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SOME EFFECTS OF WORLD WAR II ON PEGMATITE MINERALS AND MINING*

By

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INTRODUCTION

Granitic pegmatite deposits are the chief source of feldspar; sheet mica; beryllium, tantalum-columbium, and lithium minerals; and certain types of kaolin. They also have yielded significant quantities of cassiterite, uranium-thorium and rare-earth minerals, gems, scrap mica, molybdenite, zircon, and tungsten minerals, either directly or as the sources of tributary placers deposits. The output from pegmatite mines in the United States is very small as compared with other mineral products in terms of bulk or value, and much of it comprises so-called "minor" metals and non-metals. Nevertheless, pegmatite minerals play a vital part in domestic industrial economy, particularly in the ceramic and electrical fields. Numerous special-purpose uses also are important, even though they require very small quantities of raw material.

At no time was our dependence upon pegmatite mining more clearly emphasized than during the recent wartime period, when greatly expanded demands and uncertainties of foreign sources of

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supply caused much concern. Such commodities as beryl, tantalite, and sheet muscovite remained high on the critical list for months at a time, and in some instances there was a real struggle to achieve and maintain a favorable ration of supply to demand. Satisfactory stock piles of certain sizes and qualities of sheet mica, for example, were not built up until late in 1944, when wartime requirements already had begun to level off or even to decrease. Production of all the strategic pegmatite minerals from domestic deposits during World War II constituted only a tenth or less of the total domestic consumption of these minerals, but the importance of this relatively small contribution should not be minimized. Domestic production probably represented the difference between increase and further reduction of existing stocks of some commodities already in seriously short supply, and during early stages of the war it was the only insurance against cutting off of imports.

In anticipation of the need for much more detailed information on domestic pegmatites, the Federal Geological Survey began a program of geologic and economic studies prior to the outbreak of recent global conflict. This program involved examination and mapping of deposits in the New England and Southeastern states, in the Black Hills area of South Dakota, in the Rocky Mountain region of Wyoming, Colorado, and New Mexico, and in various parts of Washington, Idaho, Utah, Nevada, Arizona, and California. A total of more than 60 man-years was devoted to Survey pegmatite projects during the period 1939-1946. Much of the work was done in cooperation with such other war agencies as the Federal Bureau of Mines, the Metals Reserve Company, the Colonial Mica Corporation, and the War Production Board. Nearly all pegmatites thought to be potential sources of sheet muscovite, beryllium minerals, or tantalum-columbium minerals were examined in reconnaissance, and many of these were mapped and studied in detail. Laboratory investigations of specimens and samples from numerous deposits were conducted in Washington and at several field stations.

BERYL

Beryl is used directly as a gem material and in ceramics, and in addition is the principal source of beryllium metal and beryllium compounds. These are used in ceramics, in the preparation of X-ray tubes and fluorescent lamps and screens, in special processes of paint and textile manufacture, and in the optical systems of some electrical instruments. The metal is alloyed with aluminum for certain light-metal uses, and is a constituent of some nickel and iron alloys. The chief demand, however, is for copper-base alloys, which are exceptionally resistant to fatigue and wear, responsive to hardening treatments after being worked soft, and are harder and otherwise superior to copper in structural characteristics. In addition they are good electrical conductors, non-magnetic, and non-sparking. Alloys of the beryllium-copper groups are used, for example, in non-sparking tools and springs, contact plates, bushings, shims, and corrosion-resistant parts of motors and gauges. They also are employed for parts in precision instruments and machines.

Prices for clean-cobbed domestic beryl at the mine were quoted at $30 to $35 per short ton for several years prior to 1941, but they gradually rose during the succeeding wartime months until by May 1943 a price of $12 per dry short-ton unit was guaranteed by the Metals Reserve Company for ore containing a minimum of 8 percent beryllium oxide (BeO). Thus material with 10 percent BeO was valued at $120 per ton. In June 1944 the price was raised to $14.50 per unit, but Federal purchases were discontinued on January 1, 1945, and open-market prices have since dropped to much lower levels.

The BeO content of pure beryl varies with the proportion of certain alkalies present, notably sodium and cesium, and in general ranges from less than 10 percent to a theoretical maximum of 14 percent. It is not easily determined with accuracy, and reliable chemical analyses are time consuming and expensive. Dr. W. T. Schaller has been investigating the relations betwenn index of refraction, which is easily determined, and the BeO content of the mineral, and this may become a basis for rapid, inexpensive, and approximate analyses. A fairly rapid qualitative method for recognition of BeO in minerals has been devised (8)_/, and is

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_/ Figures in parentheses refer to papers and reports in list of references.

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reliable for those containing 1 percent or more of the oxide. An improved photometric method of analysis also has been reported(14).

Nearly all the beryl produced in the United States is a by-product derived from deposits of feldspar, lithium minerals, or other pegmatite constituents, and hence the general output ordinarily varies according to market conditions for these other minerals. The beryl is recovered from the host pegmatite by hand sorting and rough cobbing, so that only deposits containing coarse crystals and masses are of current economic interest. There seems to be little reason, however, to assume that milling operations aimed at recovery of beryl and other minerals cannot be successful at some future date, particularly if they are carried on in connection with low-cost methods of bulk mining.

The Black Hills area of South Dakota is the leading source of domestic beryl, and small quantities are obtained at irregular intervals from deposits in at least fourteen additional states. The bulk of material consumed in the United States, however, is imported from South America and other foreign countries. Other beryllium-bearing minerals, such as gadolinite and phenakite, occur in many pegmatites, both in this country and abroad, but no deposits of great commercial interest are known. Phenakite, with a BeO content of 40% or more, is a locally abundant constituent of the Morefield pegmatite, Amelia County, Virginia. A reserve of several tons of this mineral might well be present, but it occurs in masses too small to be recovered by ordinary hand sorting.

TANTALUM-COLUMBIUM MINERALS

The metals tantalum and columbium are derived mainly from members of the tantalite-columbite series. Columbium is alloyed with nickel, copper, and aluminum, and columbium-bearing ferro alloys, with their favorable welding characteristics and high temperature strength properties, are in demand for turbine and aircraft engine parts. Tantalum metal is used in radio and neon tubes, where its gas absorption properties are important, and in instruments and equipment that are exposed to corrosive liquids and fumes. It is uniquely satisfactory as a surgical metal, and is alloyed with columbium and tungsten to form dies and cutting tools. Tantalum-bearing glass is used in special camera lenses and other optical equipment.

The most desirable ores are low-tantalum columbite and low-columbium tantalite that contain little tin or titanium. Columbium ore was valued at 22 cents to 40 cents per pound, and tantalum ore at \$1.80 to \$2.75 per pound in the years preceding World War II, but prices rose to much higher levels after 1941. The highest prices paid by the Metals Reserve Company were in effect during the period July 1943 - - January 1945, after which most purchases were discontinued. They ranged from \$2.20 per pound of contained tantalum oxide for concentrates assaying 40 percent Ta_2O_5 to \$4.30 for 70-percent concentrates. Columbite containing 50 percent Cb_2O_5 or more was purchased at 50 cents per pound of contained oxide.

Accurate determination of grade is accomplished by chemical analysis, a slow and costly process, but rough estimates can be made on the basis of the consistent relation between specific gravity and Ta_2O_5 content of members of the tantalite-columbite series. In general, the gravity rises with increase in proportion of tantalum oxide. The specific gravity of most columbites ranges from 5 to 6.5, and that of all material commercially marketable as tantalite is greater than 6.5. Determinations can be made easily and quickly by means of gravity balances, which are available in many laboratories.

Nearly all tantalum-columbium ore is obtained from deposits outside the United States, mainly from Africa, South America, and Australia. Much of the highest-grade tantalite occurs in Australia and parts of South America. During recent years substantial quantities of tantalum were brought into this country in the form of smelter slags derived from central African tin ores. This material contained very low percentages of Ta_2O_5. Other tantalum-bearing minerals, such as microlite, hatchettolite, samarskite, and fergusonite, are widespread in their occurrence, but are so sparsely distributed in most tantalum-bearing pegmatites that they are of little economic interest. Notable exceptions are several microlite deposits in northern New Mexico and Southern Colorado.

SHEET MUSCOVITE

The uses of sheet muscovite are based upon its perfect cleavage, remarkably low conductivity of heat and electricity, high dielectric strength, non-inflamability, mechanical strength, flexibility, elasticity, transparency, luster, and the ease with which it can be worked into final form. The degrees of emphasis placed upon given properties by purchasers depend upon the specific end uses involved (16, 19). Flexibility is particularly important, for example, in the "cigarette" mica used in spark plugs for aircraft engines. This material, in films twelve ten thousandths of an inch or less thick, is wrapped around rod-like spindles a little more than one eighth inch in diameter (19). Condenser mica, in contrast, is valued because of its dielectric properties, and the use of mica for windows in furnace walls and doors is founded upon its transparency, heat resistance, and mechanical strength.

A very high proportion of sheet mica is used as an electrical insulating material. Washers, disks, and other small trimmed or stamped forms are not only employed as such, but they can be built up into rods, tubes, or other articles that are cemented with shellac, glyptol, or a similar bonding medium. Simple and composite pieces are used, for example, as sleeves, studs, tubes, washers, bushings, laminations, and thin perforated plates in condensers, transformers, small heating elements, rheostats, fuses, incandescent bulbs, radio and electronic tubes, various types of coils, and in acoustic, X-ray, and other specialized equipment. Thin splittings are built up into mica board or applied as facing on paper, cloth, and other materials used in the manufacture of heater elements; commutators; boards, panels, and other mounting forms; parts of condensers; and many other electrical devices.

The properties most desired in sheet muscovite of superior quality are flatness, uniform splitting characteristics, reasonable hardness and flexibility, elasticity, transparency, freedom from inclusions of other minerals, and freedom from such structural imperfections as cracks, tears, pinholes, warps, and ripples. The first rough separation of mica generally is made at the mine, where obvious scrap material is separated from the better books. Adhering fragments of quartz, feldspar, and other foreign material are then cobbed away from those books that contain sheet mica of usable quality. Some of this rough cobbed or selected mine-run mica is sold as such to jobbers or manufacturers, but at most mines it is prepared further. The books are split or "rifted" by means of knives, generally into plates three sixteenths of an inch or less in thickness. Most defective laminae removed during this rifting process are discarded as shop scrap, which is distinctly less impure than typical mine scrap.

After rifting, the ragged and broken edges of many plates are removed with the fingers, a process known as "thumb trimming". This is an especially common practice in districts where much of the mica is marred by structural imperfections. Some thumb-trimmed material is sold to manufacturers as such, but most is further trimmed with knives or shears and its value thereby increased. During recent years attempts have been made to employ several forms of blades and saws for semi-mechanized mica trimming in the United States, but without much success.

A large proportion of sheet mica is consumed in the form of splittings. These are films 0.0007 to 0.001 inch thick that generally are cleaved from the smaller sizes of sheet stock. Some also are derived from thin films or "skimmings" that are formed during the rifting of larger sheet material. Splittings are used in the manufacture of built-up mica board and other forms of electrical insulation. Although many mechanical devices have been tested for the preparation of these films, practically all are still split outside the United States by hand methods, generally in places where labor costs are very low.

The cut mica blocks that represent sheet material are processed into disks, washers, and thin plates of various sizes and shapes. This generally involves additional splitting, followed by trimming, cutting, punching, or stamping into more or less standardized patterns. Most of this material is then cut to final form, if necessary, by the manufacturers of the devices in which the mica is to be used. Composite forms can be built up to any desired thickness by the cementing together of individual pieces. In general only a small proportion of the rifted and trimmed sheet mica is represented in the finished product. The bulk of such material is trimmed or cut away as waste, which is then marketed as scrap of superior grade.

Heavy demands for sheet mica of good quality are characteristic of modern wartime periods. Such mica is used, for example, as splittings in the form of built-up mica commutator segments and coil insulations for motors and generators, and in transformers, switchboards, blasting apparatus, and aircraft generators and sparkplugs (18). In addition, an unprecedented problem was caused during World War II by the demands and exacting requirements for condenser mica. Developments in the field of military radio and electronic equipment focused attendion on mica condensers, owing to the constancy and excellency of their electrical properties under varying physical conditions (18).

Some of the problems encountered in increasing the domestic supply of so-called strategic sheet mica have been described and discussed in the recent literature (1, 9, 18). To stimulate production of strategic mica, the Metals Reserve Company, a subsidiary of the Reconstruction Finance Corporation, designated the Colonial Mica Corporation as its agent, with authority to purchase mica of certain types and to assist the operators of mines with equipment leases, development loans, and consulting services on problems of mica mining and preparation. A market for mica of superior quality was assured at favorable prices and for specified periods.

Prices for sheet mica not only fluctuate widely in response to variations in demand, but vary at any given time according to the size and quality of the material involved. The ranges for clear sheet mica are great, and during a thirty-year period the price for 3 by 3 inch trimmed sheets in the southeastern United States, for example, ranged from 58 cents to $2 per pound, and that for 1-1/2 by 2 inch trimmed sheets ranged from 12 cents to 60 cents per pound. During war periods, when demands are greatly increased and problems of supply often are complex, prices characteristically reach very high levels. Thus the trend rose rapidly during the period December 1941 - December 1944, until a flat price of $8 per pound for full-trimmed sheets 2 by 2 inches and larger was in effect. Subsequent price scales have been considerably lower, and again have been based upon size and quality of the prepared sheets.

Most of the world's production of sheet muscovite is obtained from India, and much smaller quantities are recovered from deposits in Brazil, Argentina, the United States, Russia, and several other countries. Domestic production rarely amounts to more than a fifth of consumption, and during most wartime periods this proportion decreases distinctly. Exhaustive tests have shown that there is little intrinsic difference in electrical and other physical properties between American and Indian muscovites, but much of the imported material is consistently better prepared and more carefully graded.

PEGMATITE STRUCTURE

General features

Most pegmatites can be classified as sills or dikes, depending upon whether or not they are conformable with the structure of the enclosing country rock. Variations of these forms include markedly pinching-and-swelling bodies and series of disconnected lenses and pods. In addition, trough-like, funnel-like, cigar-shaped, mushroom-shaped, and various branching forms have been recognized. Detailed studies in all parts of the United States have shown that despite numerous complexities of detail, most pegmatite bodies are rather regular in general structure. Plunging bodies are especially common, and many pegmatites that appear to be simple sills or dikes actually are shaped more like laths or flattened cigars in three dimensions, with long axes that plunge gently to moderately. Such plunge structures are extremely important so far as economic exploration of the deposits are concerned.

Many pegmatites are such simple aggregates of quartz, feldspar, and accessory minerals that they cannot be readily divided into units of contrasting composition and texture. They constitute the great bulk of pegmatitic material in some areas, but in general have received much less attention than pegmatites that are lithologic and structurally more complex. This last group includes nearly all pegmatities that contain rare minerals, as well as most of those with minable concentrations of feldspar, mica, beryl, and other minerals. A general systematic arrangement of lithologic units in such pegmatites has long been recognized, and "bands", "barrels", "columns", "layers", "lenses", "pipes", "pods", "ribs", "shoots", "streaks", "veins", and "zones" are terms commonly used by miners and referred to in geologic literature.

An essentially regular and orderly internal structure in many pegmatites was described and discussed by some earlier geologists, and was even shown on maps and sections by a few, but the attention of most investigators was focused more upon questions of mineralogy and genesis than upon structure. It has remained for more recent investigators to place greater emphasis upon detailed mapping and structural interpretation of individual parts of pegmatite bodies, and to demonstrate more fully the economic value of such studies in prospecting and in the planning of exploration, development, and mining (2, 3, 5, 6, 7, 11, 12, 13, 15). In many areas it has been shown by careful studies --and in places confirmed by subsequent mining -- that concentrations of economically desirable pegmatite minerals commonly occur in rock units quite distinct from adjacent barren units; hence the recent work has fully confirmed the suggestions of numerous earlier investigators.

According to a recently proposed classification (2), the internal units of pegmatites comprise three fundamental types:

1. Fracture fillings are bodies, generally tabular, that fill fractures in previously consolidated pegmatite.

2. Replacement bodies are units formed primarily by replacement of pre-existing pegmatite, with or without obvious structural control.

3. Zones are successive shells, complete or incomplete, that commonly reflect the shape or structure of the containing pegmatite body. Where ideally developed, they are concentric about an innermost zone or core.

Pegmatite units range widely in size, shape, and texture. The smallest are tiny fracture-filling veinlets and the thin outermost zones of many pegmatite bodies, and the largest are masses several hundred feet long and more than 50 feet in minimum dimension. Many units are easily distinguished and sharply bounded from adjacent units, especially where they differ markedly from them in composition or texture. Contacts between others are gradational, and in some very coarse-grained pegmatites they are difficult to locate within narrow limits. Even where adjacent units are mineralogically similar, however, most boundaries can be mapped conveniently on scales of 20 or 25 feet to the inch, and independent assignments of such boundaries by more than one geologist generally agree within narrow limits.

The distribution, structure, and economic significance of pegmatite units can be best explained by means of examples. The Harding pegmatites, Taos County, New Mexico, most of those in the Petaca District, Rio Arriba County, New Mexico, and most of the mica-bearing pegmatites of western North Carolina consist of two or more readily distinguishable units, and hence do not contain commercially desirable minerals that are uniformly distributed throughout. The only noteworthy exceptions are in North Carolina, where much mica has been recovered from thin, rather homogeneous pegmatite lenses.

Harding pegmatites, New Mexico

The Harding lithium-tantalum-beryllium pegmatites, in western Taos County, New Mexico, were worked during the period 1920-1930 for their lithium minerals, which were used in the manufacture of ceramic products. During World War II, however, they became the foremost domestic sources of tantalum, with a production of more than seven tons of concentrates containing about 70 percent Ta_2O_5. The chief tantalum mineral is microlite, but appreciable quantities of tantalite-columbite and a little hatchettolite were included in the concentrates marketed. More than 500 pounds of coarse tantalite-columbite, averaging 45 to 55 percent Ta_2O_5, was recovered from small placer deposits tributary to the pegmatites.

The pegmatite of principal interest is a thick, flat dike that lies within a zone of thrust faulting in steeply dipping metamorphic rocks of pre-Cambrian age. It dips southward, has an average thickness of 50 to 55 feet, and is known to contain beryllium, tantalum-columbium, and lithium minerals for distances of 350 feet along the strike and 650 feet down the dip. Its upper half is exceptionally well exposed along the face of a large quarry, and its down-dip extensions were diamond drilled by the Federal Bureau of Mines in 1943. This dike is strikingly layered, each layer consisting of a distinct rock type whose relative position within the dike is remarkably consistent, although a given layer may show considerable variation in thickness. The layered structure has been a helpful and reliable guide in the prediction of ore-mineral distribution.

Most of the commercially recoverable beryl occurs in the two 6-inch to 5-foot layers of partly albitized quartz-microcline-muscovite pegmatite, one of which lies beneath the hanging wall and the other above the footwall of the dike. They are best developed in its thickest parts. The beryl is white, pale yellowish green, and pinkish in color, and generally lacks crystal form. Some of the masses are extremly large, with weights of 20 tons or more, and there is little difficulty in recovering the material by hand cobbing

Immediately beneath the hanging-wall beryl-bearing layer is a somewhat thicker zone of massive quartz, and this unit in turn grades downward into a thick zone of quartz with long, thin laths of spodumene that are spectacularly exposed on the quarry walls. The core of the dike is a coarse-grained aggregate of spodumene, microcline, and quartz, with varying quantities of albite, muscovite, lepidolite, and tantalum-columbium minerals. The pegmatite appears to have been symmetrically zoned at one time, but many of the original units in its lower half have been obscured or even obliterated by albitization, and locally through replacement by mica.

Small masses of high-grade tantalum ore, consisting of yellow to brownish microlite and subordinate manganotantalite in lithia mica, quartz, spodumene, muscovite, and albite, occur in a rather well defined belt near the center of the dike. This belt appears to be as much as 100 feet wide, and the concentrations of tantalum minerals occur over a vertical range of about 15 feet. The distribution of rich ore is very irregular in detail, but is surprisingly uniform within many large blocks of ground. Individual shoots have been mined by means of irregularly branching drifts, inclines, and low rooms.

Tantalite-columbite, yellowish brown to black microlite, and minor quantities of hatchettolite are disseminated throughout the central, spodumene-rich unit in the pegmatite body. It consists of pinkish to gray, coarse- but even-grained pegmatite to which the name "spotted rock" has been applied. Most of the spodumene masses are nearly equant, in contrast to the laths in the zone immediately above, and they are about an inch in average diameter. They are associated with microcline, albite, and quartz. Replacement of the potash feldspar and spodumene of this rock by lepidolite has yielded several large bodies rich in the lithia mica.

In general the mass of "spotted rock", or low-grade tantalum-lithium ore lies immediately west of the high-grade microlite shoots. Its shape appears to be similar to that of a loaf of French bread, with one prominent constriction and an equally prominent vertical bulge. Its long axis plunges 2° to 7° southwest, and thus rakes slightly westward down the gentle southerly dip of the dike. The mass is about 175 feet wide and 25 to 40 feet thick, with a long, or down-plunge dimension of at least 750 feet from the original outcrop. Its position is reflected in some places by a broad bulge in the hanging wall of the dike, and in others by a sag in the footwall.

Although most of the tantalum and some of the lithium concentrations appear to have been developed by replacement of pre-existing pegmatites, their vertical distribution is broadly controlled by the layered, or zonal structure in the dike. Moreover, their along-strike and down-dip distribution is in accord with discontinuities and changes in thickness of the zones. A few small fracture-controlled replacement bodies of albite and quartz with varying quantities of beryl, microlite, tantalite, hatchettolite, and bismuth minerals ~~trans~~ transect zones and zone boundaries at distinct angles, but these are not abundant and are of little economic significance.

<u>Pegmatites of the Petaca district, New Mexico</u>

Pegmatite deposits in the Petaca district of northern New Mexico have been sources of commercial muscovite since the seventeenth century, and some of the mines may well represent the oldest systematic operations for sheet mica in this country. The petmatites include dikes, sills, trough- and funnel-like masses, and more irregular bodies, and are abundant in an elongate area of pre-Cambrian schist, quartzite, meta-rhyolite, and granite. Most are discordant, with strikingly consistent westerly trends, steep dips, and moderate westerly plunges. Their axes of plunge are consistently conformable with most minor structures in the adjacent country rock, mainly the axes of drag folds, intersections of bedding and foliation planes, and axes of "stretched" phenocrysts in the meta-volcanic rocks and pebbles in several conglomerate beds.

Microcline and quartz, the chief pegmatite minerals, commonly form easily distinguishable zones within individual pegmatite bodies. In general, cores of massive quartz are surrounded successively by zones of coarse, blocky microcline or of massive quartz with giant microcline crystals, and by outer zones of fine- to coarse-grained microcline-quartz pegmatite with granitoid texture. The border selvages of a few deposits contain albite-oligoclase. Some of the cores can be traced along their strikes into sulfide-bearing quartz veins, and offshoots from others transect the enclosing zones and continue into the country rock as apparently typical veins.

Superimposed upon the basically concentric structural pattern of the zones are fracture fillings and fracture-controlled replacement bodies of quartz, cleavelandite, muscovite, and other minerals, either singly or in combinations. An association of book muscovite with albite, particularly the variety cleavelandite, is strikingly consistent throughout the district. Little mica is present in deposits or parts of deposits that contain little albite, whereas all deposits rich in mica are also rich in the late-stage soda feldspar. The amount of muscovite in a given pegmatite unit generally is proportional to the relative abundance of albite, but this relation does not always hold where the pegmatite consists almost entirely of albite. Such rock units may contain the remnants of many books that appear to have been attacked and largely replaced by the plagioclase. There seems to be no correlation between the size of a given pegmatite body and its mica content. Both large and small pegmatites contain rich and extensive mica shoots, yet some of the largest dikes in the district are nearly barren of mica.

Concentrations of albite and mica are present in deposits of all general forms. They are most abundant at the keels and along the lower flanks of plunging dikes, and hence appear near the eastern ends of such bodies at their outcrops. They also are common at and near the keels of plunging trough-like bodies, which are U-shaped hook-shaped, or boomerang-shaped in plan. The muscovite is thus most abundant at and near the main bends, which generally constitute the most easterly exposed portions of such pegmatites. On the other hand, the mica in plunging inverted trough-like bodies is most abundant near their westerly exposed portions, and so is concentrated near and along their crests. Mica shoots in other, less regular bodies commonly occur along bulges, indentations, or junctions with branches.

The shapes of the mica shoots characteristically reflect the shape and structure of the enclosing zones, although in detail many shoots transect zone boundaries at distinct angles. In this latter respect the Petaca deposits are fundamentally different from most of the mica-bearing pegmatites of New England and the Southeastern states, in which commercial concentrations of muscovite are largely restricted to specific zones and appear to have been developed during formation of the zones.

Mica-bearing pegmatites of western North Carolina

Mica-bearing pegmatite has been mined extensively in western North Carolina for nearly half a century, and this region has accounted for more than half the total domestic production of sheet and punch mica during that time. At least 3,300 deposits are known to have been worked, and during the recent wartime period substantial quantities of mica were obtained from more than 1,200 deposits. The Spruce Pine district, which occupies parts of Avery, Mitchell, and Yancey Counties in the Blue Ridge province, is the largest in North America, both in production of mica and in the number of mines and prospects that lie within its limits. Since 1900 the output from at least 800 mines in this district has been marketed, and hundreds of other deposits have been prospected.

Most of the mica-bearing pegmatites occur in metamorphic rocks of probable pre-Cambrian age. These comprise mica schist and gneiss, impure quartzite, and hornblende schist and gneiss, with minor interlayered kyanite gneiss, sillimanite gneiss, graphitic schist, recrystallized limestone and dolomite, and various types of chloritic rocks. Large masses of silicic intrusive rocks, probably late Paleozoic in age, are exposed in many areas. They range in composition from quartz monzonite to quartz diorite, and commonly are surrounded and locally transected by somewhat finer-grained satellitic sills and dikes of similar composition. Most of the pegmatites that contain commercial concentrations of muscovite also are similar in composition to the large intrusive masses, and in some areas they are demonstrably related to them in genesis. Some of the pegmatites occur within, rather than adjacent to the larger igneous masses, but they are in the minority and account for only a small proportion of the mica produced in the state.

The pegmatites are granodioritic rather than truly granitic in composition, and consist of plagioclase and quartz with subordinate microcline, muscovite, biotite, and accessory minerals. Muscovite is present in some deposits as disseminated flakes, foils, and tiny books, but in others it occurs as very large books, a few of which are as much as two feet in diameter and weigh several hundred pounds or more. All variations between these extremes are known, and many pegmatites contain book muscovite in a wide variety of types and forms. In general, however, the concentrations of muscovite occur within certain zones and are restricted to those zones. Thus the distribution of mica within a given deposit reflects the shape of the containing pegmatite body, although there appears to be little correlation between the size of the body and the quantity of mica within it.

Some deposits of book muscovite in the Southeastern states occur in pegmatites that are not clearly zoned, but most are in well defined units that ordinarily are quite distinct from adjacent barren units. Their distribution is clearly governed by zonal structures. Entire zones in some pegmatites are sufficiently rich in mica to be mined, but most deposits are confined to certain portions of zones, and hence occur as shoots not unlike the shoots of ore minerals in metalliferous deposits. The position and distribution of such shoots commonly can be correlated with the overall shape of the containing zones, or with rolls, bends, bulges, protuberances, or other irregularities in the zones.

Little merchantable sheet mica is associated with fracture fillings or replacement bodies, particularly in the pegmatites yielding the greatest production. This is in marked contrast to the pegmatites of New Mexico, in which nearly all the book mica was developed after formation of the pegmatite zones. Most of the sheet muscovite produced from the Southeastern deposits is obtained from zones near the pegmatite walls. Substantial quantities also are recovered from disseminated books in poorly zoned pegmatites, especially those that are thin and lenticular, and from concentrations along the margins of quartz cores.

Detailed field studies have demonstrated that the mica within a given zone is rather consistent in color, clarity, type and distribution of structural defects, and other physical properties, whereas the books from different zones within the same pegmatite commonly differ very strikingly. Green mica with numerous ridges and crenulations, or "reeves", is especially abundant along the edges of quartz cores in many pegmatites, for example, whereas the mica in the earlier formed wall zones of the same pegmatites is cinnamon brown, brown or brownish olive, and is relatively free from structural defects. Severely reeved mica is most abundant in the pegmatites and pegmatite zones that are rich in potash feldspar, and books of the best quality generally are most numerous in oligoclase-rich zones.

PETMATITE MINING

Mining operations in pegmatite deposits have been repeatedly cited as poor financial risks, owing chiefly to uncertainties arising from the smallness and irregularity of minable concentrations of marketable minerals. Pegmatite mining traditionally has been started in promising outcrops, and has been continued only until the exposed concentrations of desirable minerals were worked out or until other conditions made operations unprofitable. Thus reserves rarely are developed in advance of actual mining, and individual operations are characteristically short lived. Moreover, the selective mining of the richest portions of mica shoots and other mineral concentrations leads to development of tortuous "gopherhole" workings, as well as to the leaving of much valuable material in the ground. Not only are such methods plainly wasteful, but they impose limitations on the depths to which a given shoot can be worked effectively and they fail to uncover reserves in the form of adjacent shoots.

The low margin of profit obtained from the sale of many pegmatite commodities discourages many attempts at exploration and development of reserves. Numerous attempts have been made, to be sure, and a few have been conspicuously successful, but most have antedated the accumulation of structural data on the deposit being tested. In the Petaca district of New Mexico, for example, several adits and shafts were aimed at down-dip extensions of known deposits, but were not developed in accord with the gentle to moderate plunges of those deposits. Several low-level adits that were driven to intersect productive parts of pegmatite bodies thus passed entirely beneath the keels of the bodies. Although they actually point up the significance of the plunges involved, such disappointments nevertheless have been repeatedly cited in support of the thesis that pegmatite bodies are too irregular to be developed in advance of mining.

It is no accident that the exploitation of rich mica concentrations in the Petaca district downward from their outcrops has led to development of inclines and inclined stopes that generally slope in a westerly direction. It is this raking, or down-plunge direction of mica shoots and of the pegmatite bodies themselves that plainly should receive prime consideration in the planning of future exploration and development. Comparable structural features exist in other pegmatite areas, and guides for prospecting commonly can be worked out by careful analyses of each pegmatite body involved.

As fewer and fewer pegmatite outcrops containing concentrations of salable minerals are discovered, even during periods of intensive prospecting, it becomes increasingly necessary to focus attention on mineral concentrations not exposed at the surface and upon those only partly mined out during earlier periods of activity. Serous problems generally confront the operator who considers re-opening a pegmatite mine. The workings of many mines are inaccessible, owing to flooding, caving, or to fouling with tons of back-fill. In many instances mine maps are not available, and reports concerning the size and distribution of workings are incomplete or inaccurate. Production and cost data rarely are complete and reliable, and often deposits must be judged solely on their general reputation among local residents. Ordinarily it is difficult to determine whether previous mining was discontinued because of intrinsic shortcomings of the deposit, poor planning or inefficiency of operations, market conditions, or because of other factors, and it is frequently impossible to contact former operators for discussion of such matters.

Available surface exposures of pegmatites generally are little more satisfactory than mines, so far as furnishing readily usable information is concerned. Few contain promising shoots of mica or other desirable minerals, and many are so small or discontinuous that they do not provide a clear picture of the pegmatite or its structure. Others, however, can be used to determine the internal structure of the pegmatite body, and hence to indirectly determine the probable existence or distribution of mineral concentrations.

Despite the numerous difficulties involved, prediction of future possibilities is far from a hopeless task. The recent wartime period of high prices and other subsidies led to an unprecedented expansion of pegmatite mining and prospecting in this country. Of necessity, much was done hastily and unsystematically, but opportunities for the study of pegmatites and pegmatite deposits in three dimensions were provided on a broader scale than ever before. It was possible to record and collate data on internal structure of the deposits, lithologic sequences in certain kinds of pegmatite bodies, types of book mica and other minerals encountered, and many other features of economic application. More maps and detailed sections were obtained during the short period of wartime activity than had been accumulated throughout all preceding periods. The advantages of such maps and diagrams in planning and executing future operations are evident.

After they were opened during World War II, some pod- and lens-like pegmatites were found to have been mined out during previous periods of activity, but the mine workings in a great many pegmatites are known to be short of the limits of workable mineral concentrations. Large quantities of mica and other minerals were recovered from old muck, pillars, and from thin "skims" of unmined pegmatite in some deposits, and recent operations in other were successful because of improvements in mining techniques over those previously used. The need for adequate surface exploration in advance of extensive underground development was repeatedly demonstrated, and it was further shown that the diamond drill can be an effective tool if its use is directed in close accord with known structural features of the pegmatite body being tested. Numerous blank holes bear eloquent testimony to the risks of overenthusiastic extrapolations from inadequate surface or subsurface data. Nevertheless, the drill is valuable for locating extensions of known shoots, or even for locating adjacent pegmatite bodies or shoots not elsewhere exposed, and hence permits rough calculations of reserves. On the other hand, drill cores rarely provide adequate data on grade of deposits, and they must be interpreted carefully in the light of structural and lithologic information from more complete exposures near-by.

Future operations in pegmatite districts might well be more efficient and less costly if they were conducted on the basis of extensive geologic data. Although there are few criteria for recognition of workable concentrations not exposed at the surface, it commonly is possible to identify those pegmatites that offer little promise and hence can be profitably eliminated from programs of exploration and development. The more promising deposits can be explored by means of trenches and test pits, and subsequently by diamond drilling and other subsurface means if the results of the earlier work are sufficiently encouraging.

The history of mining in most pegmatite districts clearly indicates a correlation between activity and market conditions. Periods of great demand, high prices, and intensive mining are separated by longer periods of lower prices and small-scale, often sporadic activity. The low production levels during these longer periods plainly are not due to dwindling reserves or to suddenly increased difficulties in exposing additional shoots of commercial minerals. Thus, if market conditions appear to justify an increased production, attention might well be directed toward continuous operation of those mines known to yield the most return per unit of rock moved. More efficient methods of mining, the recovery of larger proportions of the mineral shoots, and the simultaneous recovery of more than one marketable product should greatly increase the chances for successful operations. It seems likely that more systematic and efficient mining might well be the result of a shift in attention from high-grade, "pockety" deposits to more extensive and continuous deposits of somewhat lower grade. The latter would lend themselves more readily to exploration in advance of mining, and efficient methods of mining and milling might well lead to profitable operations. A study of tributary placer deposits, particularly near pegmatites not previously worked, should yield information of potential value, so far as future mining of the heavier pegmatite minerals is concerned.

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