PEGMATITE RESOURCES IN THE SOUTHWEST

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ABSTRACT

Although quantitative appraisal of pegmatite resources is at present precluded by numerous and serious gaps in basic data, it is possible to trace the occurrence of pegmatite deposits in the Southwest, to classify them geologically, and to indicate areas and types of deposits that offer maximum or minimum economic promise.

The pegmatites of the Southwestern States occur chiefly in (1) the Rocky Mountain belt of northern New Mexico; (2) the Basin and Range belt of southeastern California, southern Nevada, west-central and southern Arizona, southwestern New Mexico, western Texas, and adjacent parts of Mexico; (3) the Peninsular Range belt of southern California and Baja California; and (4) the Sierra Nevada belt of south-central California. The pegmatites in the two first-named belts are pre-Cambrian, and occur mainly in schists and gneisses, whereas those in the California belts are late Mesozoic in age and occur mainly in igneous rocks. Nearly all forms of pegmatite bodies are represented, and those bodies of commercial promise show well defined internal zoning. Many also contain fracture fillings and replacement bodies of one or more minerals.

Nearly all the pegmatites are truly granitic in composition, with abundant potash feldspar. Trends in distribution of commercially desirable minerals can be summarized with respect to beryl, feldspar, gem minerals, lithium minerals, mica, and tantalum-columbium minerals. These trends are only partly reflected by commercial exploitation to date, as many of the deposits are undeveloped.

Most Southwestern pegmatite deposits face the handicap of relatively high transportation costs to centers of demand, but there are fair possibilities for future development. These probably could be improved by increased use of geologic data in exploration, development, and mining, and especially by improvements in mining and milling techniques. It seems likely that numerous exposed pegmatite deposits remain to be discovered in the Southwestern region.

INTRODUCTION

Pegmatite deposits are best known commercially as sources of beryllium, tantalum-columbium, and lithium minerals, sheet and scrap mica, feldspar, and certain types of clay and gem minerals. So far as their bulk or the value of their output is concerned, these materials are overshadowed by numerous other commodities, yet they satisfy important requirements in domestic industry. The demands of the ceramic industry, for example, provide markets for feldspar, lepidolite and other lithium minerals, clays of pegmatite origin, beryllium minerals, some types of mica and pegmatite quartz, and numerous minor metals and non-metals. The electrical industry is a particularly heavy user of mica and of many ceramic products derived at least in part from pegmatite deposits. In addition, there are many highly specialized commercial applications of pegmatite minerals, based mainly upon certain unusual or even unique properties of these minerals or of compounds obtained from them.

Systemite pegmatite mining in the United States dates from the seventeenth century, when coarse muscovite was split for window-pane material in northern New Mexico. Prior to that time, the Aborigenes in various parts of the country had worked some deposits by very crude methods, obtaining mica and other minerals for ornaments or for use as media of exchange. With the beginning of the modern epoch of mining in the early part of the nineteenth century, numerous deposits were developed sufficiently to reveal something of their three-dimensional form. Additional deposits were encountered as the country was more and more widely settled, and many of them were tested by prospecting or mining operations. Rarely did the discovery rate lag sufficiently to seriously reduce the typical high supply-demand ratio for some pegmatite commodities, although for others we were forced to depend then, as now, upon imports from abroad. The degree of this dependence has varied considerably from commodity to commodity and from time to time, founded as it has been upon relative richness and quality of the deposits, their relative accessibility, labor costs, and numerous other factors.

There was little systematic search for new areas of pegmatite deposits prior to World War I, owing to adequate supplies from existing foreign and domestic sources at fairly low price schedules. New deposits were discovered, to be sure, but most of the discoveries either were made during scrutiny of the areas immediately adjacent to known deposits, or were purely accidental. Indeed, several large pegmatites in the Southwestern States were originally prospected for gold, silver, or other metals, on the basis of erroneous assumptions that they might yield commercial quantities of these elements.

During World War I, when the concept of "strategic minerals" was taking form in this country, some effort was made by the U.S. Geological Survey and other organizations to appraise the domestic resources of pegmatite minerals. Valuable information was obtained, but this program was severely curtailed as a result of the war's termination. It remained for World War II to again forcefully demonstrate the real need for careful and much more complete evaluation of the Nation's resources. Great wartime increases in demand and concomitant uncertainties in foreign sources of supply made it necessary to stimulate domestic discovery and production as much as possible, particularly with respect to such pegmatite commodities as beryl, tantalum-columbium minerals, and sheet muscovite of high quality. (1, 15, 20).*

During the period 1939-1946 several Federal and State agencies devoted hundreds of man years to studies of domestic deposits of all minerals that were in short supply, and a substantial part of this time and effort was directed toward pegmatite deposits. The results of these and earlier investigations were analysed in 1944, and were subsequently presented in integrated form as the first quantitative appraisal of the mineral position of the United States (18). This sort of appraisal appears to reflect a general trend in basic philosophy among those concerned with the Nation's mineral resources. More and more complete data are being sought in advance of periods of critical need, both for direct application to economic and geologic problems and for more extended use in making generalizations to guide broad exploration for new deposits.

The scope of current analyses of domestic resources is seriously restricted

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* Numbers in parentheses apply to references listed at end of paper.

by deficiencies in data, as pointed out and discussed by Lasky (18, pp. 187-190). Many of these deficiencies constitute formidable obstacles, so far as pegmatite deposits are concerned, and they commonly involve data that would be extremely difficult to obtain. This is particularly true for the southwestern part of the United States, where pegmatite deposits have not been opened up to the extent common in several other parts of the country, and where production records and data on grade are fragmentary or are not available at all. Moreover, deposits in Southwestern pegmatites -- as those in pegmatites almost anywhere -- rarely are developed far in advance of mining, so that it commonly is impossible to judge the probable tonnage and grade of their reserves except by geologic inference.

Despite the factors that at present preclude a full quantitative appraisal of pegmatite resources in the Southwest, some sort of start might well be made on such an appraisal -- even if only in qualitative terms -- to aid in making a fuller ultimate evaluation. With data now at hand, it is possible to trace the occurrence of pegmatite deposits in the Southwestern States, to classify these deposits geologically and in terms of what commodities they yield or might yield, and to indicate areas and even types of deposits that are worthy of relatively little or relatively great economic consideration. Such generalizations may be useful in aiding new discoveries by the directing of attention toward broadly defined areas of greatest promise, as well as away from areas that hold little or no promise for future discovery or development.

DISTRIBUTION AND OCCURRENCE OF THE PEGMATITES

The region under consideration, herein termed "the Southwest", embraces Arizona, New Mexico, the Texas Panhandle, those parts of California and Nevada that lie south of the 37th parallel, and adjacent parts of Mexico. In this region there are four principal areas in which masses of pegmatite are known to occur in relative abundance.

The easternmost area lies in northern New Mexico, and constitutes the southern tip of the Southern Rocky Mountain province. West of the Rio Grande it includes the southern extension of the San Juan Mountains; east of the Rio Grande, the southern part of the Sangre de Cristo Range. In general the deposits lie north of the latitude of Santa Fe and Las Vegas. The pegmatites occur in crystalline rocks, chiefly schists and gneisses, and in some areas they are genetically associated with large intrusive masses of granitic composition. All the rocks appear to be pre-Cambrian in age.

The pegmatites, which have been described in some detail by Sterrett (16), Just (8), and Jahns (3, 4, 5, 6), form the southern part of an extensive belt of deposits that can be traced northward through the Rocky Mountains of Colorado and southeastern Wyoming. The numerous pegmatites in the Black Hills uplift of South Dakota may well form a part of this same great belt.

The second pegmatite area is large but rather well defined. It extends from the southern tip of Nevada and the immediately adjacent parts of California south-southeastward and southeastward through western and west-central Arizona, and thence east-southeastward through southeastern Arizona and southwestern New Mexico into the Texas Panhandle. Part of this crescentic belt, which is concave toward the northeast, also lies in northern Mexico. The area as a whole is in the southern and southeastern parts of the Basin and Range province, although little of it lies in the Great Basin itself.

The pegmatites, like those of the Rocky Mountain belt of New Mexico, occur in schists, gneisses, and other crystalline rocks, and are pre-Cambrian in age. Indeed, the pegmatite belt can be followed in a general way on the geologic map of the United States by means of the pattern shown for pre-Cambrian rocks. Unlike the pegmatites in the Rocky Mountain belt, few of those in this more southwesterly area have received much attention directed toward their possible commercial exploitation.

The third pegmatite belt lies in the Peninsular Range province of southwestern California and northern Baja California. From the southern margin of the Los Angeles-San Bernardino Basin area, it trends south-southwest for a distance of more than 300 miles. The pegmatites occur in igneous rocks, chiefly of gabbroic type, and are late Mesozoic in age. They are genetically associated with a great composite intrusive mass known as the Southern California batholith. Both the pegmatites and some of the deposits in them have been described by Waring (19), Kunz (10), Merrill (11), Schaller (12), Jahns and Wright (7), and others.

The fourth belt lies farther to the northwest in California, and includes parts of the Tehachapi and southern Sierra Nevada Ranges. The pegmatite-bearing area extends from points in the vicinity of Mojave northeastward and north-northeastward into the higher Sierra Nevada. Geologically the area is somewhat like the Peninsular Range belt, in that both the pegmatites and the genetically associated igneous rocks are late Mesozoic in age, and are parts of a large, complex batholithic mass. The pegmatites occur in granitic, rather than gabbroic rocks, however, and many of them are in migmatites or in schists of pre-batholith age.

The four major belts extend across large areas in which pegmatite masses are rare or absent. The Rocky Mountain and Basin and Range belts are separated in central New Mexico by parts of the Basin and Range province in which few pre-Cambrian rocks are exposed. Elsewhere they are separated by the broad southerly part of the Colorado Plateau province, which is underlain mainly by Paleozoic and younger sedimentary rocks, and by great masses of Tertiary volcanic rocks. Virtually the only pegmatites known from the Colorado Plateau province are those in relatively small areas of pre-Cambrian rocks that have been exposed in deep canyons like that of the Colorado River or in cores of broad uplifts like that of the Zuni Mountains of west-central New Mexico. Some interesting pegmatites, apparently of Tertiary age, occur locally within the volcanic rocks in parts of southwestern New Mexico, but these are of little economic importance except as small-scale sources of the gem material moonstone.

Whereas the rocks along the northeastern edge of the Basin and Range pegmatite belt disappear abruptly beneath the younger rocks of the Colorado Plateau province, the west edge of the belt is less sharply defined. A broad area in southeastern California, known as the Mojave region,, includes numerous exposed masses of pre-Cambrian rocks, but with few exceptions these are barren of pegmatites. Similarly, the so-called Transverse Ranges, which separate the Peninsular Range and the Sierra Nevada pegmatite belts, are virtually pegmatite-free, even though they are underlain chiefly by crystalline rocks.

STRUCTURAL FEATURES OF THE PEGMATITES

Nearly all shapes of pegmatite bodies are represented in all four of the major pegmatite belts. On the other hand, certain forms predominate in certain districts. In the Rocky Mountain belt the pegmatites occur as steeply dipping dikes, sills, pipes, elongate pods, trough-shaped bodies, and masses of more irregular shape. They are mainly moderately thick lenses with rather stubby ends, although a few have great along-strike continuity and hence are more tabular in shape. The average length of the pegmatites that have been prospected or worked commercially is about 500 feet at the surface, and their average thickness is about 30 feet. The plunges of most pegmatite masses in this belt can be correlated with plunges of minor structural elements in the adjacent foliated country rock.

Relations in the Basin and Range province are similar, but in general there is a higher proportion of thick pods and plug-like masses. In some districts the pegmatites tend to be conformable with the country-rock structure, but most of them transect it in detail.

Some pods and other thick masses also occur in the two California belts, and numerous more irregular bodies are known as well. The great bulk of the pegmatites, however, are dikes with remarkable along-strike and down-dip dimensions relative to their thickness. Those that have been prospected or mined are about 800 feet in average length and 10 feet or slightly less in average thickness. In most districts such dikes are very uniform in attitude, with moderate to gentle dips. Neither their general form nor their minor irregularities ordinarily can be correlated with any structural features in the wall rock, although there are some exceptions in the Sierra Nevada belt. Most of these exceptions are involved in pegmatites that are enclosed by schist or gneiss.

Many pegmatites in all the belts are rather homogeneous internally, in that they are simple aggregates of quartz, feldspar, and accessory minerals. They show no marked change in mineral composition or texture from one wall to the other, or from one end to the other. Nearly all the pegmatites of commercial interest, however, are in sharp contrast to these. They show a systematic internal arrangement of their constituent minerals. Differences in mineralogy or textures, or in both, permit their ready subdivision into distinct lithologic units. Some of these internal units clearly were formed by the filling of fractures in pre-existing pegmatite, and others were developed by replacement of pre-existing pegmatite. Perhaps the bulk of these units, however, appear to have been formed earlier as successive shells from the walls of the pegmatite bodies inward. These have been termed pegmatite zones by many geologists who have studied them during recent years (2), but were recognized and described under several different names by earlier geologists.

The internal structure of zoned pegmatites is remarkably consistent from one belt to another. The outer zones are generally granitoid in texture, and are fine- to coarse-grained aggregates of feldspar and quartz, with or without micas and with or without accessory minerals. The inner zones, in contrast, are essentially monomineralic or consist of two or more minerals in giant-textured aggregates. Microcline, much of it with graphically intergrown quartz, is abundant near the walls of many pegmatites, but where both plagioclase and potash feldspar are present in a given pegmatite body, the plagioclase is ordinarily in zones nearer the walls. A noteworthy exception is the cleavelandite variety of albite, which has a much wider distribution and is a common constituent of fracture fillings and replacement bodies. Quartz and potash feldspar are the most abundant minerals in the inner zones. The quartz is accompanied by spodumene in most of the lithium-rich pegmatites.

Brown to pale green muscovite is abundant near the walls of many pegmatite bodies, whereas green to yellowish green muscovite is more common in the inner zones and in fracture fillings and replacement bodies. Amblygonite ordinarily accompanies spodumene in the central parts of pegmatite masses, but is not nearly so widespread. Lepidolite, in contrast, is a later constituent, and commonly forms irregular fracture fillings and replacement bodies. It is generally associated with cleavelandite.

Beryl is present in both zones and other units, but most of the very coarse-grained material that is recoverable by the hand-sorting methods now in use occurs in the inner zones of pegmatite bodies, where it is ordinarily associated with quartz and coarse potash feldspar. Large quantities of finer-grained beryl occur in the outer zones of many pegmatites, but generally require some mechanical means for satisfactory separation and recovery. The quantity of industrial beryl in fracture fillings and replacement bodies is of little commercial significance, but most of the gem beryl produced in the Southwestern States occurs in such units.

Tantalum-columbium minerals are widespread in their occurence with respect to the walls of the pegmatite bodies. They form fine-grained disseminations in or near the cores of some large pegmatite bodies, and disseminations in the outer zones of others. In still others, they occur in fracture fillings and replacement bodies, commonly as well formed crystals. Both gem minerals and rare-earth minerals appear to be rather sporadic in their distribution, but in general are confined to fracture fillings or to deposits of replacement origin. Most of their irregularities are irregularities of detail, in that they appear to follow broadly consistent structural patterns in most pegmatites.

Tourmaline is most abundant in the central parts of the pegmatite bodies in which it occurs. Black varieties are common in some districts, but the green, pink, and other colored gem varieties are less abundant. Most of these occur only in the so-called "pocket zones" of some pegmatites, where they appear to be in part of replacement origin.

These generalizations apply with remarkable consistency, not only to pegmatites in the Southwest, but to those in other parts of the United States as well (2, 5). The internal structure of pegmatites that can be subdivided into two or more units typically reflects the overall shapes of the bodies themselves. The sequence of minerals from outer to inner zones follows the same broad pattern from pegmatite to pegmatite, district to district, and from belt to belt, regardless of differences in age or general geologic environment of the pegmatites. Similar generalizations can be applied to the fracture fillings and replacement bodies, although they so commonly consist of varietal and accessory minerals that they are more subject to variation with minor variations in bulk composition of the containing pegmatites.

The potential economic value of such generalizations as these becomes evident in view of the typical occurrence of economically desirable minerals in rock units quite distinct from adjacent barren units within a given pegmatite body. Guarded application of these generalizations is of potential use in extending observations limited to two dimensions, in completing even the two-dimensional pattern of rock units in pagmatites that are very poorly exposed at the present surface, or in using the results of observations in one pegmatite to interpret obscure or incompletely exposed relations in another.

COMPOSITION OF THE PEGMATITES

Nearly all the pegmatites in all four belts are truly granitic in composition, with quartz and potash feldspar as their dominant minerals. The presence of much soda, however, is attested by the widespread occurrence of cleavelandite. A few pegmatites in the northern part of the Basin and Range belt contain abundant oligoclase in their outer zones, and are quartz monzonitic or even granodioritic in composition. These are the only pegmatites in the Southwest region that appear to contain coarse muscovite with moderate proportions of high-quality sheet material. Such muscovite generally is in the outer zones of the pegmatite bodies, although in a few it occurs around the margins of the innermost zones of very coarsely crystallized quartz.

Sheet muscovite of large size also is moderately abundant in several pegmatites in southern Nevada and adjacent parts of Arizona, but most of this material contains numerous inclusions of iron oxides, and hence is not suitable for the highest-quality electrical uses. Scrap muscovite is abundant in many of the Rocky Mountain pegmatites, and also in a few of those in the Basin and Range province.

In contrast, it is a widespread but sparse constituent of the pegmatites in the Peninsular Range and Sierra Nevada belts.

Coarse potash feldspar, both of No. 1 and of No. 2 grades, is abundant in numerous pegmatites of the Rocky Mountain and Basin and Range belts. It is most common in the inner pegmatite zones, where it ordinarily occurs with coarse-grained quartz. In contrast, such feldspar is a major constituent of pegmatites in only a few scattered areas of the California belts. In those areas, however, it is of commercial significance.

Coarse-grained aggregates of potash and soda-lime feldspars are locally abundant in both New Mexico and Arizona, but do not appear to be of great commercial interest at present. Such mixed feldspar, used chiefly in glass making, is obtainable from other pegmatites that are nearer domestic centers of demand.

Beryl is a sparse constituent of numerous pegmatites in both the Rocky Mountain and the Basin and Range belts, where it does not appear to be sufficiently abundant to justify mining aimed at its recovery alone. It has been obtained in lots amounting to a few tons or a few tens of tons as a by-product from operations for feldspar, mica, or tantalum-columbium minerals in some pegmatites, but most of it is so fine grained that it cannot be effectively treated by hand-sorting methods. Although beryl as a whole is not as common in the California belts, it is noteworthy in the Peninsular Range area because of its occurrence there as a gem. Such material has been recovered commercially from pegmatites in San Diego and Riverside Counties, California, in the amount of several hundreds of pounds.

Spodumene, lepidolite, and other lithium minerals are abundant in several pegmatites in the Rocky Mountain, Basin and Range, and Peninsular Range belts. Such minerals occurred or appear to occur in commercial quantities in at least pegmatites in the Sangre de Cristo Range of New Mexico, two others in San Diego County, California, and in several others in the part of the Basin and Range belt-between Kingman and Wickenburg, Arizona. Where present in greatest abundance, the spodumene is associated with quartz in the innermost zones, and the lepidolite forms large, irregular masses in the inner parts of the pegmatite bodies.

Tantalum-columbium minerals are remarkably abundant in a few pegmatites of the Rocky Mountain belt, and are present sparingly in numerous others. The minerals of greatest commercial significance are tantalite, columbite, microlite, and hatchettolite. They are relatively rare in pegmatites of the other belts, although surprisingly widespread.

Rare-earth minerals also are widespread, but in no pegmatite are they sufficiently abundant to warrant attempts at recovery except as minor by-products. The pegmatites that are richest in rare-earth minerals occur in the southernmost part of the Rocky Mountain belt, between Santa Fe and Las Vegas; in that part of the Basin and Range belt between Kingman and Wickenburg, Arizona; and in the northernmost part of the Peninsular Range belt. Gem minerals are extremely rare in all but the Peninsular Range belt, where clear varieties of beryl, garnet, quartz, spodumene, topaz, and tourmaline occur in numerous pegmatites, both in southern California and in Baja California.

The broad distribution of commercially desirable minerals in the pegmatites of the Southwest is summarized in the accompanying table. Some generalizations can be made on the basis of this summary. High-grade potash feldspars is most abundant in the pre-Cambrian pegmatites, or in those of the two eastern belts, and lower-grade material is abundant in all the belts. Also widespread are spodumene, lepidolite, and other lithium minerals. Coarse muscovite is common only in the pre-Cambrian pegmatites, and gem minerals only in the Mesozoic deposits. All the pegmatite areas contain beryllium, and this element is most abundant in pre-Cambrian deposits.

The pegmatites of the Rocky Mountain and Basin and Range belts are relatively rich in flourine and rare-earth constituents, but in general are boron-poor. In contrast, the younger pegmatites of the California belts are not nearly so rich in flourine, but contain abundant boron, as attested by the widespread occurrence of tourmaline. Some tungsten and tin minerals occur in pegmatites of the Basin and Range province, and all belts but the Sierra Nevada contain pegmatites with widespread lithium, columbium, tantalum, and manganese, as well as rare bismuth and copper.

PRESENT KNOWN OCCURRENCE OF COMMERCIALLY DESIRABLE MINERALS IN PEGMATITES OF THE SOUTHWEST 1/

Mineral	Pegmatite belt			
	Rocky Mountain	Basin and Range	Peninsular Range	Sierra Nevada
Coarse potash feldspar	Abundant	Abundant	Sparse	Sparse
Mixed soda and potash feldspars, coarse	Common 2/	Sparse	Sparse	Sparse
Coarse beryl	Sparse	Sparse	Very rare	Very rare
Coarse spodumene	Sparse	Sparse	Sparse	Not known
Lepidolite	Sparse	Rare	Sparse	Very rare
Sheet muscovite, clear	Sparse 3/	Sparse 4/	none known	None known
Sheet muscovite, stained	Rare	Sparse	none known	None known
Scrap muscovite	Abundant	Sparse	Very rare	Very rare
Tantalum-columbium minerals	Sparse	Rare	Rare	Very rare
Rare-earth minerals	Rare	Rare	Very rare	Very rare
Gem minerals	None known	Very rare	Common	Very Rare

Commercial quartz	Common 2/	Common 2/	Sparse	Common 2/

1/ Terms are intended to have commercial applications as follows:

Abundant -- major constituent of several pegmatites; commercially significant.

Common -- major constituent of only a few pegmatites; or sparse to moderately abundant in many; of lesser commercial significance.

Sparse -- major constituent of only one or two pegmatites, moderately abundant in a few, or sparse in many; of minor commercial significance.

Other designations are self explanatory.

2/ Rarely or never marketed because of low demand.

3/ Abundant coarse mica, but low proportion of recoverable sheet material.

4/ Moderately abundant in only a few pegmatites.

COMMERCIAL EXPLOITATION

The pegmatites of the Rocky Mountain belt have been worked in a small way for more than three centuries, chiefly for mica. Most deposits of coarse-grained mica occur in the Petaca district, west of the Rio Grande, and in a poorly defined area at the southern tip of the Sangre de Cristo Range between Santa Fe and Las Vegas. The chief output has been scrap muscovite that yields an unusually white product when ground, with by-product sheet muscovite, tantalum-columbium minerals, and a little feldspar. A few pegmatites farther north in the Sangre de Cristo Range have been worked for lithium minerals, and substantial quantities of lepidolite have been recovered from at least two, the Harding and the Pidlite. In addition, the Harding has yielded large quantities of tantalum-columbium minerals, as well as some by-product spodumene and beryl. Other Sangre de Cristo pegmatites have been worked in a small way for beryl and scrap mica.

Few of the pegmatites in the Basin and Range province have been developed commercially. Perhaps the most noteworthy exception is the large operation of the Consolidated Feldspar Company near Kingman, Arizona. Some sheet muscovite was obtained from deposits southwest of Kingman during World War II, and a few other pegmatites in that area, as well as in parts of the belt farther southeast, have been worked on a small scale for beryl. Several hundred pounds of gadolinite and other rare-earth minerals were obtained many years ago from deposits in the area between Kingman and Bagdad, Arizona.

The gem-bearing pegmatites of the Peninsular Range province have been mined intermittently since about 1890, but much of the easily recoverable material appears to have been worked out (7). The Stewart mine, in San Diego County, California, yielded large tonnages of lepidolite and some amblygonite and spodumene when it was operated during the period 1895-1928. Several pegmatites also were worked on a moderate scale for high-grade potash feldspar, both in the northernmost part of the belt and farther south, near the California-Mexico boundary. Silica was obtained from the cores of at least two pegmatite bodies in Riverside County, California.

Like those of the Basin and Range province, the pegmatites in the Sierra Nevada belt have been developed very little on a commercial scale. Some mining was done for beryl and rose quartz, and three much larger operations for potash feldspar are known. At least one of these, in the vicinity of Rosamond, California, has yielded substantial tonnages.

FUTURE POSSIBILITIES

Most pegmatite mining in the Southwest has been based upon production of minerals that command relatively high unit prices, such as tantalite and gems, or upon recovery of relatively high-quality types of such lower-priced materials as feldspar and certain grades of mica. This has been made necessary by the great distances of most deposits from centers of demands, with attendant high transportation costs. In the past, low labor costs in the Southwest aided materially in competition with Eastern areas of production, but a pronounced wage-scale differential no longer appears to exist.

In some districts, the output of pegmatite minerals has not resulted from operations in one or two deposits, but instead represents the sum of numerous very small-scale -- often individual -- operations. Two lepidolite mines, the Harding and the Stewart, and several feldspar mines represent the only large-scale pegmatite mining in the entire region, although widespread activity for gems in southern California and for scrap mica in the Petaca district of New Mexico should be mentioned as substantial contributors to Southwestern production.

Pegmatite mining in the Southwest, like that in most other parts of the country, has been carried on in terms of the obvious exposed features of the deposits being worked. Concentrations of commercially desirable minerals were followed downward from their outcrops until they were mined out or until it became impracticable to handle the material exposed in the lower parts of the mine workings. In many instances the workings themselves were developed haphazardly, so that they became too narrow and tortuous, or too much fouled with waste material to permit efficient handling of the broken pegmatite. The general process of "gophering", so widespread in most pegmatite mining, results not only in inefficiency of operation, but ordinarily is very wasteful, involving as it does the leaving of much valuable material in the ground adjacent to the workings, to say nothing of eliminating the chances for penetrating other, nearby concentrations of useful minerals. In some "gopher-hole" mines the development of workings was such that operations became inconvenient and unprofitable long before the deposits were worked out.

Just (8, pp. 60-62) presents an admirable discussion of this problem as encountered in the Petaca district of New Mexico, and many of his remarks apply equally well to other districts in the Southwest. He concludes that improvements in exploration of pegmatite deposits are urgently needed, stating that advances in mining must depend on new methods or on modification of the common methods in mining. In this connection, the advantages of bulk mining of large parts of pegmatite deposits, or even of the pegmatite bodies as a whole, should not be ignored, provided that some satisfactory means of extraction is available. An interesting development along these lines is now progressing in the Ojo Caliente district, New Mexico, where a mica-bearing pegmatite is being mined in bulk and nearly all of the mined rock is being milled (4). This experiment may have considerable significance in terms of the light it throws on future possibilities for scrap mica production from the northern New Mexico region.

Simultaneous recovery of more than one marketable product, either by hand sorting or by milling of pegmatite material, might greatly increase the chances for successful operation in many areas. Any shift of attention from high-grade, "pockety" deposits to more extensive and continuous exploitation of bulky, more widespread and lower-grade materials might well make for increased overall efficiency, provided that the operation is carefully planned in terms of all economic factors involved.

A great deal of potentially marketable pegmatite material lies in dumps or is as yet in the ground, because no satisfactory method for its recovery has yet been devised. One of the best examples of this is beryl, which to date has been recovered almost entirely as a coarse concentrate by hand-sorting methods. This has prevented the opening up of several deposits of fine-grained beryl. Vigorous attempts are being made to devise techniques for the mechanical extraction of such material (9, 13). If successful, they should open up an important new field in the mining of beryllium-bearing pegmatites. Similar procedures might ultimately result in the recovery of spodumene and tantalum-columbium minerals from the Harding and other pegmatites in the Rocky Mountain belt, where there are some large masses of relatively fine-grained lithium-tantalum-columbium ore.

Increased use of geological data also might be of considerable aid in future development of pegmatite mining. Such data can be applied to the general problem from the stage of prospecting to the final stages of mining operations. To begin with, effective search for pegmatite areas can be made in general geologic terms, by confining most efforts to areas or regions of maximum promise. Individual deposits or groups of deposits can be explored by means of judiciously laid out programs of trenching, test pitting, stripping, or drilling. Numerous past experiences have testified to the desirability of planning programs of exploration in terms of geologic data for individual deposits. This is particularly true of drill holes or of underground workings designed to penetrate subsurface parts of pegmatite bodies.

With fewer and fewer workable deposits exposed at the present surface, it becomes increasingly important to apply all currently available geologic data -- most of them obtained from surface and subsurface observations at pegmatite mines -- to the problem of appraising unexposed parts of pegmatite bodies. In the early stages of many such appraisals, geologic inference alone must suffice, but in later stages various types of exploration can be called upon. An outstanding example of effective exploration of a large and complex pegmatite body was the trenching and drilling program of the U.S. Bureau of Mines at the Harding property in northern New Mexico (14). This was based upon a preliminary geologic study, and the exploration was guided during the program by geologic interpretations of the results as they were obtained (5, 6, 14). Similar exploration might well be done in other areas where detailed geologic studies have been made.

That new discoveries of pegmatite deposits remain to be made in the Southwest is indicated by the successful results of several recent programs of exploration. Most of the surface showings of desirable pegmatite minerals elsewhere in the United States have been prospected or otherwise tested, but the Southwest seems to be a sort of "last frontier" for surface discoveries. Without question there are numerous lithium-bearing pegmatites that have not been developed in the Sangre de Cristo Mountains of northern New Mexico, for example, just as there are undeveloped feldspar- and lithium-bearing pegmatites in Arizona. Mica and feldspar pegmatites remain to be opened up in Nevada and adjacent parts of Arizona, and it seems probable that other feldspar pegmatites of potential commercial usefulness are exposed in the Sierra Nevada province. Only in the Petaca and the San Diego County districts of the Rocky Mountain and Peninsular Range belts, respectively, does detailed prospecting appear to have revealed most of the exposed pegmatites, but even in these districts new discoveries are made from time to time.

An excellent example of a well planned program of exploration for pegmatite material in the Southwest has been furnished by the Whitehall Feldspar Company of Keene, New Hampshire. This organization, in an attempt to appraise the resources of high-grade potash feldspar in the Southwestern States during the period 1947-1948, began with a thorough check of the literature on the geology and occurrence of pegmatites in the Southwest, including published summaries of state resources (e.g. 17, 21). Thus the preliminary search was focused, through wholly geologic considerations, on the belts mentioned previously in this paper, in that attention was concentrated on those areas known to be underlain by rocks in which pegmatites could well occur.

The characteristic association of high-grade potash feldspar with large masses of coarse white quartz permitted still further narrowing of the search. This correlation, together with the open, barren nature of much of the country explored, made a preliminary examination from the air entirely practicable, and permitted rapid coverage of large areas. Thousands of square miles of country were viewed from an airplane in the course of a few weeks. The pegmatite deposits with large quartz cores, as well as the simple "quartz blowouts" with little or no feldspar, were spotted on maps. Later a ground crew, travelling in rough-terrain vehicles, checked each of these occurrences, and eliminated from further consideration those that appeared to offer little commercial promise. Those that appeared to contain considerable quantities of very coarse-grained quartz and feldspar were prospected in more detail, and the best ones were stripped by means of bulldozers. This simple, well integrated program resulted in the discovery of at least one new pegmatite district near Wickenburg, Arizona, and in the ercognition of several large deposits of high-grade feldspar.

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