and both minerals appear to have been deposited at the same time.

Exterior. Exterior pegmatites occur in greatest numbers close to the granite contact and are tabular to lens-like in shape. All but a few occur in schists intruded along foliation or original bedding planes, and are most abundant where the schist dips steeply.

The "essential" minerals consist of potassium feldspar, beta-quartz and albite, where tourmaline is almost entirely absent. Albite commonly occurs as a micro-perthitic intergrowth with microcline and was formed extensively throughout the post-magmatic stages as well. Hydrothermal activity was intense and formed black tourmaline, the almandite-spessartite garnets, topaz, and some cassiterite in the first phases. The later phases deposited large amounts of muscovite, lepidolite, cassiterite, albite, and lenses of alpha-quartz, and minor amounts of tantalite, wolframite, lithium tourmaline, triplite, lazulite, and sulphides (argentiferous bismuthinite, molybdenite, and arsenopyrite).

Zoning

Zoning is fairly well-developed in both the marginal and the exterior pegmatites and has greatly influenced the distribution of minerals within them. The cores are lens- or stringer-like bodies of quartz, that occurs either pure or with variable amounts of potassium feldspar. The intermediate zones were originally composed of quartz and feldspar and have been extensively albitized and locally replaced by muscovite and lepidolite. The wall zones are more or less continuous along one or both sides of the tabular pegmatites and in the exterior ones have been widely replaced by muscovite, lepidolite, and cassiterite in bands and patches parallel to the wall. Gevers (1940, p. 140) notes that wall zone replacement is nearly equal on both sides of steeply dipping tabular bodies in schist, but in those with less dip replacement is confined mostly to the hanging wall.

Paragenesis

The magmatic stage developed the "essential" minerals, beta-quartz, and potassium feldspar. Later albite and quartz replaced microcline to form perthite and graphic granite, and at that time some garnet and black tourmaline formed and zoning was established. The magmatic stage graded into the hydrothermal stage without any perceptible discontinuity in the process of pegmatite formation.

The characteristics of the various phases during the hydrothermal stage vary over the area. In nearly all cases albitization was the dominant process, with black tourmaline, the spessartite-almandite garnets, topaz and minor cassiterite, as the earliest replacement minerals. In the exterior pegmatites, tin, and minor amounts of tungsten and tantalite were deposited as oxides during extensive replacement of feldspars by muscovite and lepidolite. Lithium tourmaline, triplite, lazulite and very minor amounts of sulphides were deposited last.

The hydrothermal stage was more limited in the marginal pegmatites and black tourmaline, mica, and garnet were the chief minerals.

Evaluation

Plastic deformation of limestone, differential movement along bedding planes in the schist, absence of major faulting, and the invariable injection of the exterior pegmatites into contorted portions of the country rock indicate that pegmatite emplacement took place at great depth and under stress that was active during intrusion.

The Salem granite batholith is at present exposed in the acrobatholithic stage (Emmons, 1940, p. 189) and erosion of the cupola features is not yet deep enough to penetrate the hood portions. This is indicated by the scattered distribution of the isolated bodies of parent granite; the abundance of the greisen minerals (tourmaline, topaz, and zircon) in the granite --- a feature to be expected in an earlier consolidated hood; the extensive hydrothermal aureole surrounding the granite outcrops; the conformable nature of the intrusives; the marked absence of barren, interior-type pegmatites.

The areal distribution of tin and tourmaline with respect to the granite bodies indicates that the two minerals have mutually excluded one another during pegmatite crystallization. Tourmaline not only occurs in great quantity in the marginal pegmatites, but is also abundant in the surrounding granite, and tin is almost entirely absent. In the exterior pegmatites cassiterite in the dominant mineral and tourmaline is subordinate.

In general, hydrothermal activity has been most intense in the exterior pegmatites closest to the granite and gradually decreases in intensity away from it.

Other Pegmatite Districts

General Statement

Many features of distribution, structure, and mineralogy of the Namaqualand, Eight Mile Park, and Erongo pegmatites are duplicated in other areas. Two of these districts, Spruce Pine, North Carolina, and Preissac-La Corne, Quebec, are summarized in the following paragraphs.

Spruce Pine Pegmatites

The country rocks in the Spruce Pine district of North Carolina (Olson, 1944), consist of much-folded mica and hornblende schist and gneiss, and some thoroughly recrystallized marble. The pegmatite-producing intrusive is a pegmatitic granite of alaskite composition that crops out in three extremely irregular units, each surrounded by a broad band of migmatite. The alaskite is massive, generally uniform in texture, but has slight foliation developed along the contacts with the country rock. It is composed of a very coarse-grained mixture of oligoclase, quartz, microcline, and muscovite, and it is notably lacking in the iron and magnesium minerals.

The encircling migmatite is somewhat similar to the Eight Mile Park injection gneiss and consists of schist and gneiss that has been widely injected by pegmatitic material along the planes of foliation.

The interior pegmatites occur well inside the contact between the alaskite and the country rocks, are extremely irregular in shape, and grade into the surrounding rock without clearly defined boundaries. The mineralogy is essentially the same as that of the alaskite, and the pegmatites are distinguished chiefly by their larger grain size and texture.

The marginal pegmatites farthest from the contact cannot be well distinguished from the interior pegmatites, but as the margin of the granite is approached they acquire a tabular shape, develop well-defined boundaries, and contain increasing amounts of hydrothermal minerals. The marginal pegmatites were apparently injected into fractures in earlier consolidated marginal alaskite, unlike those pegmatites in the interior which completed the process of consolidation almost simultaneously with the enclosing rock. Hydrothermal alteration was fairly extensive and developed abundant green muscovite and albite, as well as a limited suite of the rarer minerals.

The exterior pegmatites are sheet-like or tabular in form, largely because they were injected in great numbers conformable to the foliation of the country rocks. The mineralogy is markedly different from that of the marginal pegmatites. Oligoclase is the dominant plagioclase and increases in proportion with respect to albite as the distance from the batholith increases. Potassium feldspar is subordinate, and green mica is fairly common near the igneous body. Ruby mica, which is characteristically developed in pegmatites that occur in kyanitic schist, increases with distance from the contact. Biotite, absent in the interior and marginal pegmatites, appears in quantity at considerable distances from the intrusive, along with an extensive suite of rare minerals.

Preissac-La Corne Pegmatites

The pre-Cambrian pegmatites of the Preissac-La Corne area (Norman, 1945), Abitibi County, Quebec, are in a district north of the Kirkland Lake-Bourlamaque gold belt which contains several molybdenite vein deposits. The pegmatites are genetically related to two bodies of garnetiferous, biotite-muscovite granites. The latter intrude country rock consisting of metamorphosed and folded Archean volcanics and sediments that were invaded by thick, sill-like masses of pre-granite peridotite.

The granite bodies are nearly identical in composition. The larger one, called the La Motte intrusive, is approximately 25 square miles in area and has a marginal zone one-half to one mile wide in which pegmatite bodies make up fifty percent of the rock. The foliated mass, roughly oval in outline, grades into the country rock in alternating bands of granite and schist. The smaller Preissac mass is about half the area of the La Motte. It is massive, unfoliated and has an abrupt contact with the country rock.

The interior pegmatites are of two types --- narrow, dike-like bodies with sharp contacts and simple mineralogy, and larger irregularly-shaped, replacement and segregation units that grade into the enclosing granite. These pegmatites consist of microcline, albite, perthite, quartz, muscovite, and minor garnet.

Marginal pegmatites are fairly abundant and occur as irregular, branching, tabular bodies several feet wide commonly emplaced parallel to the granite contact. Some of them are well-zoned, a feature which largely controlled the localization of the hydrothermal stage minerals within the pegmatites. The chief minerals are quartz and muscovite associated with considerable quantities of perthite and graphic granite. The hydrothermal stage minerals include red garnet, chrome spinel, tantalite, beryl, and molybdenite in varying amounts.

The exterior pegmatites occur at intervals for a distance of several miles from the larger granite body and are tabular or dike-like with respect to the country rock. They have little zoning and are composed chiefly of albite, microcline, quartz, and spodumene, together with minor amounts of muscovite, beryl, and tantalite-columbite.

The granite outcrops may represent the cupola features of an underlying batholith. This possibility is suggested by the difference in texture between two other wise identical granite bodies. The larger foliated mass may be eroded to a greater relative depth than the smaller one. Additional evidence is offered by the wide distribution of the spodumeme-bearing exterior pegmatites, which undoubtedly have a connection with a granitic mass below the present surface.

Conclusions

The pegmatites of Namaqualand, Eight Mile Park, Erongo and other districts have certain features of structure, mineralogy and distribution that are criteria for dividing pegmatites into three spatial groups, interior, marginal and exterior, with respect to their distance from the source intrusive. These characteristics may be applied to pegmatites in districts where the actual spatial relations to the parent igneous body are obscure. The criteria, as demonstrated in the areas discussed, are summarized as follows:

Interior Pegmatites

1. Interior pegmatites occur in the central portions of the source intrusive and are most abundant in the upper and outer portions of the "core".

2. They may have any shape or size but the three most important types are:

a. Small, tabular, dike-like or sill-like bodies that have sharp contacts with the surrounding rocks.

b. Pipe-like to prolate-spheroid segregation pegmatites that have gradational boundaries with the enclosing granite as at Preissac-La Corne and the Quincy granite of Massachusetts (Warren and Palache, 1911).

c. Pegmatitic facies of the parent granite as in the Erongo district. These facies may comprise a large part of the intrusive body as they do in the Harney Peak granite of the Black Hills.

3. They are irregularly distributed through the interior of the batholith, and occur as isolated units, swarms of dikes and sills, or networks of anastomosing veins. The segregation pegmatites occur farther from the margins of the intrusive than do the majority of the tabular bodies.

4. The mineralogy is simple and essentially the same as that of the surrounding rock. The chief constituents are quartz and microcline, with variable amounts of later magmatic minerals such as the plagioclases, muscovite, black tourmaline, garnet and beryl.

5. Zoning may be present, but as in Eight Mile Park it is not complex and consists chiefly of an irregular core of massive quartz, or quartz and microcline, surrounded by a finer-grained zone of the same minerals.

Marginal Pegmatites

1. Marginal pegmatites occur within the intrusive, but are

restricted to the "hood" portions and are less widely distributed than interior and exterior pegmatites.

2. Contacts with the surrounding rock are sharp and little contact metamorphism is developed.

3. The most common forms are of two types: tabular, dike-like or sill-like bodies, and pod-shaped to lens-shaped units. In the Preissac-La Corne area the marginal pegmatites are irregular to tabular and are commonly diaschistic. Those of Eight Mile Park are sheet-like. They form dikes in Namaqualand and sills in Erongo with respect to the country rock.

4. They may be emplaced at any angle to the primary foliation of the parent body or its contact with the country rock, but in a given locality these relations are more or less uniform. At Preissac-La Corne the pegmatites parallel the contact of the granite with the country rock. They are at right angles to foliation in Eight Mile Park, while in Namaqualand they cut the primary foliation and parallel the general strike of the country rocks. In Erongo they parallel primary flow structure as well as the country rock contact.

5. The mineralogy is simple or complex. The hydrothermal stage is well-developed in Erongo, but in most districts it is more feeble than that of the exterior pegmatites. Graphic granite, perthite, plagioclases and muscovite may be extensively developed

as in Eight Mile Park, Preissac-La Corne and Spruce Pine. The rarer minerals of these districts are present in the marginal pegmatites to a limited degree.

6. Zoning is commonly well-developed but the contacts between zones are often gradational as in Eight Mile Park and Preissac-La Corne.

7. At Spruce Pine there is a change in mineralogy, texture, and form with distance from the contact until they become indistinguishable from the true interior pegmatites.

Exterior Pegmatites

1. Exterior pegmatites include all those that occur outside the granite body.

2. They are most abundant in the "roof" region above and along the upper sides of the batholith and diminish in number away from the source intrusive.

3. Tabular, lens-shaped and pod-like bodies are the most common forms. Lit-par-lit relations may be developed where the country rocks are schistose.

4. Few have much extent in depth, and the largest bodies occur closest to the contact of the granite with the country rock, as in the Eight Mile Park area.

5. Zoning reaches its greatest development in these pegmatites.

A fine-grained border zone may be produced along the contact with the country rock as well as several intermediate zones as in the Petaca and Eight Mile Park districts.

6. Structural control of emplacement by the country rock is often established as in Erongo, Eight Mile Park and Spruce Pine, but in Namaqualand and Preissac-La Corne the pegmatites cut the structural trends of the country rock. As a rule the majority of exterior pegmatites in a given district have the same general relationship to the structure of the country rock.

7. The majority have a simple mineralogy but the hydrothermal stage may produce a complex paragenetic sequence in some districts and develop a great variety of rare minerals.

8. Contact effects with susceptible country rocks sometimes occur. In Eight Mile Park the pegmatites have added material to the country rock in some cases, and in others have acquired material from it.

9. Exterior pegmatites may develop characteristic minerals at restricted distances from the batholith, as indicated by the distribution of biotite, green mica, ruby mica and the plagioclases at Spruce Pine, and the occurrences of cassiterite and tourmaline in Erongo.

10. In all cases the intensity of hydrothermal activity and the abundance and variety of minerals decreases with distance from the source intrusive.

References Cited

Ahlfeld, F. (1936) The Bolivian tin belt, Econ. Geol., Vol. 31, No. 1, p. 48-72.

Alling, H.L. (1932) Perthites, Amer. Mineral., Vol. 17, No. 2, p. 43-65.

Anderson, A.L. (1933) Genesis of mica pegmatite deposits, Latah County, Idaho, Econ. Geol., Vol. 28, No. 1, p. 41-58.

Baldauf, R., and Beck, A. (1910) Ueber das Kryolith Vorkommen in Grönland, Zeitschr. prakt. Geol., Vol. 18, p. 432-446.

Balk, R. (1937) Structural behavior of igneous rocks, Geol. Soc. Amer., Mem. No. 5, 117 pp.

Bastin, E.S. (1910) Economic geology of the feldspar deposits of the United States, U.S. Geol. Survey, Bull. 420.

------------ (1911) Geology of the pegmatites and associated rocks of Maine, U.S. Geol. Survey, Bull. 445.

Bjørlykke, H. (1937) The granite pegmatites of southern Norway, Amer. Mineral., Vol. 22, No. 4, p. 241-255.

Bowen, N.L. (1933) The broader story of magmatic differentiation briefly told, A.I.M.M.E., Lindgren Volume, p. 118-122.

Broedel, C.H. (1937) Structure of the gneiss domes near Baltimore, Maryland, Md. Geol. Survey, Bull., Vol. 13, Pt. 3, p. 151-187.

Cook, C.W. (1925) Molybdenite deposit near New Ross, Nova Scotia, Econ. Geol., Vol. 20, p. 185-188.

Darton, N.H. and Paige, S. (1924) Central Black Hills folio, South Dakota, U.S. Geol. Survey Folio 219.

Duncan, G.S. (1913) Contribution to the study of the pre-Cambrian rocks in the Harney Peak district, South Dakota, A.I.M.M.E., Transactions, Vol. 43, p. 207-218.

Emmons, W.H. (1933) On the mechanism of the deposition of certain metalliferous lode systems associated with granitic batholiths, A.I.M.M.E., Lindgren Volume, p. 327-349.

--------- (1940) Association of metalliferous lodes and igneous rocks, Principles of Econ. Geol., McGraw-Hill Book Co., Ch. 15.

Fenner, C.N. (1933) Pneumatolytic processes in the formation of minerals and ores, A.I.M.M.E., Lindgren Volume, p. 58-105.

Fersmann, A.E. (1931) Über die geochemische-genetische Klassifikation der Granitpegmatite, Tscherm. Min. Petr, Mitt., Vol. 41, No. 1.

Finlay, G.I. (1916) Colorado Springs folio, Colorado, U.S. Geol. Survey Folio 203.

Gevers, T.W. (1936) Phases of mineralization in Namaqualand pegmatites, Geol. Soc. S. Africa, Transactions, Vol. 39, p. 331-378.

------------ (1942) The tin-bearing pegmatites of the Erongo area, South-West Africa, Ore Dep. and Structural Features, Newhouse, Natl. Res. Council, p. 138-140.

------------, and Frommurze, H.F. (1929a) The geology of North-Western Damaraland, in South-West Africa, Geol. Soc. S. Africa, Transactions, Vol. 32, p. 31-55.

-----------, -------------- (1929b) The tin-bearing pegmatites of the Erongo area, South-West Africa, Geol. Soc. S. Africa, Transactions, Vol. 32, p. 111-150.

-----------, Partridge, F.C., and Joubert, G.K. (1936) The pegmatite area of Namaqualand, Un. S. Africa. Geol. Survey, Mem. 31.

Gratacap, L.P. (1916) Some minerals from Madagascar as described in Prof. A. Lacroix's "Mineralogie de la France et ses Colonies". Amer. Mineral., Vol. 1, No. 2, p. 17-33.

Graton, L.C. (1940) Nature of the ore-forming fluid, Econ. Geol. Vol. 35, No. 2, (supplement), p. 197-358.

Heinrich, E. Wm. (1947) Geology of the Eight Mile Park pegmatite area, Colorado, Unpublished Ph.D. Thesis, Harvard University, May 1947.

----------- (1948) Oral Communication, University of Michigan, April 1948.

Hess, F.L. (1925) The natural history of pegmatites, Engr. & Min. Jour.-Press, Vol. 120, No. 8, p. 289-298.

Ingerson, E., and Morey, G.W. (1940) Nature of the ore-forming fluid (a discussion), Econ. Geol., Vol. 35, No. 6, p. 772-785.

Jahns, R.H. (1946) Mica deposits of the Petaca district, Rio Arriba County, New Mexico, N. Mex. Bur. Mines and Min. Res., Vol. 25, 294 pages.

Kelley, V.C. and Branson, O.T. (1947) Shallow, high temperature pegmatites, Grant County, New Mexico, Econ. Geol., Vol. 42, No. 8, p. 699-712.

Kynaston, H. and Mellor, E.T. (1909) The geology of the Waterberg Tin-fields, Transvaal Geol. Survey, Mem. 4.

Landes, K.K. (1925) The paragenesis of the granite pegmatites of Maine, Amer. Mineral., Vol. 10, No. 11, p. 355-411.

Landes, K.K. (1928) Sequence of mineralization in the Keystone, South Dakota, pegmatites, Amer. Mineral., Vol. 13, No. 10, p. 519-530; No. 11, p. 537-558.

------------ (1933) Origin and classification of the pegmatites, Amer. Mineral., Vol. 18, No. 2, p. 33-55; No. 3, p. 95-103.

------------ (1935) Colorado pegmatites, Amer. Mineral., Vol. 20, p. 319-333.

------------ (1937) Pegmatites and hydrothermal veins, Amer. Mineral., Vol. 22, No. 5, p. 551-560.

------------ (1942) Effect of structure on intrusion of pegmatites, Ore Dep. and Structural Features, Newhouse, Natl. Res. Council, p. 140-143.

Lindgren, W. (1926) Replacement in the tin-bearing veins of Caracoles, Bolivia, Econ. Geol., Vol. 21, No. 2, p. 135-144.

McLaughlin, T.G. (1940) The pegmatite dikes of the Bridger Mountains, Wyoming, Amer. Mineral., Vol. 25, No. 1, p. 46-68.

Müllbauer, F. (1925) Die Phosphatpegmatite von Hagendorf in Bayern, Zeits. Krist., Vol. 61, p. 318-336.

Norman, G.W.H. (1945) Molybdenite deposits and pegmatites in the Preissac-La Corne area, Abitibi County, Quebec, Econ. Geol., Vol. 40, No. 1, p. 1-17.

Olson, J.C. (1944) Economic geology of the Spruce Pine pegmatite district, North Carolina, N.C. Dept. Conservation, Bull. 43, Pts. 1 and 2.

Oppenheim, V. (1948) The Muzo emerald zone, Colombia, Econ. Geol., Vol. 43, No. 1, p. 31-48.

Rogers, A.W. (1914) The geology of part of Namaqualand, South Africa, Geol. Soc. S. Africa, Transactions, Vol. 4, Part 1.

Schaller, W.T. (1925) The genesis of lithium pegmatites, Amer. Jour. Sci., Vol. 10, p. 269-279.

Tolman, C. and Landes, K.K. (1939) The igneous rocks of the Mississippi Valley, Geol. Soc. Amer., Spec. Papers, p. 71-103.

Turneaure, F.S. (1947) Ore Deposits: a series of lectures and assignments given at the University of Michigan, Fall Term, 1947, Personal Notes of the Author.

Warren, C.H. and Palache, C. (1911) The pegmatites of the riebeckite-aegerite granite of Quincy, Massachusetts, Amer. Acad. Arts and Sci., Vol. 47, No. 4, p. 125-168.

Williams, G.H. (1895) Origin of Maryland pegmatites, U.S. Geol. Survey, 15th Annual Report, p. 675.