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1974, pp. 371-375. https://doi.org/10.56577/FFC-25.371

in:

Ghost Ranch, Siemers, C. T.; Woodward, L. A.; Callender, J. F.; [eds.], New Mexico Geological Society 25 th Annual Fall Field Conference Guidebook, 404 p. https://doi.org/10.56577/FFC-25

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STRUCTURAL AND PETROGENETIC RELATIONSHIPS OF PEGMATITES IN THE PETACA DISTRICT, NEW MEXICO

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INTRODUCTION

The Petaca pegmatites have been known for more than a century as commercial sources of sheet, punch, and scrap muscovite. They also have yielded, from time to time, small quantities of beryl and columbite-tantalite along with a modest abundance of specimen materials containing such other minerals as bismutite, fluorite, garnet, monazite, and samarskite. Mining operations, ranging in expression from little more than surface scrapings to pits and underground workings of considerable extent, have exposed more than two hundred of the pegmatite bodies in three dimensions. Such exposure has provided useful information concerning the distribution, form and attitude, and internal structure of these bodies.

The Petaca district lies west of the Rio Grande near the eastern margin of Rio Arriba County, in rugged country that is a southward extension of the San Juan Mountains of Colorado. It occupies a broadly curving belt, 1 to $4^{1}/_{2}$ miles wide and about 15 miles long, that can be traced from Kiawa Mountain southeastward and southward to the village of La Madera. The occurrences of principal interest lie between the Tusas and Vallecitos Rivers, mainly on Jarita Mesa and in broken canyon country that flanks this upland on the east. The pegmatites are exposed within a Precambrian terrane of igneous and metamorphic rocks that is adjoined and discontinuously veneered by volcanic and volcaniclastic rocks of Cenozoic age.

The purpose of this paper is to outline those features of the pegmatite bodies and their structural environment that are most pertinent to interpretations of origin. The broad rationale for a genetic model is indicated, but no attempt can be made in this necessarily brief treatment to describe or document it in detail.

PEGMATITES

The pegmatite bodies are highly varied in shape and size. They include dikes, sills, pipes, pods, and masses with more complex form; bulges, branches, and other irregularities are common. Some of the bodies are wholly or in part conformable with country-rock structure, but most are discordant. They range in maximum dimension from a few feet to nearly half a mile, but with an average of less than 500 feet, and in maximum thickness from a few inches to about 300 feet. Most of them are so oriented in three dimensions that observed walls are steep or vertical, but moderate to moderately steep westerly plunges also are characteristic. Thus the bodies, regardless of size or individual shape, typically have well-defined crests and keels.

Nearly all of the pegmatite masses are internally zoned, with distinctive lithologic units that are systematic in distribution. The outer parts of the bodies comprise one or more units with moderately to extremely coarse granitoid textures and that consist of potash feldspar, quartz, and albite with or without muscovite. These zones tend to be continuous, especially along crests and flanks of the bodies. In marked contrast are interior units that are much coarser grained and less continuous, and that seem to represent extreme segregation of major constituents within the pegmatite systems. Each of these units is dominated by only one or two minerals, and their order of occurrence, from flanks to cores and from crests toward keels of the enclosing bodies, is perthite graphic granite—blocky perthite—quartz and euhedral perthite—quartz. All observed keelward parts of the bodies are rich in sugary to very coarse grained albite, with or without muscovite, and concentrations of coarsely crystallized muscovite with accompanying albite commonly extend upward along the flanks of overlying quartz masses.

Accessory minerals, which are nowhere highly abundant, include beryl, bismutite, chalcocite, chalcopyrite, columbite-tantalite (Fig. 1), fluorite, galena, garnet, hematite, ilmenite, magnetite, monazite (Fig. 1), pyrite, samarskite, and tourmaline. Among others of rarer occurrence are apatite, bismuth, bismuthinite, bornite, cassiterite, covellite, cuprite, fergusonite, gadolinite, gummite, lepidolite, malachite, phenakite, phlogopite, scheelite, uraninite, and yttrotantalite. Most of these minerals are found either in massive quartz or in albite-rich pegmatite.

Evidences of mineral corrosion and replacement are widespread within all of the pegmatite bodies, and especially within their keelward parts. Albite, as both fine-grained aggregates and medium- to coarse-grained masses of cleavelandite, commonly forms pseudomorphs after perthite crystals or appears within them as cross-cutting veins with highly irregular outlines (Fig. 2). It also is present in partial replacements of

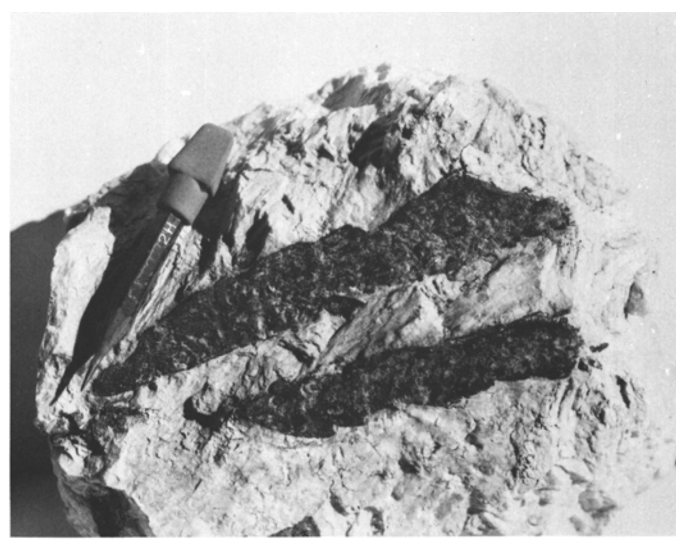

Figure 1. Feather-shaped crystals of black columbite in coarse-grained albite, Globe mine. The crystals are imbricate in form, with step-like contacts between successive platy units, and they include numerous tablets of reddish brown monazite.

Figure 2. Large fragments of perthite crystals (dark) veined and corroded by coarse-grained albite (light) along cleavage and fracture surfaces, Globe mine. The very dark specimen at upper left is deep brownish tan albite with crystals of columbite, monazite, and purple fluorite.

coarse quartz, muscovite (Fig. 3), and, at a few localities, fluorite. Associated with such albite in numerous occurrences are fine- to medium-grained aggregates of late-stage muscovite.

Despite the complexities of mineral segregation and the presence of some rarer elements in local concentrations, the pegmatite bodies differ little from many granites in their bulk composition. Analyses of bulk samples from one large body and megametric determinations on several other exposures of pegmatite indicate total compositions well within the range of alkalic granites, with SiO_2 percentages between 71 and 75 and Na_2O/K_2O ratios substantially greater than unity.

RELATIONSHIPS BETWEEN PEGMATITES AND COUNTRY ROCKS

The Petaca pegmatites occur in a Precambrian terrane of siliceous and pelitic metasedimentary rocks, silicic and basic metavolcanic rocks, and metamorphosed plutonites of grano

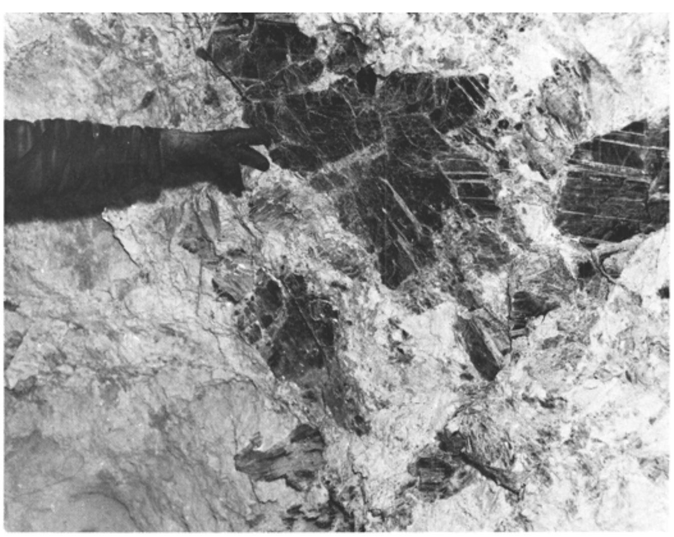

Figure 3. Large ruled books of muscovite (dark) in white albite and gray quartz, central mica shoot in Cribbenville mine.

dioritic to granitic composition. The most abundant rock types are vitreous quartzite, muscovitic quartzite, siliceous conglomerate, quartz—albite—muscovite—biotite schist, plagioclase—chlorite schist and phyllite, chlorite schist, schistose metarhyolite, amphibole schist and amphibolite, and foliated granitic rocks. The complex history of these rocks has been interpreted with different emphases and in different ways by Just (1937), Barker (1958), and Bingler (1965), but it seems clear that they reflect at least three major episodes of deformation, two episodes of regional metamorphism, and several kinds of subsequent metasomatism. They have been folded in contrasting styles and over a very wide range of scales, and many of them show effects of pervasive shearing. Two sets of folds and allied structural features appear to have played an important role in guiding emplacement of the pegmatite bodies, and in controlling their prevailing westerly elongations and plunges (Figs. 4, 5).

Evidences of both progressive and retrogressive metamorphism are widespread, and preserved expressions of maximum metamorphic grade indicate a general increase from north to south in the district. The pegmatites, though also Precambrian in age, postdate all regional metamorphism. They are no more than mildly deformed, and they are younger than numerous faults and shear zones within the older terrane (Fig. 6). A few pegmatite bodies are offset along faults (Fig. 4), and some closely spaced fractures and rows of bent or broken mica books can be traced from pegmatite into faults that transect adjoining country rocks, but these disturbances may well be Tertiary in age.

Much of the metamorphic section shows pervasive effects of metasomatism, expressed mainly by abundant muscovite in the more quartzose rocks and biotite in the amphibole-bearing rocks. Several remarkably continuous belts of finely crenulated muscovite-rich schist, tens to hundreds of feet in outcrop breadth, represent particularly intense metasomatism of quartzite and metarhyolite in several parts of the district. These micaceous belts follow bedding and foliation planes in detail, but in general they transgress the country-rock structure at acute angles. The mica concentrations, which are characteristically associated with lenses and vein-like masses of quartz, may be genetically related to nearby pegmatites, but most of the pegmatite bodies cut across both the micaceous belts and their boundaries with adjacent quartzose metamorphic rocks.

More obviously related to the pegmatite bodies are distinctive fringes and aureoles of wallrock alteration, commonly featured by a zonal distribution of minerals. The typical sequence in quartzose rocks, as traced away from the pegmatite contacts, is (1) fine-grained mica-rich rock that is unfoliated and difficult to differentiate from the pegmatite border zone, (2) muscovite-impregnated country rock with abundant small metacrysts of potash feldspar, sodic plagioclase, and muscovite in thick books, (3) country rock with muscovite-rich partings and disseminated small flakes of green muscovite, and (4) country rock with essentially no mica or with pale greenish mica in coarse, sparsely scattered flakes that define a broad schistosity. Such sequences commonly are complete over outcrop breadths of a few feet or tens of feet, but others are much more extensive (Fig. 6). Alteration sequences in amphibole-bearing country rocks generally are more limited, and are characterized by concentrations of biotite derived from amphibole and chlorite.

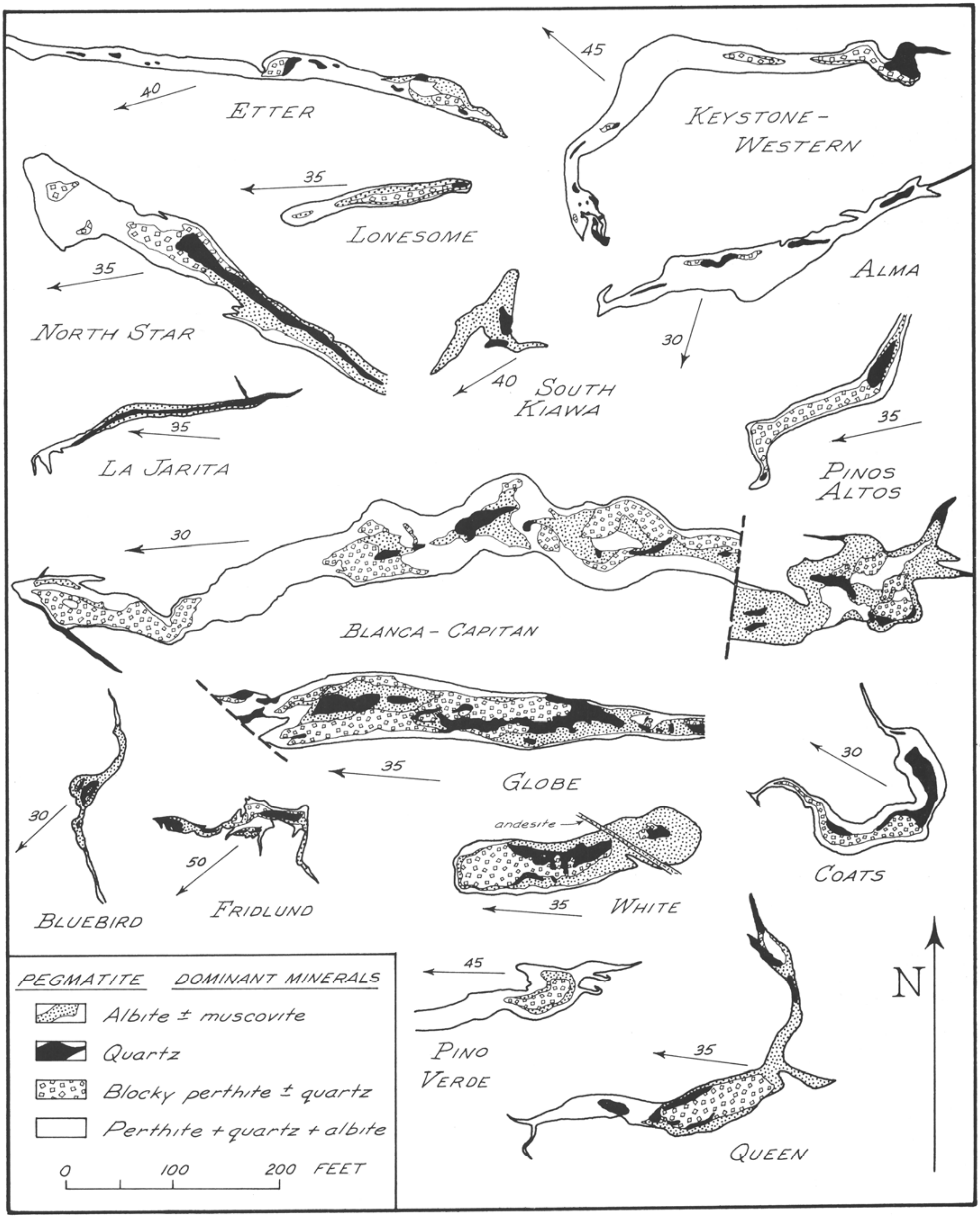

Figure 4. Simplified geologic maps of sixteen internally zoned pegmatite bodies in the Petaca district, showing typical distribution of major lithologic units as exposed at surface. Numbered arrows indicate general trend and degree of plunge of respective bodies, most of which are otherwise nearly vertical.

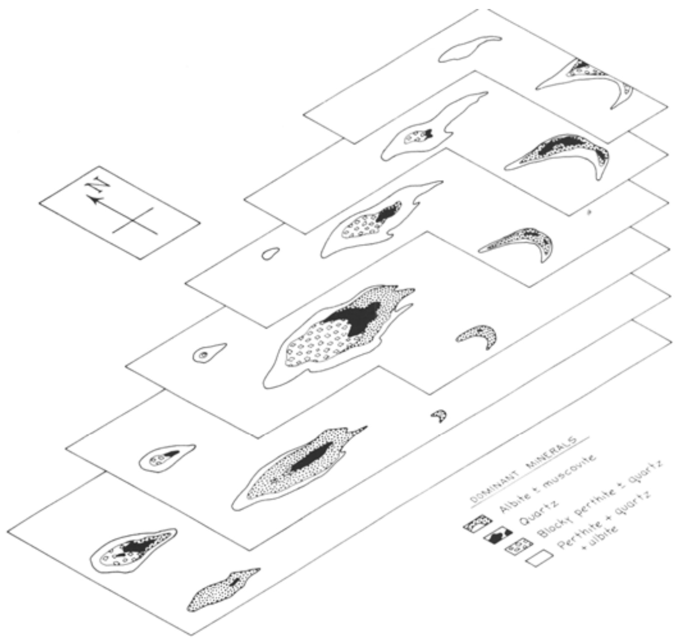

Figure 5. Isometric plate diagram of three pegmatite bodies of contrasting shapes and with moderately steep westerly plunges, showing distribution of major internal lithologic units. The three-dimensional relationships, regarded as typical for the Petaca district, are a composite from results of surface and underground mapping.

Many of the pegmatite-wallrock contacts are sharp, whereas others in effect are all but lost within the inner parts of alteration sequences of the kinds just noted. Some of the pegmatite bodies appear almost literally to have soaked through the enclosing rocks both before and during early stages of consolidation. In all occurrences, however, reactions between pegmatite and country rocks evidently had little or no influence upon development of zones and other units within the pegmatite bodies.

PEGMATITE FORMATION

It is tempting to relate the Petaca pegmatites to one or more of the granitic rocks prominently exposed in and near the district, but these rocks show unmistakable effects of metamorphism whereas the pegmatites do not. Moreover, the pegmatite bodies are not distributed in a recognizably systematic way with respect to the granitic plutons at present levels of exposure. Alternatively, the pegmatites might be regarded as products of metamorphism or metasomatism, a notion made attractive by numerous gradational contacts and aureoles of country-rock alteration. This view, however, is difficult to defend in the light of several factors that include: (1) the margins off many pegmatite bodies are sharp and cut directly across country-rock structure; (2) the adjoining country rocks commonly are bowed outward around bulges in the pegmatite bodies; (3) the bodies themselves are consistently granitic in bulk composition and show no significant compositional variations that might be related to major lithologic variations observed in immediately adjacent parts of the metamorphic terrane; (4) the bodies are distinguished by sys-

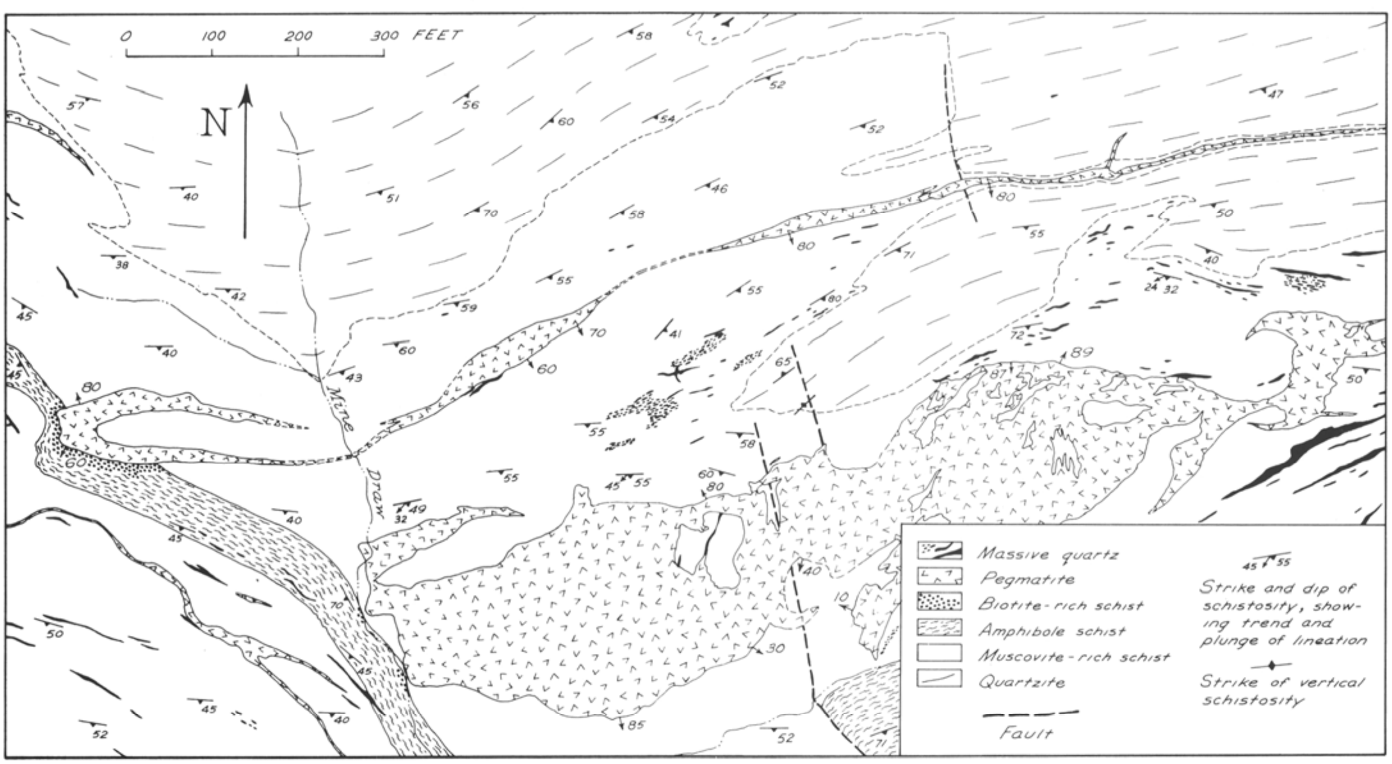

Figure 6. Simplified geologic map of a part of the Kiawa mine area, Petaca district, showing typical relationships between pegmatite and country-rock quartzite and amphibole schist. Pegmatite bodies are surrounded by aureoles of biotite-rich schist and muscovite-rich schist with numerous masses of quartz.

tematic internal zoning in which the paragenetic sequence of major minerals is consistent throughout the district; and (5) the pegmatites contain Be, Nb, Ta, Th, U, and other trace elements at levels of concentration not readily explained in terms of nearby country-rock sources.

These and other features of occurrence bespeak an igneous origin for the pegmatites, presumably involving either partial melts or rest-liquids derived from magma cooling at greater depths. To be acceptable, however, a genetic model with an igneous base must also account for extensive pegmatite-wall-rock interaction and the evident gross segregations and mineral replacements within the pegmatite bodies. Such a model, fortified by results of experimental investigations on synthetic pegmatite systems, can be briefly summarized in sequential form as follows:

1. Emplacement of silicate liquid of granitic composition, rich in water and other volatile constituents but in general not saturated with respect to an aqueous phase.
2. Limited reaction between the body of silicate liquid and the country rocks, with or without more extensive movement of alkalies and other constituents into the adjacent rocks by diffusion through an aqueous pore fluid.
3. Crystallization from the silicate liquid, with falling temperature, to form one or more granitoid units of quartz-alkali feldspar pegmatite in outer parts of the body.
4. Exsolution from the liquid of an aqueous phase of low viscosity, high mobility in the gravitational field, and effective transmissivity with respect to non-volatile constituents.
5. Progressive partitioning of constituents between silicate liquid and aqueous fluid, selective diffusion of constituents through the rising aqueous phase to form K-rich alkali feldspars and muscovite in outer and upper parts of the pegmatite body and locally in adjacent country rocks (see step 2 above), and diffusion of Si02 to form quartz mainly in central parts of the body. Concomitant crystallization of albite and quartz from the silicate liquid in all parts of the body, but maximally in its lowest parts.
6. Progressive exsolution of alkali feldspars, extensive reactions among liquid, aqueous fluid, and crystalline phases, and, following exhaustion of all silicate liquid, continued reactions among aqueous fluid and crystalline phases. Widespread subsolidus mobilization of exsolved albitic constituents, and refixing them in part at the expense of other minerals.

This model is in good accord with the gross distribution of major minerals in the Petaca pegmatites (Fig. 4). Owing to the general westward plunge of these bodies, their asymmetric internal segregation is expressed in both horizontal and vertical sections. The typical distribution of internal zones (Fig. 5) suggests that present attitudes of the pegmatite bodies are not greatly different from their attitudes at the time of consolidation. It also suggests that little of the South Kiawa body (Fig. 4), for example, remains beneath its present outcrop, whereas most parts of the original Etter, Alma, and Pino Verde bodies are yet preserved at depth. Mining operations already have demonstrated the validity of such inferences for several other bodies in the district.

The Petaca pegmatites appear to have been formed at considerable depths, probably 12 km or more, and in this respect they may resemble pegmatites in the Dixon-Penasco area east of the Rio Grande (see paper by P. E. Long, this Guidebook). A deep-seated origin, with attendant slow cooling under high confining pressure, is suggested by the sum of many features. The pegmatite bodies were emplaced in a terrane of moderate to high metamorphic rank, and they are much younger than the metarhyolite and other country rocks formed at or near the surface. Many of them have intricately branching forms, and many also are fringed by zones of pervasive reaction with wallrocks. No pockets or primary cavities are present in the pegmatites, nor are there associated aplitic rocks that could have been formed through sudden relief of confining pressure. The bulk composition of the pegmatite bodies, which is markedly sodic, corresponds to high values of "H_2O"P in the quaternary eutectic region of the synthetic haplogranite system ($NaAlSi_3O_8$—$KAlSi_3O_8$—SiO_2-H_2O); this is consistent with the assemblages of relatively low-temperature minerals in the pegmatites, with subsolvus crystallization and subsequent nearly complete exsolution of their alkali feldspars, and with widespread mineral recrystallization and replacement under subsolidus conditions.

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