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The Harding mine, Taos County, New Mexico

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THE HARDING MINE TAOS COUNTY NEW MEXICO

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INTRODUCTION

The Harding mine, in the western part of the Picuris Range about 20 miles southwest of Taos (Fig. 1), has yielded substantial amounts of commercial beryl, lepidolite, spodumene, and tantalum-niobium minerals over a period of half a century. It also has become widely known as a source of handsome mineral specimens, as a provocative locality for scientific studies, and as an attraction for those who appreciate spectacular exposures of pegmatite. It lies four miles southeast of the Rio Grande Canyon at an altitude of 7400 ft (sec. 29, T. 23 N., R. 11 E.), and it is readily accessible from a nearby point on State Highway 75 about 6 miles east of Dixon.

The mine property has been generously leased by the owner, Dr. Arthur Montgomery, to the University of New Mexico for preservation as one of the State's unusual natural assets. The University plans also to make this classic locality continually available for public inspection, study, and mineral

collecting on a modest scale. Anyone with an interest in visiting the property should contact the Chairman, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131. A splendid collection of representative Harding minerals, donated by Dr. Montgomery, can be viewed in the University's Geology Museum.

The published record of the Harding mine comprises early general descriptions (Roos, 1926; Just, 1937) and mineralogic notes (e.g., Schaller and Henderson, 1926; Hirschi, 1928, 1931; Hess, 1933), summaries of extensive exploratory work by the U.S. Bureau of Mines in 1943 and 1948 (Soule, 1946; Berliner, 1949), descriptions of milling operations for tantalum minerals (Wood, 1946) and mining operations for beryl (Montgomery, 1951), and various discussions of mineralogic and structural relationships in the pegmatite bodies (e.g.,

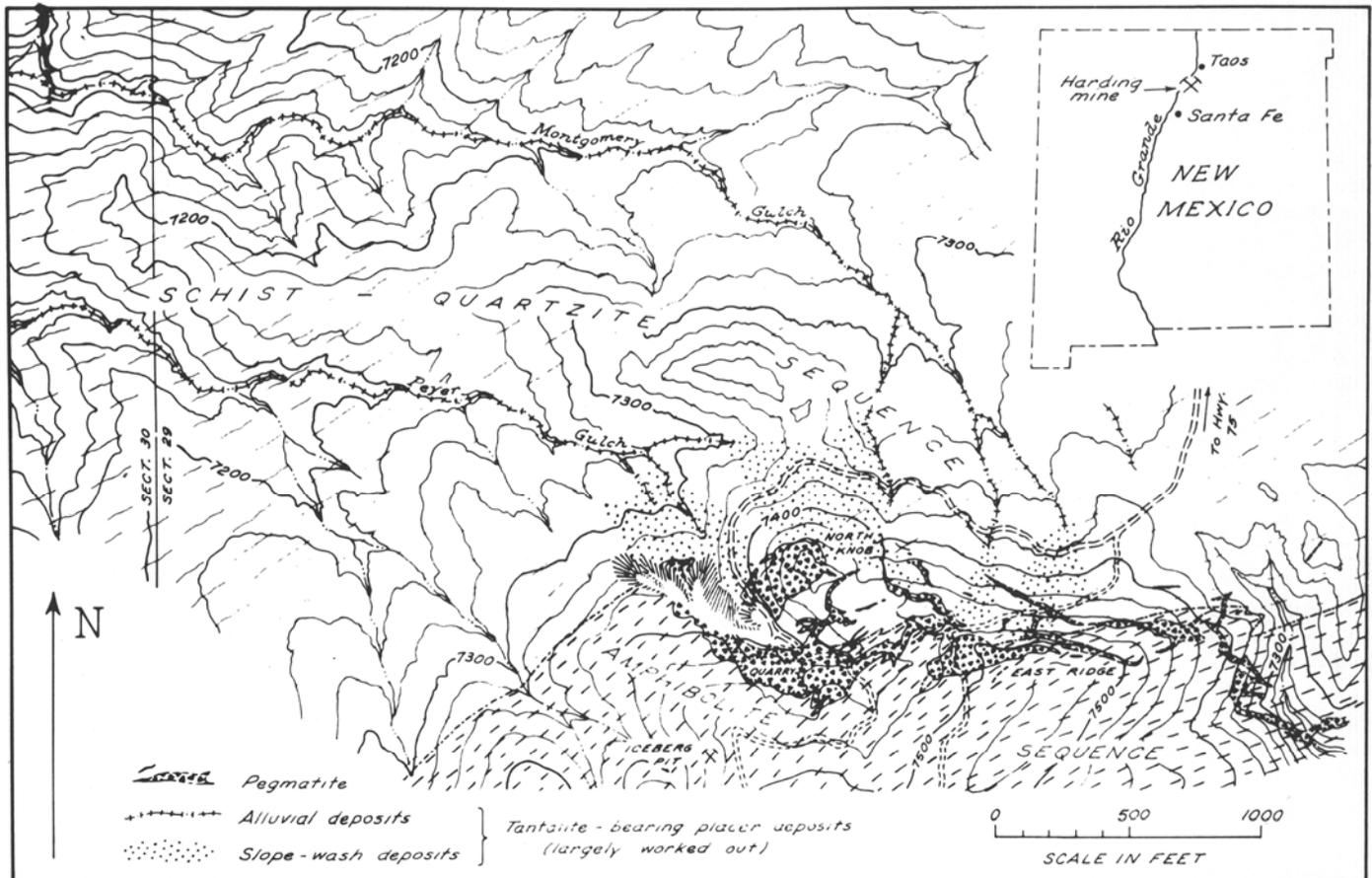


Figure 1. Generalized map of Harding pegmatite bodies. Insert shows location within the State of New Mexico.

Cameron and others, 1949; Montgomery, 1950; Page, 1950; Jahns, 1951; 1953a,b; Mrose, 1952; Rimal, 1962). The purpose of the present paper is briefly to describe the mining history and geology of the Harding locality, in part as an aid to those who visit the property or who view some of its characteristic minerals in Albuquerque at the Geology Museum. The treatment is based on detailed field studies that began in 1942 under the aegis of the U.S. Geological Survey and continued intermittently for more than two decades, and on mineralogical investigations in several laboratories.

We are indebted to John W. Adams and William P. Irwin of the U.S. Geological Survey and to Lauren A. Wright of The Pennsylvania State University for important contributions during the early periods of field work, and to Arthur Montgomery of Lafayette College and Lincoln R. Page and the late Waldemar T. Schaller of the U.S. Geological Survey for numerous penetrating discussions of the Harding mineral associations. We wish also to acknowledge the valued aid of Stuart A. Northrop of the University of New Mexico in compiling an authoritative list of minerals found in the Harding pegmatites. It is a special pleasure to recall, in connection with the field investigations, the hospitality and many courtesies received from Arthur Montgomery, John H. Soule of the U.S. Bureau of Mines, and Eliseo Griego, the late Flaudio Griego, and Lydia and "Doc" Zellers of Dixon.

HISTORICAL SKETCH

The Lepidolite Chapter, 1919-1930

Scattered large blocks and low but prominent outcrops of pegmatite quartz attracted prospectors to the Harding locality before 1900 but it was not until 1918 that Joseph J. Peyer of Taos recognized accompanying large, compact masses of lilac-colored lepidolite as indications of significant lithium mineralization. Beginning in 1919 Peyer and two partners, Frank Gallup of Taos and Arthur H. Gossett of Embudo, broke up the tough, bouldery masses by means of TNT-rich poultices, and obtained additional lepidolite from the main pegmatite ledge by open-cut work on the north-facing hillside. They hand-sorted the broken ore, hauled it by wagon to Embudo via a narrow access road they blasted across the high ground east of Dixon, and thence shipped it by rail to Wheeling, West Virginia, for grinding and sale to the ceramic industry. At that time the material was used mainly in the manufacture of opaque white glass for jar tops and indirect lighting fixtures, as it was an effective flux, opacifier, and toughener.

Late in 1920, after parts of the deposit had been explored by shot-core drilling, operations were taken over by the Mineral Mining and Milling Corporation of New York under lease and assignment agreements. An adit was driven southward into the hillside to permit expansion of the open cut by glory-hole methods, and a second cut, adjacent on the east, later was opened from a short entry (northeast entry, Fig. 2). By 1923 production of rich shipping ore had reached a level of nearly 800 tons per year. The economics of the enterprise proved to be disappointing, however, and mining was suspended in 1924. During that year two shipments of apparently excellent lepidolite caused grave difficulties when the material was used for making glass. Sketchy reports indicate that this material may have contained substantial quantities of the tantalum mineral microlite; indeed, some of it may have been high-grade Ta-Nb ore.

In 1924 the Embudo Milling Company, under the direction

of J. L. Danziger of Los Angeles, began construction of a crushing and grinding plant near the railroad depot at Embudo, and in 1927, after the mill had been completed, this company also assumed control of new work at the mine. The main pit was much enlarged, and as it merged with the east cut and grew toward its present elongate form (Fig. 2), a second adit was driven to it from the west. Both this adit and the main adit ultimately were daylighted, and they now appear as main and west entries to the quarry. The hand-sorted ore, broken at the mine to a maximum dimension of 9 inches, was trucked to the Embudo mill where it was passed through a jaw



Figure 2. Southwestward view of Harding quarry from North Knob, showing the sharp, irregular hanging wall of the main pegmatite body as exposed by open-cut mining prior to 1943. The body dips gently away from the observer, and its footwall is exposed near portal of main entry in right foreground. Active workings for microlite ore are at left in quarry, beyond the northeast entry. Temporary structure of U.S. Bureau of Mines camp appears on the wooded slope in center distance.

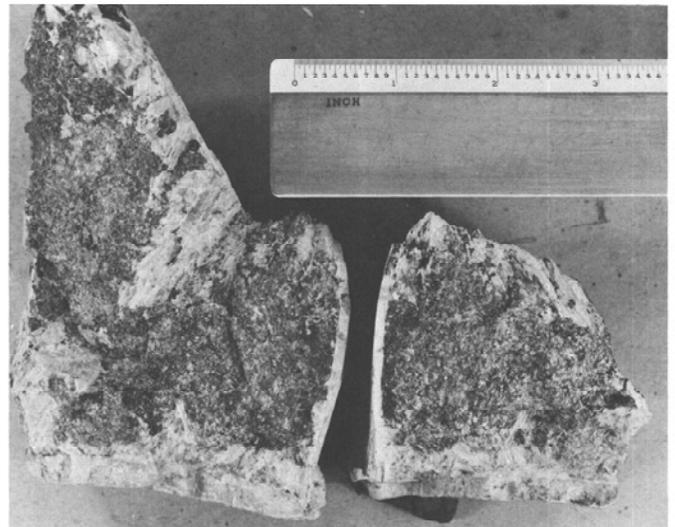


Figure 3. Tantalum ore of exceptionally high grade, obtained from eastern part of main quarry in 1943. Large but thin blades of spodumene, some of them with highly corroded edges, enclose a finer-grained aggregate of microlite, tantalite-columbite (dark), muscovite, lepidolite, albite, and spodumene. The abundant microlite appears mainly as light gray spots, 0.03 to 0.05 in. in diameter, that are crowded within a darker matrix of scaly micas.

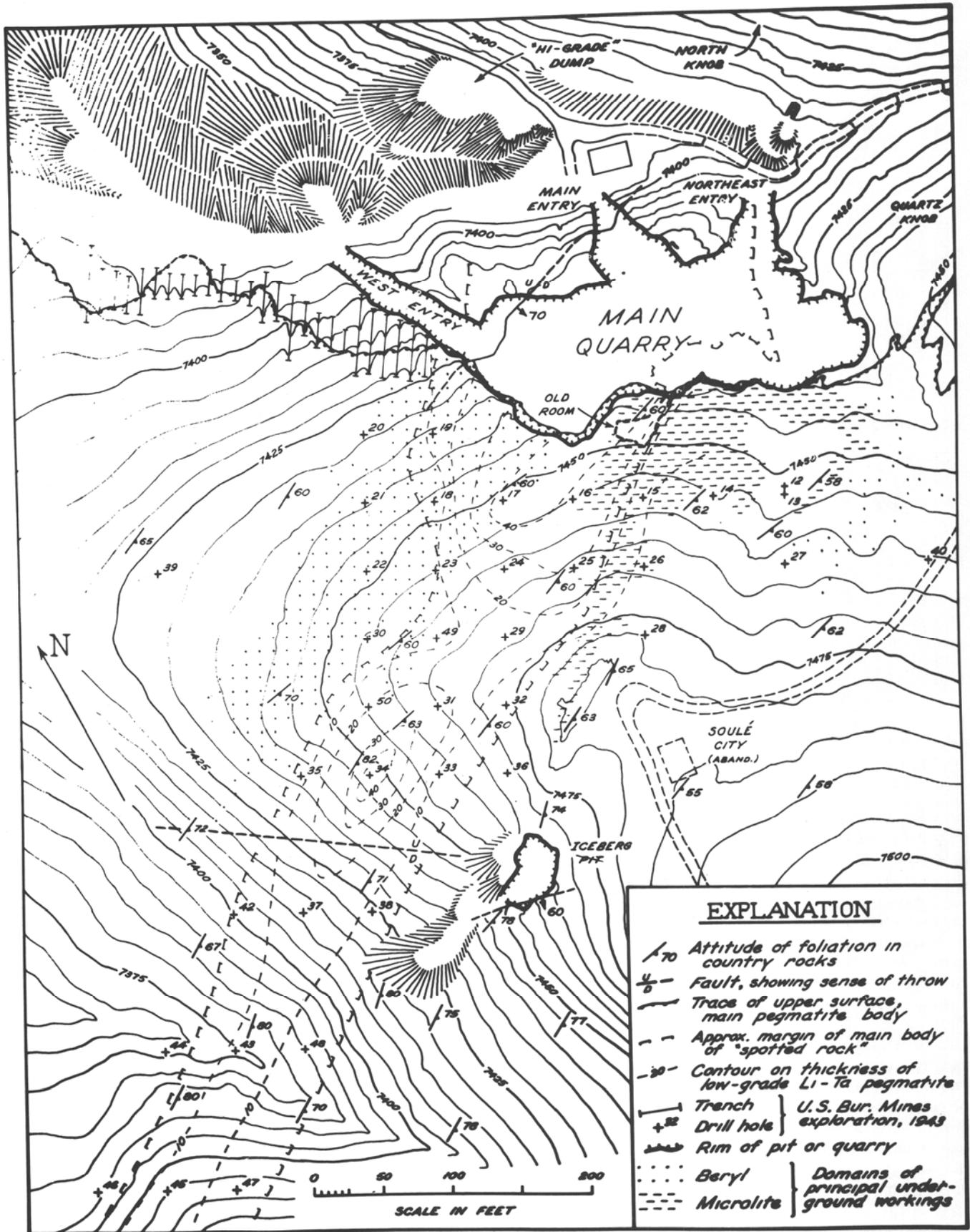


Figure 4. Map of a part of the Harding area showing general distribution of mine workings, exploratory trenches and drill holes, and principal concentrations of Be, Li, and Ta-Nb minerals.

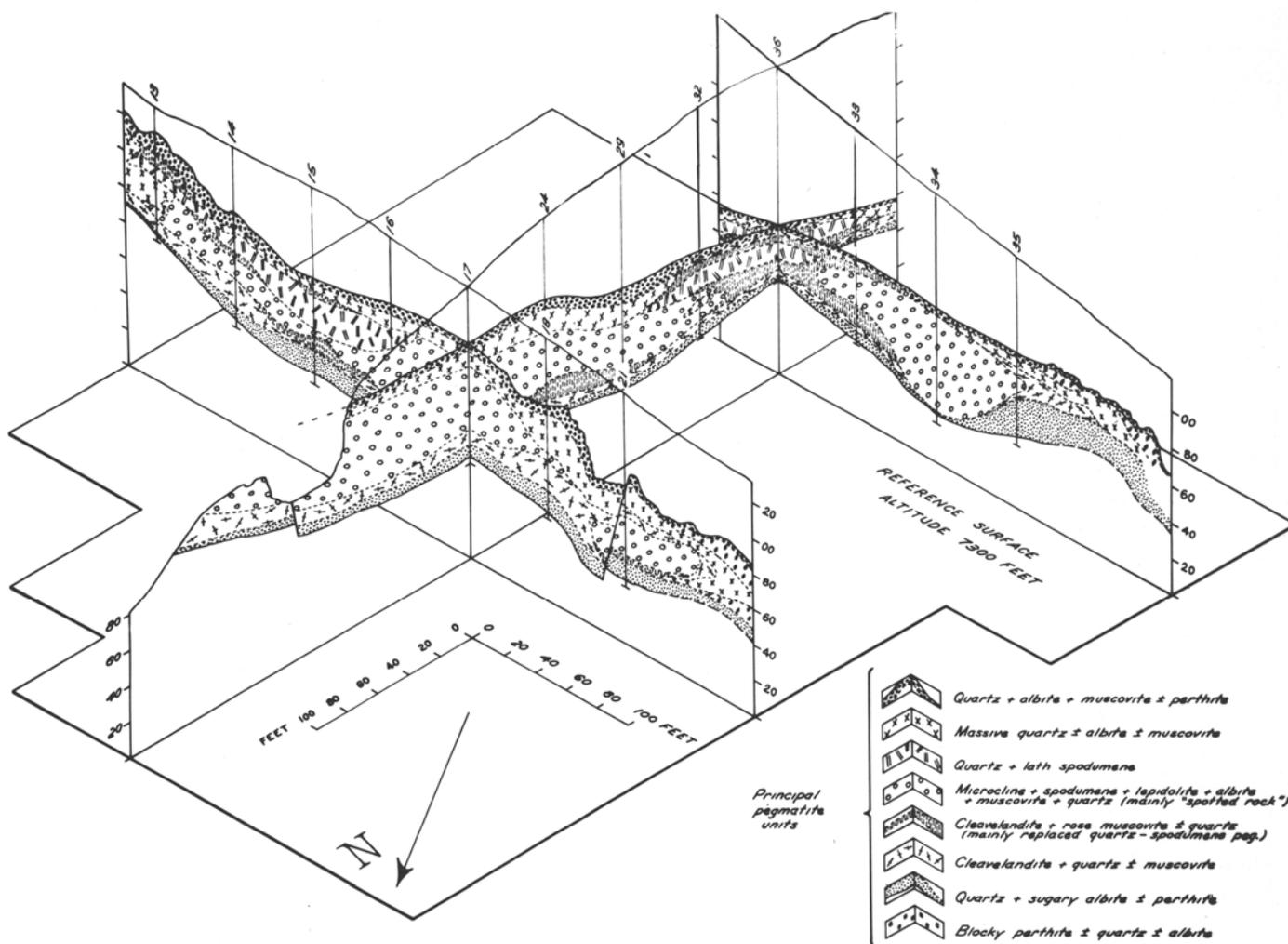


Figure 5. Fence diagram showing two vertical sections through the pegmatite body and its constituent lithologic zones in ground southwest of main quarry. Locations of numbered diamond-drill holes are indicated in Figure 4.

crusher and then continuously ground in a quartzite-lined mill. Six-inch lumps of ore served as the principal grinding agent. After screening and passage through a magnetic separator, the product was sacked for direct shipment to glass manufacturers.

There was considerable demand for the ground lepidolite, especially in the production of glasses resistant to thermal shock, and the output soon reached levels far beyond those of the earlier years. But expenses also were great, and in 1928, for example, a net income of only \$619.42 was generated from shipments of 3612 tons valued at \$58,858.00. Quality of the product was maintained at high levels, and it was not difficult to meet the specified tolerance of 0.1 percent for iron content. However, much of the output contained both lepidolite and lithian muscovite, so that the usual tenor requirement of 3.0 percent of Li₂O was not so easily satisfied unless some spodumene was included with the lepidolite. Undoubtedly most shipments contained a fraction of spodumene, which was closely associated with the micas in the mined ore.

By 1929 the large, pod-like body of rich lepidolite ore had been essentially mined out, and efforts were turned increasingly toward the more expensive extraction of irregular projections and shoots. Several undercuts were made from the south face of the quarry (Fig. 6), and finally a large opening, still

accessible, was developed opposite the main quarry entry (Fig. 4). The mine was closed in 1930, and the property transferred back to the original owners in 1931.

The score sheet for the opening chapter of lepidolite operations, 1919-1930, shows mixed results, among them (1) shipments of broken ore and ground products amounting to approximately 13,500 tons, (2) a gross output value of about \$140,000, f.o.b. Embudo, (3) small net profits for three years but a net loss for the entire period of mining, and (4) development of a large quarry, appended openings, and many scattered small workings that together provide some of the world's finest exposures of mineralogically complex pegmatite.

The Microlite Chapter, 1942-1947

The Harding mine was reborn in 1942, when the United States was in such critical need of tantalum metal that an almost frantic search was under way for domestic sources of ore. Microlite, a relatively rare calcium tantalate, had been reported from the main quarry (e.g., Hirschi, 1931) and was known in a few rock specimens collected there during earlier mining. Small amounts of tantalite-columbite also had been recovered from localized placer deposits north and west of the mine, but the property hardly was regarded as a potentially

HARDING MINE

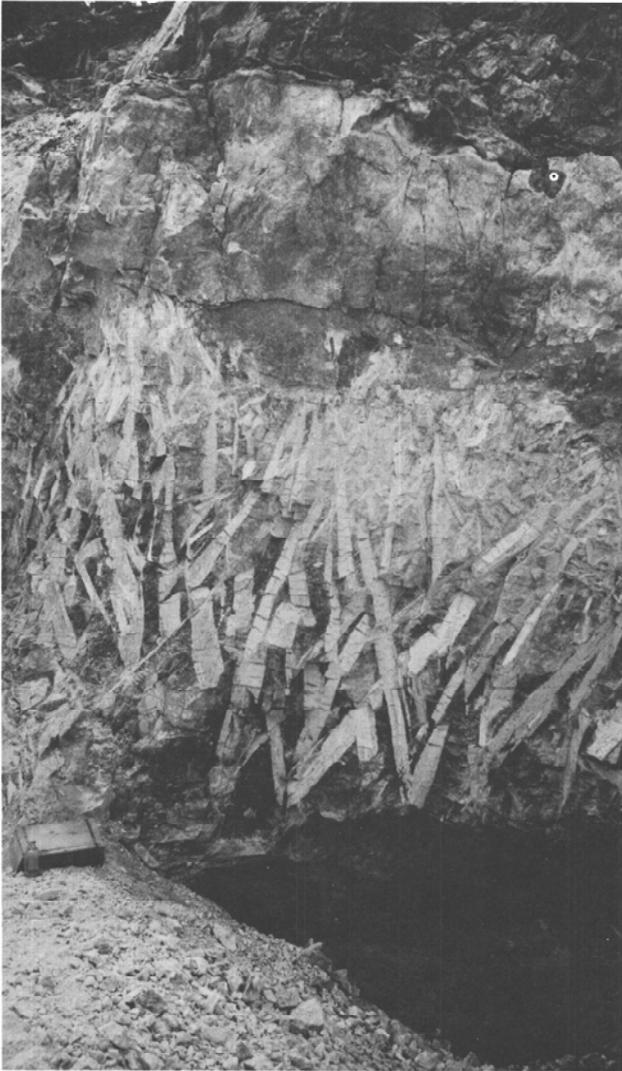


Figure 6. An easterly part of main quarry face as well exposed in December 1942. Beneath the sharply convoluted contact between pegmatite and overlying amphibolitic country rock near top of view are five distinctive pegmatite units: (1) ½-inch border rind (white) of fine-grained quartz-albite-muscovite pegmatite, (2) 2- to 3-ft layer (gray) of coarse-grained quartz-albite-microcline-muscovite pegmatite with locally abundant apatite and beryl, (3) 2- to 5-ft layer (darker gray) of coarse-grained massive quartz, (4) 10- to 15-ft layer of coarse-grained quartz (dark) with large, lath-like crystals of spodumene (light) and local coarse microcline, apatite, and beryl, and (5) lepidolite-spodumene-microcline pegmatite with some albite and scattered small crystals of microlite (removed from undercut as lepidolite ore).

important source of tantalum when Arthur Montgomery visited it to check for occurrences of microlite. He soon found rich material in one of the old dumps (Fig. 4), as well as small concentrations of similar material in place near the east end of the quarry (Fig. 2).

The U.S. Geological Survey then was called upon to sample the microlite-bearing dump and to map the mine workings in

detail. This work confirmed Montgomery's favorable appraisal, and late in 1942 he entered a lease-purchase agreement for the property. With a crew of local miners, he sorted and sacked five tons of dump material containing more than 10 percent of microlite. He soon turned his attention to the part of the mine whence this material had come, ground that presumably also was the source of the unsatisfactory lepidolite shipped for glass making in 1924. In Montgomery's own words, "The mining that ensued along the low east wall of the quarry surely was one of the strangest ever seen. Six men attacked that rock wall with chisels. The ore was far too valuable to be blasted. And it proved possible to chisel, pry, and hammer it out of the surrounding spodumene-rich rock by hand. Primitive mining, yes, but astonishing results were forthcoming. The small lepidolite ore masses showing in the wall grew bigger and bigger as they became fully exposed.... It was incredibly rich ore, quite as valuable as high-grade ore in economic importance, and it came out of the quarry wall in amazing quantity."

Sorting of the ore was a straightforward but difficult procedure, as much of the microlite occurred in the form of tiny, pale yellow to almost colorless grains within irregular aggregates of micas (Fig. 3) and was easily overlooked. Montgomery soon developed considerable expertise in the rapid identification of high-grade material by means of two simple tests based on physical properties of the microlite. Its high density gave an unusual heft to rich specimens, and its very high index of refraction clearly revealed the outlines of individual crystals on saliva-moistened rock surfaces.

The sorted ore, though rich, required mechanical concentration that no commercial firm could provide for small lots of such unusual and valuable material. Fortunately a special arrangement was made for use of the U.S. Bureau of Mines Testing Laboratory in Rolla, Missouri for the experimental processing of 33.5 tons of ore by gravity methods. The resulting yield, obtained by mid-1943, was by far the largest single unit of domestic tantalum production ever recorded—6137 pounds of concentrate containing 71.14 percent of Ta₂O₅ and 6.41 percent of Nb₂O₅. During the following two years several smaller lots of ore were batch-milled, first in a facility at the California Institute of Technology and later at commercial ore-testing stations. In 1945 a small mill was built near the Rio Grande at Rinconada, in order directly to serve the mine through recovery of microlite and tantalite-columbite from a mixed feed of high- and low-grade materials. This facility, which embodied hammermill grinding followed by gravity separation in Humphreys spiral launders (Wood, 1946), reportedly yielded fair to good recoveries but fell short of its rated capacity of 12 tons per 8-hour day.

In response to a special request by the War Production Board, a carload of high-grade spodumene was produced in 1943, mainly from the eastern part of the quarry. This material was hand-picked from pegmatite containing relatively large, lath-like crystals (Fig. 6), a very tedious process because these crystals were so thin and fragile that they were separated into small fragments by blasting. In 1946, some lepidolite ore of good quality also was recovered during the mining operations for microlite. By the time production of tantalum minerals ceased in 1947, the eastern parts of the main quarry face had been considerably reshaped, and a labyrinth of tunnels and small, finger-like rooms had been developed south of this face (Fig. 4). Most of the underground workings have since become inaccessible or unsafe for entry.



Figure 7. Specimens of lithium-tantalum ore from main quarry. At left is a variety of "spotted rock" in which patches of coarse microcline are outlined by small, dark-colored crystals of lepidolite, tantalite-columbite, and uranian microlite-pyrochlore. The microcline is partly replaced by minute scales of lepidolite, which also are abundant in remainder of the rock. At right is an aggregate of spodumene laths and plates, most of them much corroded, in a matrix of purple lepidolite (dark), albite, and quartz with scattered small crystals of tantalum-niobium minerals.

During 1943 the U.S. Bureau of Mines explored south of the quarry by means of 39 diamond-drill holes with an aggregate length of 4371 ft, and in 1948 seven additional exploratory holes totaling 1 1399 ft were drilled. The recovered cores were logged by the U.S. Geological Survey, and assayed by the Bureau of Mines. These investigations led to definition of a considerable tonnage of pegmatite with sufficient content of spodumene and tantalum-niobium minerals to be classified as potential milling-grade ore. Thus the Harding became the first domestic pegmatite mine with blocked-out reserves, that remain in place at the present time.

The unusual microlite operations and allied activities of the five-year period 1942-1947 were relatively small in scale, simple in style, and prevailingly successful. Among the results were (1) a prompt and effective response to urgent wartime needs for tantalum and lithium, (2) a yield of 41 tons of high-grade spodumene, 558 tons of lepidolite ore, nearly 500 pounds of placer tantalite-columbite containing an average of 43 percent Ta_2O_5 , and 22,116 pounds of microlite concentrates containing an average of 68 percent Ta_2O_5 and 7 percent Nb_2O_5 , and (3) sufficient net income from production to permit purchase of the property.

The Beryl Chapter, 1950-1958

Beryl was identified at the Harding locality during the early years of mining (e.g., Just, 1937, p. 26), but it was regarded as no more than a rare accessory mineral in the pegmatite. That it actually is a widespread and locally abundant constituent, easily mistaken for quartz or coarse feldspar, was initially recognized by the U.S. Geological Survey late in 1942. Its economic potential at first was viewed in terms of recovery by milling, but Arthur Montgomery subsequently discovered very coarse material readily amenable to hand-cobbing. In 1944 he found, on one of the old dumps, a block of beryl weighing

nearly 100 pounds, and he soon recovered about 4 tons of smaller chunks from nearby parts of this dump. Then turning his attention to a small knob exposed high on the quarry face near the west entry, he removed the overlying country rock to expose a thick, elongate lens of nearly pure beryl lying at the upper surface of the pegmatite "much like a thick dab of frosting on the top of a cake." The 23-ton shipment from this occurrence contained nearly 11 percent of BeO .

The 1943 results of U.S. Bureau of Mines exploration also provided encouragement. Several of the drill holes had penetrated beryl in various parts of the main pegmatite body, and in one of them (No. 22, Fig. 4), about five feet of nearly pure beryl in many parts of this hanging-wall zone was demonstrated by detailed surface mapping and, on the hill-slope immediately west of the quarry, by 26 sample trenches with an aggregate length of 788 ft (Soule, 1946).

The Harding was born as a full-scale beryl mine in 1949, when Montgomery and Flaudio Griego of Dixon began to drive a tunnel southwestward toward USBM Drill Hole 22 from a point in the quarry near the previously removed lens of beryl. After initially disappointing results, the new activities began to yield remarkable returns as increasingly larger and more continuous masses of ore were encountered. By early 1950 the working faces of the tunnel and some of its branches were in solid beryl for days at a time, and production of hand-sorted material rose to levels of more than a ton per day. The sorting, no easy task whether done in daylight or underground by the light of a Coleman lantern, was based in part on two distinctive features of the beryl, a faintly greasy to resinous luster and a rude basal cleavage along which the coarsest material typically broke into thick plates and slabs.

Shipments reached the 150-ton level in both 1950 and 1951, when they placed New Mexico in the forefront of all beryl-producing states, and they averaged nearly 100 tons per year from 1950 until operations ceased with Griego's death in 1958. Yet these activities were extremely modest by normal mining standards. At no time was a crew of more than four men used, and no mechanical concentration ever was involved. Nearly all mine haulage was done by a sturdy \$12.00 he-mule who answered to the particularly appropriate name Beryl.

The impressive score for the 1950-1958 beryl chapter of Harding mine history includes (1) production of 690 tons of concentrates with an average BeO content of 11.2 percent, as well as 184 tons of lower-grade material with an estimated average BeO content of 5.5 percent, (2) incidental small production of lepidolite ore, mainly in 1950 and 1951, (3) a highly profitable operation from which a large fraction of the returns was assigned to the needs and interests of residents in the Dixon area, and (4) further proof that the spatial distribution of many economically desirable pegmatite minerals, however irregular, is nonetheless systematic (e.g., Cameron and others, 1949).

GEOLOGIC SETTING

The Harding pegmatites lie within a complex terrane of Precambrian rocks that have been mapped, described, and variously interpreted by Just (1937), Montgomery (1953), and Long (1974). This terrane is characterized by a thick section of arenaceous and pelitic metasedimentary rocks with inter-layered metavolcanic rocks of basaltic to rhyolitic composition, and by large intrusive bodies of younger igneous rocks that have been collectively referred to as the Dixon Granite or

Embudo Granite. Both Just and Montgomery recognized important textural and compositional differences among the exposed granitic rocks, and more recently Long (1974) has shown that they probably represent at least four distinct episodes of magmatism occurring at progressively increasing depth over a considerable span of Precambrian time.

The east-west outcrop belt of pegmatite bodies at the Harding locality corresponds in general position with a complicated boundary between quartz-muscovite schists on the north and amphibolitic rocks on the south (Fig. 1). The well-defined planar structure in these rocks trends northeast to east-northeast and dips steeply southeastward (Figs. 1, 2), and the boundary between them has a similar general attitude in both directions beyond the pegmatite area. No granitic rocks are exposed in the immediate vicinity of the mine, but less than a mile to the east the prominent Cerro Alto consists of intrusive metadacite, and in the area west of the mine porphyritic quartz monzonite underlies Cerro de los Arboles and Cerro Puntigudo. To the south, in the canyon area traversed by the Rio de Penasco (Rio Pueblo), are many exposures of biotite quartz monzonite and granodiorite that represent a large pluton of considerable complexity (Long, 1974).

Bodies of pegmatite, youngest among the Precambrian rock units, are widespread in the region and are especially abundant in the belt of metamorphic rocks traversed by State Highway 75. Many are long, thin dikes, with northeasterly trend and steep dip, that consist of quartz, alkali feldspars, muscovite, garnet, and sparse yellowish green to green beryl in well-formed prisms. Most of these dikes are internally zoned, with prominent core segments of massive quartz. Other zoned bodies, in general smaller and more pod-like, consist almost wholly of quartz, albite, and muscovite. Bodies of a third kind, characterized by greater thickness, prevailing gentle dip, and unusual abundances of Be, Li, and Ta-Nb minerals, are known only in the mine area and at a locality about half a mile to the northwest.

Marked differences in composition, structure, and host-rock relationships suggest that the several kinds of pegmatite in the region may be of different ages, but a sequence cannot be firmly established and dated from radiometric information now available. Aldrich and others (1958) reported K-Ar and Rb-Sr ages of 1260 m.y. B.P. for four Harding muscovites and 1350 m.y. B.P. for a Harding lepidolite, and Gresens (1975) reported a K-Ar age of 1335 m.y. for muscovite from an unnamed pegmatite in the Picuris Range. Neither these ages nor that suggested by Fullagar and Shiver (1973) for granitic rocks in the region can be unequivocally translated into a dated episode or sequence of plutonism, but Long (1974) has pointed out that the Harding pegmatites may be as much as 100 million years younger than the youngest of the granitic plutonites. An age difference of such magnitude is consonant with field and photographic evidence suggesting that these pegmatites may not be genetically related to any of the granitic intrusives now exposed in the Picuris Range.

THE PEGMATITE BODIES

General Features

The Harding pegmatites crop out in a well-defined belt about 2500 ft long and 150 to 500 ft wide (Fig. 1). Most of the bodies are pinching-and-swelling dikes that in general are 5 ft to 20 ft or more in thickness, trend west to west-northwest,

and dip southward at low to moderate angles. Several thinner, steeply dipping branches and connections trend north to northwest. The main body, at the western end of the belt, is well exposed in outcrop and mine workings along the southwestern side of a shallow canyon (Fig. 2), and an extensive up-dip erosional remnant lies opposite on the flank of North Knob. The ridge extending east-southeastward from this knob is marked by the outcrops of several thinner dikes, most of which have been opened by means of pits, cuts, and short tunnels. The easternmost of these bodies can be traced across a steep-walled canyon that drains southward into the Rio de Penasco.

All the dikes are granitic in bulk composition and consist chiefly of quartz, potash feldspar, and albite. Muscovite is widespread, along with lesser amounts of accessory apatite, beryl, garnet, magnetite, microlite, and tantalite-columbite. Some of the bodies are grossly homogeneous or contain no more than pods of quartz and other local expressions of internal zoning, but those in the central and western parts of the belt comprise extensive and well-defined internal units of markedly contrasting lithology. It is in these distinctly zoned bodies that nearly all major concentrations of beryl, lepidolite, spodumene, microlite, and tantalite-columbite are found.

Some of the Harding dikes are enclosed by amphibolitic rocks, chiefly hornblende-plagioclase schist with layers and pods of epidote and dark, impure quartzite; other dikes extend northward into the terrane of quartz-muscovite schists (Fig. 1). The main dike is overlain at the present outcrop level by the amphibolitic sequence (Fig. 2) and underlain by schists with numerous thick layers of amphibolite. Alkali metasomatism of the wall rocks adjacent to pegmatite is indicated by extensive conversion of hornblende to biotite, and by abundant metacrysts of potash feldspar, muscovite, and albite. Some quartzite and quartz-rich schist on North Knob is heavily impregnated with lithium-bearing micas.

The Main Dike

General Relationships

The main Harding dike is highly irregular in surface plan, with an exposed length of about 1100 ft and breadth ranging from a few feet to as much as 250 ft in the quarry area (Fig. 1); maximum breadth is considerably greater if the pegmatite on North Knob is included. The principal quarry face (Fig. 2), trending west-northwest approximately parallel to the original outcrop, provides more of a cross section than a longitudinal section, because in three dimensions the body has the general shape of a wide and nearly flat, southwestward-extending tongue with tapering, sharply downturned lateral margins and a central region 50 to 80 ft thick. The gently undulatory major axis of the tongue has an average plunge of about 10 degrees and an explored length of nearly 1600 ft. The original length is not known, as up-plunge parts of the body have been removed by erosion beyond North Knob.

Upper and lower surfaces of the tongue are broadly wavy (Fig. 2), and in places they also are marked by sharp corrugations with amplitudes of a few inches to at least 15 ft. Nearly all these rolls plunge at low angles, and in general their trend is parallel to the strike of foliation in the adjacent country rocks. Parallel to this foliation in both strike and dip is a well-defined set of numerous fractures that transect the pegmatite. A fault with like attitude and vertical separation of 5 to 8 ft also cuts

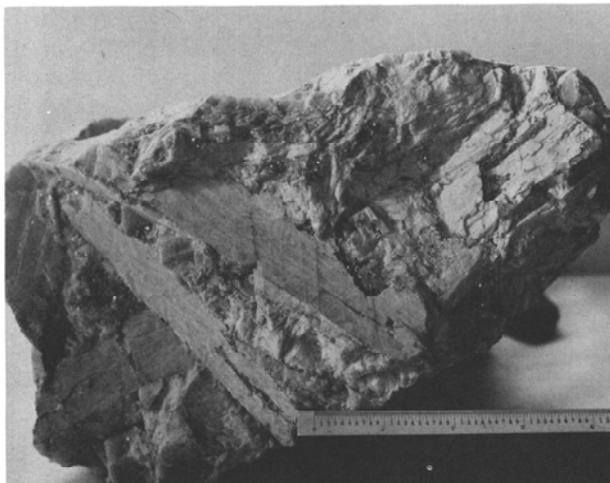


Figure 8. A typical museum specimen of Harding pegmatite. Large laths of spodumene, locally seamed and bordered by scaly aggregates of rose muscovite, form a jackstraw-like framework enclosing lustrous white blades of cleavelandite and spodumene, irregular pods of muscovite, and scattered small crystals of tantalum-niobium minerals. Parts of the specimen are traversed by veinlets of gray smoky quartz.

the pegmatite exposed near the inner end of the west entry and the outer end of the main entry (Fig. 4).

Internal Zoning

The main dike displays a remarkable segregation of constituent minerals into contrasting zones whose general shape and distribution reflect the upper and lower surfaces of the body (Fig. 5). Most of the zones thus appear as wide subhorizontal stripes on the main quarry face and in areas of extensive outcrop, although their surface distribution on North Knob is complicated by the geometry of dip-slope exposure. For present purposes, a brief description of zones in the thickest portion of the main dike, well known in three dimensions from surface exposures and exploratory drilling, will suffice to illustrate the major aspects of segregation.

The upper contact with country rocks is marked by a white border rind, 1/2 to 1 in. thick, of fine-grained quartz-albite-muscovite pegmatite. Beneath this rind is a continuous layer, typically 1 to 5 ft and locally as much as 10 to 14 ft thick, that also is rich in quartz, albite, and muscovite but is in large part very coarse grained. Potash feldspar is locally abundant, and apatite, beryl, and tantalite-columbite are widespread accessory constituents. Spectacular concentrations of coarse to very coarse beryl also have been found, especially beneath the crests of major rolls that are most abundant in lateral parts of the tongue. An analogous layer, characterized by the same accessory minerals but in general with less beryl, is present along the lower surface of the tongue. It is rich in coarse quartz, but in many places its prevailing texture is more aplitic than pegmatitic and is distinctively sugary in appearance because of abundant fine-grained albite.

Beneath the upper beryl zone is a continuous layer of massive quartz, 2 to 8 ft thick, that is well exposed in the main quarry and on the low knob immediately to the east. In some down-plunge parts of the dike it reaches subsurface thicknesses

of 20 to 35 ft. Muscovite, microcline, and albite of the cleavelandite variety are present locally, and both cleavelandite and muscovite are widespread and abundant constituents of an analogous massive-quartz unit in the footwall half of the dike (Fig. 5).

The upper massive-quartz zone is underlain by a spectacular quartz, lath-spodumene zone. This widespread unit is 6 to 20 ft thick in surface exposures, and reaches subsurface thicknesses of 20 to 40 ft at places where it fills the entire interior of the dike. The spodumene characteristically occurs as long, thin, blade-like crystals of moderate to great size, usually arranged in jackstraw fashion. In the eastern half of the main quarry, the crystals are oriented somewhat more regularly to form a crudely comb-like pattern (Figs. 2, 6). Beryl, apatite, white to green microcline, and Ta-Nb minerals are present locally in the lower part of this zone. Some portions of the quartz, lath-spodumene rock have been pseudomorphously replaced, the spodumene selectively by rose muscovite and the quartz by cleavelandite. Similar replacement rock is present in footwall parts of the dike (Fig. 5).

The core of the dike is distinguished by varieties of lithium- and tantalum-bearing pegmatite that in general are less coarse grained than rocks of the overlying zones. The dominant variety, known as "spotted rock," is a relatively even-grained aggregate of spodumene, microcline, and quartz, with various combinations of accompanying finer-grained albite, lithium-bearing muscovite, lepidolite, microlite, and tantalite-columbite. Much of the spodumene and potash feldspar occurs as rounded masses about an inch in average diameter, with surfaces that are ragged in detail (Fig. 7). Both minerals have been extensively corroded and replaced by micas in aggregates of tiny flakes.

The "spotted rock" contains an average of 12 to 15 percent of spodumene and about 0.15 percent of Ta-Nb minerals, and hence might be viewed as low-grade ore. The principal body of this rock has the general form of a loaf of French bread, with one prominent constriction and an equally prominent vertical bulge (Figs. 4, 5). It is 20 to 55 ft in maximum thickness and 50 to 175 ft wide (Fig. 4), with a long, or down-plunge extent of nearly 700 ft southwestward beyond the main quarry face. Its position is reflected in some places by a broad bulge in the hanging wall of the pegmatite body, and in others by a sag in the footwall (Fig. 5).

Typical "spotted rock" grades into lepidolite ore that contains rounded masses of spodumene but relatively little potash feldspar, and with decreasing spodumene content into bodies of nearly pure lepidolite. Several of these bodies were encountered long ago in the main quarry, but little of the material remains in place today. Another core variant, common in the eastern part of the quarry and also found locally in the western part, is distinguished by platy or lath-like individuals of spodumene 2 to 30 in. long. These occur either as isolated units (Fig. 7) or as jackstraw aggregates (Fig. 8) with finer-grained matrices of spodumene, lepidolite, Li-muscovite, albite, quartz, and Ta-Nb minerals. Veinlets and small, irregular masses of dark smoky quartz are present locally. This rock has been the host for most of the high-grade tantalum ore thus far encountered, and it has been referred to as the largest known body of microlite in the world (Baker, 1945).

Bulk Composition

The main pegmatite body, as exposed in the quarry and

penetrated by drill holes, has been extensively sampled and analyzed (Table 1). The pegmatite is typically granitic in terms of major constituents, with a high Na₂O/K₂O ratio that in part is reflected by an abundance of albite in footwall parts of the body that are not well exposed. It is low in iron and strikingly deficient in calcium and magnesium. Remarkable for any large mass of granitic rock are its high contents of lithium (mainly in spodumene and micas), cesium and rubidium (mainly in micas, potash feldspar, and beryl), and fluorine (mainly in micas, apatite, and Ta-Nb minerals). It also contains about 0.03 percent of Be and 0.08 percent of Ta + Nb.

The composition of the border rind along the hanging wall (column 2, Table 1) is distinctly different from that of the pegmatite body as a whole, hence the rind cannot be readily viewed as a conventional chilled margin. It is relatively rich in Na₂O and poor in K₂O and SiO₂, and it may well be compositionally complementary to added constituents in the zone of potash and silica metasomatism in adjoining country rocks.

The SiO₂ content of "spotted rock" (third column of Table 1) corresponds to a relatively low percentage of quartz, the high K₂O/Na₂O ratio to an abundance of potash feldspar and micas, and the high Li₂O content to an abundance of spodumene and lithium-bearing micas. Listed for comparison is an analysis for a section through the pegmatite as provided by the south face of the quarry. "Spotted rock" is well represented in this section, hence it is not surprising that the analytical results are intermediate between those listed in the first and third columns of the table.

MINERALOGY

The following brief summary of Harding minerals and their occurrence is based chiefly on our own studies of the peg-

matites and materials collected from them. Its purpose is to provide notes on the most abundant or important species at this locality, and to list the remainder as additional search targets for the diligent collector (Table 5). Reports by other investigators are referenced for special features or for species we have not personally seen and confirmed. For many useful details not included here, reference should be made to Minerals of New Mexico (Northrop, 1959).

Major Minerals

Quartz [SiO₂] By far the most widespread pegmatite mineral. Occurs prominently as thick layers and pod-like masses of milky white to smoky gray anhedral crystals 0.5 in. to 3 ft in diameter, some with rude rhombohedral cleavage, and as very coarse aggregates interstitial to large crystals of spodumene (Fig. 6). Also forms extensive fine-grained, sugary-appearing aggregates with albite and microcline. Common elsewhere as a fine- to medium-grained interstitial or groundmass mineral. Light to very dark smoky quartz forms scattered irregular veinlets and small pods, in places containing well-faced crystals of beryl, spodumene, uranian microlite-pyrochlore, and tantalite-columbite, also rare allanite, thorite, and zircon.

Albite [NaAlSi₃O₈]. Occurs as fine-grained aggregates, especially with quartz and muscovite in outer parts of dikes, and also as the variety cleavelandite in lustrous curving plates and blades 0.3 to 2.5 in. long. Common as coarse fracture-filling and replacement aggregates in quartz. Generally white, also light gray and very pale green. Compositional range Ab₉₁-Ab₉₉, with the remainder mainly or entirely Or; most coarse material is nearly pure Ab.

Microcline [KAlSi₃O₈]. Widespread as extensive aggregates of coarsely perthitic subhedral crystals 1 in. to 4 ft in diameter, and as large, roughly euhedral individuals in massive quartz. Typically cream-colored, gray, and pale pinkish tan. Also abundant with quartz and muscovite in fine-grained aggregates. Locally interstitial to large laths of spodumene as white to light green (amazonstone) crystals 1 to 3 in. in diameter. A major constituent of "spotted rock" as 1/2- to 4-in. individuals with rounded and corroded margins (Fig. 7); non-perthitic and in general almost soda-free, ranging from white to lilac according to degree of impregnation by extremely fine-grained lepidolite and Li-muscovite. Some pale pink masses may have been mistaken for amblygonite by early observers (e.g., Hirschi, 1931).

Muscovite [KAl₂(AlSi₃)O₁₀(OH)₂] 1. Abundant in smaller dikes and in outer parts of main dike as pale yellow-green to green flakes and thick plates 0.1 to 1.5 in. in diameter, typically containing 0.3 to 0.8 percent of Li₂O. In inner parts of several dikes as aggregates of tiny lilac, lavender, violet, pink, or gray flakes and plates forming large irregular pods or smaller masses interstitial to crystals of spodumene, cleavelandite, and other minerals. Such aggregates, somewhat translucent and waxy in appearance, generally contain 1.0 to 3.4 percent of Li₂O. Also occurs as columnar crystals 0.2 to 2.5 in. long (parallel to c-axis), typically in radiating aggregates with cleavelandite and quartz. A widespread rose variety, in bright, pink flakes 0.1 to 0.8 in. in diameter and generally with less than 0.3 percent of Li₂O, occurs variously as fracture fillings and replacement masses in "spotted rock" and adjacent pegmatite, as overgrowths on crystals and crystalline aggregates of lepidolite, as pseudomorphs after spodumene, micro-

TABLE 1. BULK COMPOSITIONS OF MAIN PEGMATITE BODY AND SOME OF ITS PARTS, HARDING MINE

	1 Main Body	2 Border Rind	3 "Spotted Rock"	4 Quarry Section
SiO ₂	75.24	68.02	65.15	69.79
Al ₂ O ₃	14.42	19.19	21.51	18.22
Fe ₂ O ₃	0.14	0.05	0.06	0.05
FeO	0.35	0.60	0.46	0.34
MnO	0.18	0.13	0.11	0.09
MgO	0.01	0.37	0.06	0.04
Li ₂ O	0.65	0.15	2.21	1.49
CaO	0.20	1.66	0.10	0.04
Na ₂ O	4.23	7.22	2.65	2.07
K ₂ O	2.74	1.59	6.25	6.16
Rb ₂ O	0.19	...	0.72	0.53
Cs ₂ O	0.05	...	0.20	0.06
H ₂ O+	0.66	0.51	0.36	0.38
H ₂ O-	0.20	0.09	0.06	0.04
CO ₂	0.03	...	0.03	0.09
TiO ₂	0.05	0.03	0.02	0.03
ZrO ₂	tr	...	tr	...
P ₂ O ₅	0.13	0.36	0.05	0.08
Cl	0.002	...	0.003	0.003
F	0.64	0.29	0.44	0.42
S	0.00	...	0.00	0.00
	100.11	100.26	100.44	99.92
Less OmF	0.27	0.13	0.19	0.18
Total	99.84	100.13	100.25	99.74

- Weighted composite of chips from quarry and underground workings, and of core-splits from diamond-drill holes. C. O. Ingamells, analyst.
- Composite of chips from 1/2- to 1-inch hanging-wall border rind exposed in main quarry. F. S. Grimaldi, analyst.
- Weighted composite of chips from quarry and underground workings, and of core-splits from diamond-drill holes. E. K. Oslund and C. O. Ingamells, analysts.
- Composite of chips from 1-foot square grid on south wall of quarry. C. O. Ingamells, analyst.

cline, and topaz, and as complex intergrowths with cleave-1 andite. Gray to faintly lavender-gray Li-muscovite also impregnates quartzose wall rocks in several places along main dike.

Characteristic variations in appearance and alkali composition among Harding muscovites are indicated in Table 2. See also Roos (1926), Schaller and Henderson (1926), Heinrich and Levinson (1953), and Rimal (1962).

Lepidolite [$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$]. Most abundant in "spotted rock" and other interior zones of main dike as finely crystalline to extremely fine-grained translucent, waxy-appearing masses 0.2 in. to tens of ft in maximum dimension. Color bluish gray, wine red, lilac, lavender, and pale to deep purple, with general range of 3.5 to 4.6 percent contained Li₂O. Also forms fracture fillings, embayments, and replacement masses in microcline, less commonly in spodumene. Occurs with quartz and albite in several dikes and outer parts of main dike as individual thick crystals and as aggregates of lilac to pale purple flakes and plates 0.1 to 0.3 in. in diameter. Some larger plates, 0.2 to 0.7 in. across, comprise several smaller crystals, each elongated parallel to its c-axis and rotated about this axis relative to its neighbor, giving the three-dimensional appearance of single tapering crystals or narrow sprays of slender prisms.

Characteristic variations in appearance and alkali compositions among Harding lepidolites are indicated in Table 2. Distinction from the muscovites often is difficult, as many of the properties and associations are similar, but in general the

lepidolites are slightly more bluish and are readily fusible on thin edges exposed to a hot flame. Firm identification ordinarily requires chemical analysis, optical studies under the microscope, or X-ray determination of crystal structure. See also Levinson (1953) and Rimal (1-962).

Spodumene [$LiAlSi_2O_6$]. Typically white to very light gray, but faintly greenish or yellowish on many freshly broken surfaces. Abundant in massive quartz as thin, slightly tapering, lath-shaped crystals and crystal fragments a few inches to several feet long, arranged in various parallel, radiating, and crisscrossing patterns (Figs. 2, 6). Largest observed individual 14 ft long, 4 to 11 in. wide, and 0.5 to 0.9 in. thick. Most crystals broken along cross-fractures, with fissure fillings of quartz (Fig. 6) and rarely microcline. Also abundant in "spotted rock" as discoidal crystal fragments, 0.5 to 3 in. in diameter, with irregular but grossly rounded margins, and in adjacent lithium-rich parts of main dike as jackstraw aggregates of laths 2 to 30 in. long (Fig. 8). In a few pods and veins of dark smoky quartz as small, pale gray-green euhedral crystals. Most crystals in interior parts of dikes are corroded, veined, and partly replaced by various aggregates of lepidolite, Li-muscovite, rose muscovite, albite, and quartz. Some also are partly altered to very fine-grained eucryptite, micas, and albite. Li₂O content of relatively fresh crystals ranges from 6.0 to nearly 7.2 percent, with average of about 6.8 percent.

Principal Accessory Minerals

Apatite [$Ca_5(PO_4)_3(F,OH,Cl)$]. Irregular anhedral masses

TABLE 2. VARIATIONS IN APPEARANCE AND COMPOSITION AMONG PRINCIPAL MICAS IN MAIN QUARRY, HARDING MINE

Location of Specimens	Mica	Crystal Size (in.) and Form		Color	Composition				
					K ₂ O	Na ₂ O	Li ₂ O	Rb ₂ O	Cs ₂ O
Beryl-bearing hanging-wall zone	Muscovite	0.2-0.8	Flakes	Pale yel.-grn	8.2	0.96	0.60	0.55	0.02
	Muscovite*	...	and	Pale green	7.9	...	0.71	0.63	0.06
	Lepidolite	0.1-0.2	plates	Lilac	10.2	0.45	3.49	1.20	0.29
"Spotted rock" and masses of rich lepidolite ore	Lepidolite*	0.02-0.1	Flakes and plates	Lavender	10.6	0.35	4.06	1.60	0.64
	Lepidolite	0.01-0.1		Wine red	10.5	0.57	3.91	1.36	0.44
	Lepidolite	0.02-0.05	Extremely fine-grained, wax-like aggregates	Lilac	...	...	3.93	...	...
	Li-muscovite	0.02-0.15		Pale lilac	...	...	1.76	...	...
	Lepidolite			Lav.-purple	9.6	2.32	4.51	...	...
	Lepidolite			Deep purple	9.8	1.90	4.40	1.62	0.77
	Li-muscovite#			Lilac	7.1	4.17	2.36	...	...
Lepidolite		Purple	...	...	3.78	...	...
Mica-rich masses beneath quartz-lath spodumene zone	Li-muscovite*	0.05-0.2	Flakes and plates	Pale lav.-white	10.1	0.55	1.17	0.96	0.43
	Li-muscovite#	0.03-0.2		Pale gray	6.0	1.12	1.03	...	...
	Li-muscovite	0.03-0.1		Pale gray	...	...	3.20	...	...
	Li-muscovite	0.03-0.2		Pearl gray	...	...	1.76	...	...
Rich microlite-spodumene ore	Lepidolite	0.01-0.1	Thin to very thick plates	Lavender	...	...	3.84	...	...
	Li-muscovite	0.01-0.2		Lilac	...	...	3.26	...	...
	Li-muscovite	0.01-0.2		Pale lilac	...	...	1.68	...	...
Bodies of quartz-cleavelandite pegmatite	Muscovite	0.01-	Flakes and plates	Rose	10.5	0.82	0.24	0.80	0.31
	Muscovite*	0.75		Rose	10.4	0.67	0.29	0.86	0.28
* Analysis from Rimal (1962).									
# Analysis from Roos (1926).									

and stubby, rough-faced crystals 0.2 to 5 in. in maximum dimension. Dark greenish blue to very deep blue, and strongly fluorescent yellow-gray under ultraviolet light. Some crystals markedly color zoned, with blue interiors and gray, non-fluorescent rinds. Occurs mainly near walls of dikes, and locally in quartz-lath spodumene pegmatite.

Beryl [$\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$]. Widespread in nearly all dikes, but by far most abundant along and near walls of main dike as equant anhedral to subhedral crystals 0.5 in. to 5 ft across, in places forming coarse lens- and layer-like aggregates of considerable tonnage. Rude basal cleavage locally prominent. Some large crystals with rough basal, prism, and pyramidal faces, and a few noted by Arthur Montgomery as enclosing prismatic phantoms 3 to 4 in. long and 0.2 to 0.5 in. in diameter. Milky white, gray, and faintly pinkish, greenish, or yellow-greenish, typically with resinous or greasy luster. Interior parts of some crystals pale rose and transparent, with vitreous luster and conchoidal fracture. Also occurs in interior parts of quartz, lath-spodumene zone as white to pink equant crystals 0.3 to 4 in. in diameter; anhedral to subhedral and in part transparent. Locally abundant as small, white to pale pink and yellowish gray tablets with hexagonal outline in light to dark smoky quartz of core pegmatite, especially in eastern parts of main dike. Present sparingly in at least three other dikes as pale yellowish green stubby prismatic crystals 0.5 to 2 in. long. Locally in adjacent country rocks as blue to greenish blue

prisms and anhedral crystals within small cleft-like cavities, where associated with crystals of quartz, schorlite, epidote, garnet, and magnetite.

Variations in form, color, index of refraction, and some aspects of composition among Harding beryls are indicated in Table 3. Corresponding to occurrence from the walls inward to the core of the main dike are shifts in crystal habit from prismatic to equant to tabular, a general increase in co index of refraction, a general decrease in BeO content, and general increases in contents of Li₂O, Na₂O, and Cs₂O. Common low-alkali beryl apparently occurs only in thin dikes with no conspicuous lithium mineralization. The blue beryl from small cavities in the country rocks is unusual in its high content of both BeO and alkalis, and it may be Li-poor and Fe-rich like the variety reported from Arizona by Schaller and others (1962).

Garnets [(Mn,Fe)₃Al₂(SiO₄)₃]. Wine red almandine as small, widely scattered crystals. Locally abundant in fine-grained footwall rocks of main dike. Pale salmon pink to orange-red spessartine sparse to abundant in interior parts of lithium-bearing dikes, and common in albite-rich pegmatite of the main dike as rough dodecahedral crystals 0.05 to 1.2 in. in diameter. Larger crystals much fractured, and some heavily stained by manganese oxides.

Microcline-pyroxhlore [(Na,Ca,U)₂(Ta,Nb)₂O₆(O,OH,F)]. Small grains and crystals with octahedral or dodecahedral form

TABLE 3. VARIATIONS IN COMPOSITION AND PHYSICAL PROPERTIES OF BERYL SPECIMENS FROM THE HARDING MINE AREA

Location of Specimen			Crystal Size and Form	Color	ω Index of Refraction	Composition			
						BeO	Li ₂ O	Na ₂ O	Cs ₂ O
Main pegmatite body	Hanging-wall zone, main west beryl workings	Main room	>8 in., anhedral	V. pale pink	1.583	12.62	0.50	1.09	0.51
		Main room	4 ft, anhedral	V. pale pink ⁺	1.582	12.77	0.62	1.14	0.44
		Main room	3 ft, anhedral	White	1.592	11.49	...	...	2.07
		South room	>2 ft, anhedral	Pale pink	1.584	12.61	...	...	0.52
		South room	15 in., subhedral	White	1.583	12.69	...	...	0.55
		Near Hole 30	6 in., anhedral	Pale gray	1.583	12.7*	...	...	...
		East room	7 in., subhedral	Greenish gray	1.584	12.6*	...	...	...
	Footwall zone	Main entry	3 in., anhedral	V. pale pink	1.586	12.4*	...	...	...
	Quartz-spodumene zone, central workings	Portal, old room	4 in., anhedral	Pink, gemmy ⁺	1.588	12.17	0.58	0.74	0.51
		East wall of room	3 in., subhedral	Pale pink	1.588	12.31	...	...	0.49
		Near face, long tunnel	11 in., subhedral	Pale pink	1.589	12.0*	...	...	...
		Winze, long tunnel	2 in. tablet	White	1.592	11.62	0.80	1.04	1.46
	Pods and veinlets of smoky quartz, east workings	Old east tunnel	1 in. euhedral	White	1.592	11.43	...	...	2.21
Quarry face		1 1/2 in. basal	V. pale pink ⁺	1.593	11.39	1.16	1.40	2.86	
Quarry face		1 in. tablets	V. pale pink ⁺	1.592	11.55	1.14	1.60	2.21	
Microcline cut		2 in.	White	1.594	11.2*	...	...	...
Thin dike, N.Knob	Prospect pit	1 1/2 in. prism	Pale yel.-green	1.576	13.41	...	...	0.10	
East dike	Quartz-cleavelandite pegmatite	West end pit	2 in. tablet	Pale yel.-white	1.594	11.2*	...	...	...
		Quartz slope	>4 in., anhedral	White	1.583	12.7*	...	...	...
		Main cut	>5 in., anhedral	Pink	1.586	12.4*	...	...	...
East ridge	Country rock above east dike	Near east end	<1 in., anhedral	Med. blue	1.586	13.11#	...	...	...
		Near main cut	1/2 in. prism	Med. blue	1.595	13.23#	0.39	0.90	3.14
		Near main cut	1/2 in., anhedral	Med. grn.-blue	1.593	13.21#	...	...	...

* Estimated from ω index of refraction.

+ Analysis courtesy of Petr Černý, University of Manitoba.

Probably an iron-rich variety of alkali beryl.

and many modifying faces, larger subhedral and roughly euhedral crystals 0.2 to 0.8 in. across, and rare crystals reportedly as large as 3 in. Chiefly as dispersed individuals in "spotted rock," in aggregates of lepidolite and Li-muscovite, and along margins of spodumene crystals; also as local dense concentrations (Fig. 3). White, pale yellow to honey-yellow, yellowish to bronzy brown, dark maroon, and dark reddish brown to nearly black, with dull to vitreous luster. Many crystals color zoned, generally with lighter cores and darker rims. Darkest material metamict or nearly so.

Typical variations in composition among Harding microlites are shown in Table 4. With reference to the general formula $A_2 B_{20}6X$, A in these materials is chiefly Ca, Na, and U with very minor K, Mn, Fe, and Th. B is Ta and Nb with a little Ti, and X includes both OH and F. The range from light to dark colors can be correlated with progressive decreases in Ta+Nb content and Ta/Nb ratio, and with progressive increases in OH/F ratio and U, Ti, and Mn content. The weight ratio of Ta_2O_5 to $Ta_2O_5+Nb_2O_5$ is typically 0.86 to 0.89 for the darkest material, averages about 0.92 for the brownish yellow, and is 0.93 to 0.95 for the palest yellow to off-white material. Of the 45 Harding specimens and bulk concentrates that have been analyzed, all have proved to be tantalum-rich, and hence to be microlite rather than pyrochlore. The uranian microlite, with a known maximum content of about 10 percent of UO_2+UO_3 , commonly has been referred to the variety hatchettolite, even though it is not in the pyrochlore range.

Tantalite-columbite $[(Fe,Mn)(Ta,Nb)_2O_6]$. In outer parts of dikes as blade-like to thickly tabular black crystals with dull to very bright luster. Most crystals 0.2 to 1.3 in. in maximum dimension, but a few 3- to 4-in. waterworn chunks found in nearby placer deposits. Also scattered through "spotted rock" and other internal units as thick blades, plates, and equant crystals 0.05 to 0.8 in. in maximum dimension, generally in

association with microlite. In part roughly cleavable. Rare mahogany-brown manganotantalite, associated with albite in interior parts of main dike, forms 0.3- to 1.5 in. tablets with distinct cleavage and bright, slightly resinous luster. Some crystals zoned, with thick rims of black tantalite. Very rare bismutotantalite occurs as small, irregular residua in masses of earthy yellow bismutite found locally in coarse-grained quartz.

The 18 samples of Harding tantalite-columbite thus far analyzed have ranged from Ta-rich columbite to nearly pure tantalite, with weight ratios of Ta₂O₅ to Ta₂O₅+Nb₂O₅ ranging from 0.45 to 0.94. The ratios for most crystals in the hanging-wall zone of the main dike probably are near 0.6, and those for crystals in the "spotted rock" near 0.8.

PEGMATITE GENESIS

The Harding pegmatite bodies are best explained as products of highly differentiated rest-liquid derived from granitic magma and injected into already deformed and regionally metamorphosed host rocks at considerable depth. An igneous origin, rather than metasomatic or metamorphic derivation from the host terrane, is indicated by several features of occurrence. The bodies are distinctly discordant in most places, for example, and they are sharply bounded from the country rocks. Local severe deformation of these rocks adjacent to margins of the bodies, clearly superimposed upon the results of earlier regional deformation, bespeaks forceful injection of pegmatite magma. Internal zoning of the dikes reveals a consistent paragenetic sequence of major minerals, and the gross geometry of these zones reflects the shapes of the containing bodies rather than features of the enclosing metamorphic rocks. The dikes themselves show no significant compositional variations that could be correlated with lithologically contrasting parts of the adjacent metamorphic terrane. Further, the pegmatites contain suites of Be, Li, Nb, Ta, U, and other trace elements at high concentration levels that are more compatible with an igneous than with a directly metamorphic derivation.

The pegmatites are not obviously related, in either spatial or compositional senses, to any of the exposed granitic plutonites in the region. They are not systematically distributed with respect to the plutons, nor do they reflect the regional metamorphism that left its stamp on most of the other rocks. If the remarkable abundances of rare elements in the Harding pegmatites are attributed to extreme magmatic differentiation, the compositions of known granitic plutonites of the region do not identify them as attractive candidates for a cogenetic relationship. The quartz monzonites in areas south and east of the Harding occurrences, for example, are very low-Ta, high-Ti rocks whereas the pegmatites are very rich in Ta and poor in Ti. The contrasting match-ups among these and other minor constituents are difficult to reconcile with any simple model of genetic association. Perhaps more important, the pegmatites may well be much younger than the youngest of the exposed granitic rocks (Long, 1974), and they may also represent a deeper level of emplacement.

Like the pegmatites of the Petaca District west of the Rio Grande (Jahns, 1974), those in the Harding area probably were emplaced at depths of 7 miles or more, and were slowly cooled under high confining pressure in the presence of a halide-rich aqueous fluid. Emplacement was accomplished in a terrane of pervasively deformed rocks with relatively high metamorphic rank, and it occurred long after dacitic and other igneous rocks

TABLE 4. VARIATIONS IN COMPOSITION AMONG TYPICAL VARIETIES OF MICROLITE* FROM MAIN QUARRY, HARDING MINE

	Microlite	Microlite	Microlite	Uranian Microlite	Uranian Microlite
	Very pale yellowish white	Light yellow	Pale brownish yellow	Very dark reddish brown	Nearly black
Ta ₂ O ₅	75.52	75.58	72.34	60.20	59.05
Nb ₂ O ₅	5.16	5.80	6.66	8.26	9.32
TiO ₂	0.00	0.13	0.16	0.90	0.89
Fe ₂ O ₃	0.02	...	...	...	0.08
FeO	0.03	0.10	0.14	0.06	...
MnO	0.00	0.00	0.01	0.35	0.77
MgO	0.00	0.03	0.00	0.08	0.19
CaO	10.86	10.36	10.45	9.53	9.46
Na ₂ O	5.45	5.13	4.60	2.60	2.03
K ₂ O	0.08	0.03	0.09	0.22	0.22
ThO ₂	0.04	0.00	0.01	0.11	0.02
UO ₂	0.01	0.10	0.32	0.27	0.00
UO ₃	...	...	1.63	8.19	7.73
H ₂ O	0.14	0.32	0.78	2.24	2.20#
F	3.62	3.25	3.04	1.67	1.58
	100.93	100.83	100.23	94.68	93.54
Less OmF	1.51	1.37	1.28	0.70	0.66
Total	99.42	99.46	98.95 ⁺	93.98 ^o	92.88 ^o

* Analyzed grain samples hand picked from materials separated in Clerici solution after removal of magnetic fraction. C. O. Inzsmells, analyst.

Estimated from loss on ignition.

+ Does not include 0.75 SiO₂+Al₂O₃+2rO.

o Does not include approximately 5.3 SiO₂+Al₂O₃+2rO.

TABLE 5. MINOR ACCESSORY MINERALS OF THE HARDING PEGMATITE

Silicates		Oxides	Carbonates	Phosphates	Sulfides Arsenides	Other
allanite	eucryptite	bismite	azurite	amblygonite	bismuthinite	bismuth
amphibole	illite	cassiterite	beyerite	lithiophilite	chalcocite	fluorite
andalusite	kaolinite	gahnite	bismutite	monazite	chalcopyrite	
bertrandite	montmorillonite	ilmenite	calcite	wavellite	loellingite	
biotite	pyrophyllite	limonite	malachite		pyrite	
chloritoid	thorite	magnetite				
chrysocolla	topaz	pyrolusite				
cordierite	tourmaline	rutile				
epidote	zircon	sphene				
		tenorite				

were formed at relatively shallow depths. Many of the pegmatite bodies are fringed by zones of metasomatic reaction with the wall rocks, and none of them contains crystal-lined pockets or primary cavities. Nor are they associated with aplitic rocks of the kind formed by sudden relief of confining pressure. The potent fluxing effect of volatile constituents held in magmatic solution under high pressure is attested by subsolvus crystallization of alkali feldspars in the pegmatite bodies, and especially by primary formation of nearly pure K and Na phases in their central parts.

Further discussion of the nature, gross segregation, and observed paragenetic relationships of the pegmatite minerals cannot be offered here, but in sum these features are compatible with the genetic model for pegmatite crystallization outlined by Jahns and Burnham (1969) on the basis of field, petrographic, and experimental investigations. Most of the crystallization probably occurred in the presence of both silicate melt and dense aqueous vapor rich in F and Cl, and nearly all the remainder in the presence of the vapor. Existence of this vapor can be inferred on several grounds, and is more directly attested by numerous fluid inclusions in the pegmatite quartz and beryl. Its influences as a catalyst and as a medium for material transfer are implicit in the metasomatic interactions between dikes and country rocks, in the nearly complete unmixing of early-formed alkali feldspars to yield coarse perthite, in the leaching of calcium from the feldspars for fixing in microlite and late-stage apatite, and in widespread mineral recrystallization and replacement under both hyper-solidus and subsolidus conditions. The most extensive of the replacement reactions led to formation of albite at the expense of quartz and microcline, and micas at the expense of microcline and spodumene.

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