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(Continued on inside back cover)

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## University of Arizona Bulletin

ARIZONA BUREAU OF MINES

### PEGMATITE DEPOSITS OF THE WHITE PICACHO DISTRICT, MARICOPA AND YAVAPAI COUNTIES, ARIZONA

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California Institute of Technology  
Pasadena, California

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## TABLE OF CONTENTS

	PAGE
INTRODUCTION .....	5
Background of investigations .....	5
Field and laboratory work .....	8
Acknowledgements .....	9
GEOGRAPHY .....	9
Location and accessibility .....	9
Topography and drainage .....	10
Climate and vegetation .....	11
GEOLOGIC SETTING .....	11
Older rocks .....	11
Younger rocks .....	13
Structural features .....	14
PEGMATITES .....	15
Distribution and occurrence .....	15
Form, size, and attitude .....	18
Relations to country rock .....	21
Internal structure .....	22
General features .....	22
Zones .....	24
Border zones .....	24
Wall zones .....	25
Intermediate zones .....	26
Cores .....	28
Fracture fillings and other units .....	30
Mineralogy .....	32
General statement .....	32
Essential minerals .....	34
Varietal minerals .....	36
Accessory minerals .....	44
Other minerals .....	50
Sequence of mineral formation .....	52
Genesis of the pegmatites .....	54
ECONOMIC FEATURES OF THE PEGMATITE MINERALS .....	57
Feldspars .....	57
Uses, classification, and marketing data .....	57
Occurrence .....	59
Quartz .....	60
Lithium minerals .....	60
Uses and marketing data .....	60
Determination of grade .....	62
Occurrence .....	65
Beryl .....	67
Uses and marketing data .....	67
Determination of grade .....	68
Occurrence .....	69
Mica .....	70
Classification, uses, and marketing data .....	70
Occurrence .....	71
Columbium-tantalum minerals .....	72
Bismuth minerals .....	73

MINING AND PROSPECTING .....	73
Methods and past developments .....	73
Production .....	76
Future possibilities .....	76
DESCRIPTIONS OF SELECTED MINES AND PROSPECTS .....	78
Morning Star prospects .....	78
North Morning Star mine .....	80
Sunset prospect .....	83
Lower Jumbo mine .....	84
White Jumbo prospect .....	86
Sunrise prospect .....	87
Picacho View mine .....	90
Outpost mine .....	93
Outpost Extension prospect .....	96
Friction mine .....	97
Midnight Owl (Lithia King) mine .....	98
Independence prospects .....	103
Long Dike mine .....	103
New Lookout prospects .....	104
Lone Giant prospect .....	104

ILLUSTRATIONS

	PAGE
PLATE I.—INDEX MAP OF THE WHITE PICACHO DISTRICT, MARICOPA AND YAVAPAI COUNTIES, ARIZONA, SHOWING LOCATIONS OF MAJOR PEGMATITE AREAS AND PRINCIPAL PEGMATITE DEPOSITS .....	sup.
PLATE II.—MAIN CUT OF THE PICACHO VIEW MINE, LOOKING NORTH-WEST .....	16
PLATE III.—TYPICAL POD-LIKE MASS OF PEGMATITE, WEST SIDE OF MITCHELL WASH .....	17
PLATE IV.—SMALL, CROSS-CUTTING MASS OF PEGMATITE IN FELDSPATHIC HORNBLÉNDE GNEISS, MASS OF MITCHELL CANYON NEAR LOWER JUMBO MINE .....	22
PLATE V.—TYPICAL SMALL PEGMATITE DIKE, WALL OF MITCHELL CANYON NEAR LOWER JUMBO MINE .....	23
PLATE VI.—MAIN SPODUMENE-BEARING BULGE IN LOWER JUMBO PEGMATITE .....	28
PLATE VII.—DETAIL OF THE PEGMATITE BULGE SHOWN IN PLATE VI .....	29
PLATE VIII.—MUSCOVITE .....	37
PLATE IX.—LEPIDOLITE .....	39
PLATE X.—SPODUMENE .....	41
PLATE XI.—AMBLYGONITE .....	42
PLATE XII.—VEINING OF PERTHITE AND AMBLYGONITE .....	43
PLATE XIII.—LITHIOPHILITE .....	47
PLATE XIV.—TRIPLITE .....	48
PLATE XV.—VIEW OF MIDNIGHT OWL PEGMATITE, LOOKING NORTH .....	74
PLATE XVI.—ANDERSON MICA MILL, IN UPPER PART OF SAN DOMINGO WASH .....	75
PLATE XVII.—GEOLOGIC MAP OF THE NORTH MORNING STAR MINE .....	sup.
PLATE XVIII.—CROSS SECTIONS THROUGH THE NORTH PEGMATITE BODY, MORNING STAR MINE, SHOWING DISTRIBUTION OF PEGMATITE ZONES AS INTERPRETED FROM EXPLORATORY DRILL HOLES .....	sup.
PLATE XIX.—ISOMETRIC PLATE DIAGRAM OF THE LOWER JUMBO PEGMATITE BODY, SHOWING DISTRIBUTION OF PEGMATITE ZONES AS INTERPRETED FROM SURFACE EXPOSURES AND EXPLORATORY DRILL HOLES .....	sup.
PLATE XX.—GEOLOGIC AND ECONOMIC MAPS OF THE PICACHO VIEW MINE .....	sup.
PLATE XXI.—GEOLOGIC MAP AND SECTION OF THE OUTPOST MINE .....	sup.
PLATE XXII.—ECONOMIC MAP OF THE OUTPOST MINE .....	sup.
PLATE XXIII.—ECONOMIC MAP OF THE FRICTION MINE .....	sup.
PLATE XXIV.—GEOLOGIC MAP OF THE MIDNIGHT OWL MINE .....	sup.
FIGURE 1.—INDEX MAP OF ARIZONA, SHOWING RELATION OF WHITE PICACHO DISTRICT TO THE ARIZONA PEGMATITE BELT AND TO PRINCIPAL PHYSICAL DIVISIONS .....	6
FIGURE 2.—EXPLODED BLOCK DIAGRAMS, SHOWING THREE-DIMENSIONAL RELATIONS OF PEGMATITE DIKES AND OTHER BODIES .....	20
FIGURE 3.—GENERALIZED PLANS OF TYPICAL PEGMATITE BODIES, SHOWING CHARACTERISTIC DISTRIBUTION OF ZONES WITHIN THEM .....	27
FIGURE 4.—GENERAL AGE-ABUNDANCE RELATIONS OF PRINCIPAL MINERALS IN THE PEGMATITES .....	53
FIGURE 5.—SKETCH MAP OF THE SUNRISE PEGMATITE BODIES .....	88

PEGMATITE DEPOSITS OF THE WHITE PICACHO DISTRICT, MARICOPA AND YAVAPAI COUNTIES, ARIZONA

INTRODUCTION

BACKGROUND OF INVESTIGATIONS

Deposits of pegmatite minerals are known from many parts of Arizona, and from time to time efforts have been made to develop some of them as commercial sources of feldspar, quartz, mica, beryl, lithium minerals, tungsten minerals, tantalum-columbium minerals, and other salable commodities. The pegmatites occur mainly in terranes or relatively old, crystalline rocks that appear within the Mexican Highland and Sonoran Desert portions of the state. These physical divisions of the Basin and Range province extend southeasterly from the Colorado River to the southern and eastern borders of the state, and lie southwest of the broad Colorado Plateau province (Fig. 1). Most of the largest and best known deposits lie within the so-called Arizona pegmatite belt, which is about 250 miles long, 30 to 80 miles wide, and extends south-southeastward from Lake Mead through parts of Mohave, Yavapai, Yuma, and Maricopa counties to points south of Phoenix (Fig. 1).

The mine and mill of the Consolidated Feldspar Corporation, a few miles northeast of Kingman in the northern part of the pagmatite belt, represent by far the largest and longest-lived of the commercial operations for pegmatite minerals. A production of more than 100,000 tons of crude and ground feldspar has been obtained during the past three decades, and future operations should contribute substantially to this total. Both feldspar and ceramic-grade quartz have been taken from other deposits in the belt, but on a considerably smaller scale. Some sheet mica was produced during World War II from the Mica Giant pegmatite, southeast of Kingman, and modest amounts of scrap mica have been mined over a long period of years from other properties in the Hualpai Mountains, as well as from pegmatites north of Chloride, in central western Mohave County; others in the Weaver, Bradshaw, and Wickenburg Mountains of southern Yavapai County; and from still others in various parts of Maricopa County.

Beryl has been obtained in small lots from many parts of the pegmatite belt, and from scattered localities farther east in the state, as well. Several pegmatites in the Cottonwood and Aquarius Ranges have yielded tungsten and rare-earth minerals, and pegmatitic deposits of wolframite and scheelite have been worked in numerous areas farther south and southeast. Prospecting for deposits of these and other pegmatite minerals has been intensified during recent years, in part because of increased demands for a surprising variety of relatively rare minerals.

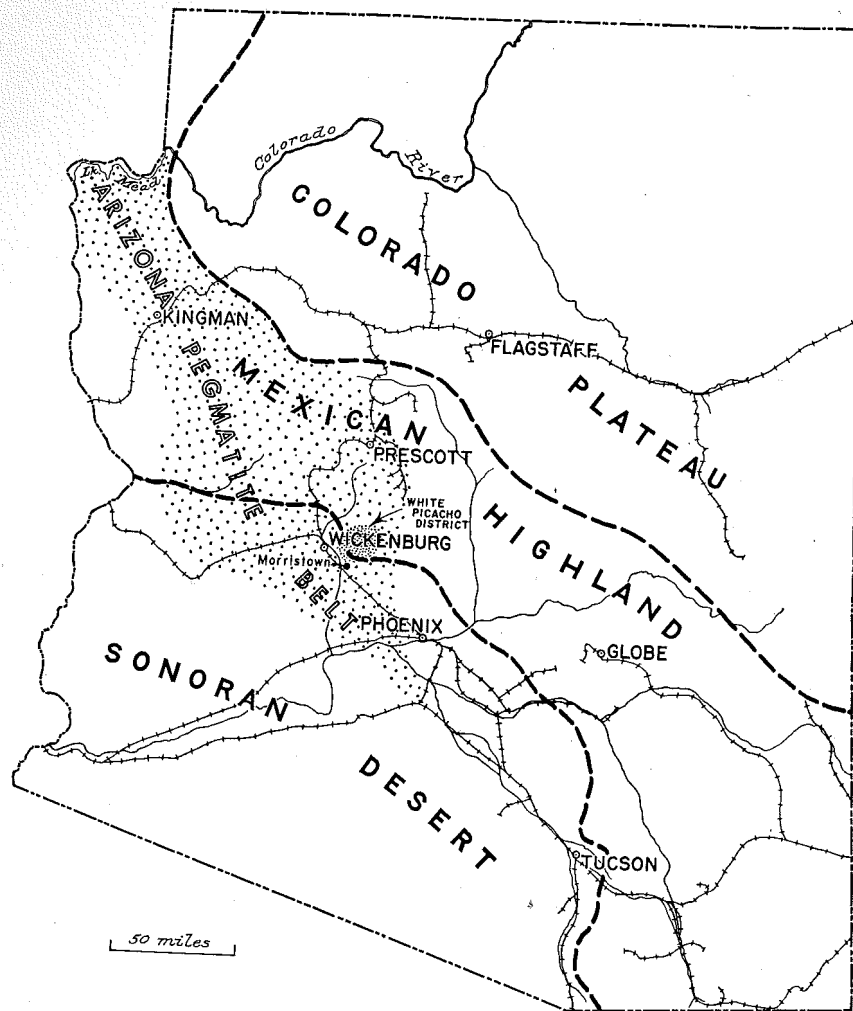


Figure 1.—Index map of Arizona, showing relation of White Picacho district to the Arizona pegmatite belt and to principal physical divisions.

Until the period following World War II, lithium-bearing pegmatites were virtually unknown in the state, even though a few specimens of amblygonite, triplite, and other lithium minerals had been obtained from several localities by venturesome collectors. As recently as 1944, Wilson<sup>1</sup> reported that "the only

lithium minerals known to occur in Arizona are lepidolite in the Bagdad area of Yavapai County, and zinnwaldite in the Duquesne area of Santa Cruz County." He appended the statement that "further prospecting for lithium minerals in pegmatites seems to be justified," and the soundness of this suggestion has been demonstrated by recent discoveries of numerous lithium deposits in several areas near Bagdad, in the Vulture Mountains area west-southwest of Wickenburg. All of these areas are in the southern half of the Arizona pegmatite belt.

The pegmatites of the White Picacho district, although long known to a few local miners and prospectors, were not examined systematically or in detail until 1947, when geologists of the Whitehall Company of Keene, New Hampshire, noted them during the course of a widespread search for western deposits of high-grade feldspar. Preliminary surveys of this and nearby areas were first made from an airplane, which not only provided rapid geographic coverage, but permitted identification and location of nearly all the exposed pegmatite bodies.<sup>2</sup> Supplementary inspection of the pegmatites on the ground was followed by exploration of the most promising ones later in the same year, and many excellent new exposures were developed.

Large concentrations of high-grade feldspar and of spodumene, amblygonite, and other lithium minerals were found at several localities, and valuable data on their extent and grade were obtained as a result of the exploration program and subsequent small-scale mining operations in the district. Most recently, four of the properties were further explored by means of diamond-drill holes during the course of a search for lithium deposits by the Pacific Coast Borax Company. This latest work, which was done during the summer and fall of 1952, revealed many additional elements of structure and mineralogy within individual pegmatite masses.

The discovery, exploration, and development of these pegmatite deposits have provided an exceptional opportunity to study them in detail, and to view their commercial possibilities in the light of geologic and economic factors. It is a matter of general record that most attempts to win profits from pegmatite deposits are abundant, the commercial production from them has amounted to only a tiny fraction of the total mineral output from the state. This situation has been variously ascribed to unfavorable locations of the deposits, adverse market conditions, difficulties or errors in proper exploration and evaluation of pegmatite deposits in general, incomplete understanding of pegmatite minerals by miners and prospectors, and especially to intrinsic shortcomings of the deposits themselves. It seems evident that the relative importance of each of these factors must vary from one district to another and from one pegmatite body to another, and hence that the factors can best be

<sup>1</sup>Wilson, E. D., Arizona nonmetallics; Univ. of Arizona, Bur. of Mines, Bull. 152, pp. 26-27, 1944.

<sup>2</sup>Whitney, R. J., How a bird's-eye view from a plane makes prospecting easier: Eng. and Min. Jour., vol. 153, no. 3, pp. 84-86, 1952.

evaluated only after many deposits within the pegmatite belt have been investigated in reasonable detail.

The chief purpose of this report is to place on record a general description of the pegmatites in the White Picacho district, and to supplement it with detailed descriptions and interpretations of representative deposits. The deposits thus treated comprise several different structural and mineralogical types, each of which presents its own problems to the prospector and miner. In these descriptions, therefore, emphasis is placed upon those features of greatest possible economic significance, and geologic estimates of reserves have been made in terms of tonnage and grade wherever possible. Some marketing data and notes on other economic features of the pegmatite minerals also are included, on the assumption that they might be useful in connection with later commercial development of these and other pegmatite deposits in the state.

#### FIELD AND LABORATORY WORK

The writer devoted approximately six weeks' time to the field studies in the district during the period March, 1948-June, 1952. Most of the large pegmatite masses and all of the known deposits of feldspar and lithium minerals were examined, and twenty-six of them were studied in detail. Six properties were mapped by means of the plane table and telescopic alidade at scales of 20 feet and 40 feet to the inch, and four others were mapped in similar detail by compass-and-tape-methods.

During the course of this work, a particular effort was made to determine the gross structure of each pegmatite mass, as well as the nature and distribution of minerals and groups of minerals within it. Identifications of individual minerals were made in the field wherever possible, and later were checked in the laboratory. Within the limitations of rock exposures and the time for field study, the geologic maps were supplemented by economic maps showing the distribution of feldspar and other minerals by general grade of commercially recoverable material.

Data on the proportions of specific minerals in given masses of rock were obtained by field measurements of mineral intercepts along closely spaced linear traverses. The technique employed is essentially that of linear-traverse analysis under the microscope, except that the extreme coarseness of many of the pegmatite minerals permits a megascopic approach to the problem on the ground. Most of the determinations were made by means of a "pegmatite traversometer," which basically is a wheel that can be rolled along any given line on the pegmatite exposure. A counter records the revolutions of this wheel, and a second counter, which can be engaged or disengaged by means of a simple clutch, records in addition the revolutions made by the wheel in traversing the crystals of the mineral whose relative abundance is sought. By means of this device, the abundance of a given pegmatite mineral can be determined to the nearest

1 per cent over an exposure of 1,000 square feet in a period of about two hours.

Laboratory investigations, made chiefly at the California Institute of Technology in Pasadena, California, comprised the examination and study of rocks and individual minerals under the petrographic microscope, spectrographic analyses of several of the rarer minerals, and chemical analyses of the principal lithium minerals. In addition, several bulk samples were crushed and separated into their respective mineral components, mainly to check the results of grade estimates that were made in the field. All this work was aimed at evaluation of the pegmatites in general geologic and economic terms, and may be considered preliminary to more exact mineralogical studies that the writer expects to complete in the future.

#### ACKNOWLEDGEMENTS

The writer's attention was first drawn to the White Picacho district in 1947 by Roscoe J. Whitney, Exploration Geologist for the Whitehall Company of Keene, New Hampshire. Mr. Whitney had just completed a preliminary survey of the area, and kindly furnished several specimens of unusual pegmatite minerals. In March, 1948, the writer was guided through the district by W. J. Alexander, Chief Engineer for the same company, who pointed out the principal features of economic interest and supplied much useful information that had been obtained during a program of extensive exploration. Additional data on locations of deposits and history of prospecting and mining operations were provided by Earl F. Anderson of Mesa, whose activities in the district cover a period of many years.

The field studies upon which this report is based were facilitated by a research grant from the California Institute of Technology. The writer is indebted to Joseph H. Birman of Occidental College and to Carl Sugar of Famous Green Enterprises for helpful assistance in the field, and to Mr. Alexander and to L. A. Norman, Jr. of the California State Division of Mines for their generous contribution of ideas and critical comments during the course of discussions in the field. It is a pleasure also to thank Harrison P. Gower, Chief Geologist for the Pacific Coast Borax Company, who made available to the writer the subsurface data obtained from recent drill-hole exploration of several pegmatite bodies.

Preparation of the manuscript was aided considerably by Florence Wiltse, and many of the illustrations were drafted by Ellen Powelson and David P. Willoughby.

#### GEOGRAPHY

##### LOCATION AND ACCESSIBILITY

The White Picacho district is in the southern part of the Arizona pegmatite belt, and embraces an area of about 150 square miles in Maricopa and Yavapai counties. This area lies within the rectangle formed by Townships 6, 7, and 8 N., and

Ranges 2 and 3 W., Gila and Salt River Base and Meridian. The center of the district is 7 miles east of Wickenburg, 8 miles north of Morrystown, and approximately 50 miles northwest of Phoenix (Fig. 1).

The district is readily accessible from main routes of travel. To the south and west are U.S. Highway 60-70 and the Phoenix line of the Atchison, Topeka and Santa Fe Railway, both of which serve Wickenburg and Morrystown. A graded and graveled road that extends northeastward from Morrystown to Castle Hot Springs traverses the southeastern part of the district, and provides the best approach route to the pegmatite deposits. As shown in Plate I, a network of minor roads serves nearly all parts of the district. Most of them follow main washes and canyons, and several connecting routes lie athwart this drainage. Most of these roads are maintained intermittently for access to mines and ranches, and many are passable for automobiles throughout the year.

The northern parts of the district are most easily reached via Trilby and Buckhorn Washes, roads in which connect southeastward with the Castle Hot Springs road. The southern parts also are accessible from the Castle Hot Springs road, and all but a few of the major mines and prospects are best reached via the Old Stage Route and a road that extends northeastward up San Domingo Wash (Pl. I). The Old Stage Route joins the Castle Hot Springs road at a point about  $4\frac{1}{2}$  miles northeast of Morrystown. A poor road that extends west-southwestward down San Domingo Wash serves parts of the district not shown on Plate I, and joins U.S. Highway 60-70 at Cactus Gardens, 8 miles by highway southeast of Wickenburg.

#### TOPOGRAPHY AND DRAINAGE

Most of the district lies within the Wickenburg Mountains, a series of irregular ridges and scattered sharp points, or "picachos." To the north and northeast are the higher and more rugged Bradshaw Mountains, and to the south is a broad, much-dissected area of relatively low relief.

The drainage within most of the district is broadly southward and southwestward toward the Hassayampa River, which flows in a southeasterly direction from Wickenburg. The principal drainage lines, listed from west to east, are Tub Springs Wash, Mitchell Wash, San Domingo Wash, Little San Domingo Wash, Trilby Wash, and Picacho Wash. These washes and their uppermost tributaries head along a major divide that crosses the district with an east-west course, and north of this divide the drainage is mainly eastward by Buckhorn and Castle Canyons (Pl. I), which are tributaries of the Agua Fria River. None of the streams is permanent, although surface water ordinarily is present in parts of the San Domingo and other main washes for periods of several months each year.

Streams in the southern part of the district have incised themselves 50 feet to 300 feet beneath a flat to moderately

irregular surface whose relief in most places is less than 200 feet. Farther north, however, the country becomes progressively more rugged; many deep, steep-walled gulches and canyons are present, and the relief locally is as much as 1,500 feet. The highest ridges lie north of San Domingo Wash, and two spectacular peaks, White Picacho and Red Picacho, dominate the landscape beyond Trilby Wash to the southeast (Pl. I). The lowest point in the district, San Domingo Wash near Cactus Gardens (southwest of the area shown in Pl. I), is slightly less than 2,000 feet in altitude, and the highest peaks and ridges at the north rise to altitudes of 4,000 feet or more.

#### CLIMATE AND VEGETATION

The climate in this part of the state is essentially that of the broad Sonoran Desert region to the west and south. Maximum temperatures are high, commonly above 100° F., during the summer months, and below-freezing temperatures are not rare during the winter season. The average annual precipitation is approximately 12 inches, and falls mainly during the periods July-September and December-February. The summer-time rains are characteristically spotty in their distribution, and frequently are products of violent storms. Winter precipitation is much more general in extent, and in the higher areas often falls as snow. Humidity is prevailingly low during the relatively long periods of fair weather.

The vegetation also is typically Sonoran. Trees are abundant but rarely are closely spaced. The mesquite, palo verde, ocotillo, and catsclaw are widely represented; the desert willow, cottonwood, and sycamore flourish along some of the water courses; and juniper and piñon pine are present on the highest slopes. Sahuaro, cholla, and other cacti are abundant and widespread, as are creosote bush and other varieties of desert brush. Nowhere, however, is vegetation so dense that it interferes with geologic investigations.

#### GEOLOGIC SETTING

##### OLDER ROCKS

The pegmatites of the White Picacho district occur in igneous and metamorphic rocks of Precambrian age. These are largely covered by sedimentary and volcanic rocks of Tertiary and Quaternary age in the southern part of the district, where they appear locally on the lower walls of canyons and as knobs that project upward through the younger rocks. Farther north they are relatively more abundant over broad areas of exposure, and in the upper reaches of the principal washes the landscape is developed almost wholly on the Precambrian terrane.

The oldest of the major rock units, the Yavapai schist, comprises thinly foliated quartz-mica schist, quartz-mica-hornblende schist and gneiss, feldspathic hornblende gneiss, quartz-feldspar-mica gneisses, amphiobolite, epidosite, impure quartzite, and

various types of migmatitic or hybrid rocks. Most of these are rocks of middle metamorphic rank, as evidenced mainly by the presence of hornblende, garnet, biotite, and calcic plagioclase. In general they are silvery gray to very dark greenish gray, and form sombre-appearing areas of exposure that contrast markedly with those of the lighter-colored Tertiary rocks.

Many of the quartzites and quartz-rich schists are plainly of sedimentary origin, as indicated by graded bedding, cross bedding, cut-and-fill relations, and other primary structural features. Most of the more mafic rocks, on the other hand, probably were original volcanic flows and pyroclastic types. Amygdaloidal and flow structures are clearly preserved in some of them, and several units of agglomerate and flow breccia are readily recognizable. Also present are layers and lenses of what appear to be metamorphosed tuffaceous rocks, as well as light-colored feldspathic rocks that may represent metamorphosed flows and dikes of rhyolitic composition.

The Yavapai schist, first described from the Bradshaw Mountains to the north and northeast<sup>3</sup>, is similar in many respects to the Vishnu schist exposed in other parts of the state. Its more general characteristics have been summarized by Darton<sup>4</sup>, and some of its occurrences in areas north and northeast of the White Picacho district have been described by Lindgren<sup>5</sup>, Wilson<sup>6</sup>, Anderson<sup>7</sup>, and others. Wilson and Anderson have shown that these ancient rocks are divisible into stratigraphic and lithologic units that can be traced for considerable distances, but no attempt was made during the course of this investigation to study the schists and gneisses in such detail.

Younger intrusive masses of porphyritic rhyolite, diorite, and gabbro are present locally, especially in the northern parts of the district. Most of these masses are small, with widths measurable in tens or hundreds of feet. Their maximum known length is about 2,000 feet, but some poorly exposed masses may be considerably longer. These younger intrusive rocks probably are similar to those described by Anderson<sup>8</sup> from the Bagdad and Prescott-Jerome areas, where they are younger than the Yavapai schist and older than the principal Precambrian granitic rocks of the region.

Granitic intrusive rocks are exposed in many places, and are most abundant in the northernmost parts of the district. The most widespread type is medium to pinkish gray, medium

<sup>3</sup>Jaggar, T. A., Jr., and Palache, Charles, U.S. Geol. Survey Geol. Atlas, Bradshaw Mountains folio (No. 126), pp. 1-3, 1905.

<sup>4</sup>Darton, N. H., A resumé of Arizona geology: Univ. of Arizona, Bur. of Mines, Bull. 119 pp. 18-23, 1925.

<sup>5</sup>Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U.S. Geol. Survey, Bull. 782, pp. 17-21, 1926.

<sup>6</sup>Wilson, E. D., Pre-Cambrian Mazatzal revolution in central Arizona: Geol. Soc. Amer. Bull., vol. 50, pp. 1113-2164, 1939.

<sup>7</sup>Anderson, C. A., Older Precambrian structure in Arizona: Geol. Soc. Amer. Bull., vol. 62 pp. 1331-1246, 1951.

<sup>8</sup>Anderson, C. A., *op. cit.*, pp. 1334-1346, 1951.

to coarse grained, and even grained to slightly porphyritic. It consists mainly of potash feldspar, quartz, and plagioclase. Biotite is the most abundant dark constituent, although it is rare as compared with the quartz and feldspars. A little hornblende is present locally. This granitic rock probably is correlative with the Bradshaw granite, which is widely exposed in areas to the north and northeast. It is one of the youngest of the Precambrian rocks in the district, but nevertheless is a part of the so-called "older Precambrian" series or rocks in the state.

Masses of pegmatite are present in both the granite and the older metamorphic rocks, and in general are smallest and most irregular where they occur in the granitic rocks. They vary considerably in size, form, attitude, and internal features of mineralogy and structure, and are discussed in detail farther on.

Quartz veins and lenses are rather common, and have been worked for gold and tungsten in several parts of the district. Also present are somewhat thicker and more irregular masses of pegmatitic quartz, most of which contain a little perthite and some of the accessory minerals that are typical of the less quartz-rich pegmatites of the district.

#### YOUNGER ROCKS

Paleozoic and Mesozoic rocks do not appear to be present in the district, but in many places the precambrian terrane is blanketed by volcanic and sedimentary accumulations of Tertiary age. These much younger rocks rest upon an irregular surface of erosion, and represent a once-extensive cover of flows and sedimentary deposits that locally was at least 1,000 feet thick. They are best preserved in the northern and eastern parts of the district, where they form numerous cliffs and sharp ridges. The sides of White Picacho and Red Picacho provide especially complete and spectacular exposures, and many others are present elsewhere in the upper parts of the Trilby Wash drainage, as well as in the areas drained by Buckhorn and Castle Creeks (Pl. I). These rocks are masked by younger sedimentary rocks in much of the southwestern part of the district, but many excellent exposures do appear along the sides of San Domingo Wash and other major water courses.

The Tertiary rocks comprise interlayered coarse volcanic agglomerate and flow breccia, volcanic ash, coarse-grained sedimentary rocks of fluvial origin, and some flows of andesitic to latitic composition. Rhyolitic and basaltic flows are present, as well, but form only a small part of the section. The volcanic rock types also are represented by dikes, small plugs, and other intrusive bodies that may have been feeders for flows since eroded away.

The most abundant varieties of sedimentary rocks in the section are red to brown arkose and pebble conglomerate, variegated tuffaceous sandstone and arkose, bouldery volcanic conglomerate, and breccias of probable mudflow or debris-flow

origin. Some beds of conglomerate and breccia at the base of the section are crowded with fragments of schist, quartzite, granite, pegmatite, and other Precambrian rocks. Fragments of volcanic rocks are relatively more abundant higher in the section.

In the southern part of the district the volcanic and associated sedimentary rocks are overlain unconformably by coarse, poorly to well bedded sandstones, conglomerates, and breccias that probably are of late Tertiary or Quaternary age. They appear to have been formed as alluvial-fan and valley-fill deposits, and they contain fragments of nearly all of the older rock types known from this general area. Thin flows of basalt, interlayered with the fluvial beds, are exposed at several places.

A thin, irregular capping of coarse gravel appears on the remnants of a broad but much dissected pediment surface in the southern part of the district, especially in areas south and southwest of that shown in Plate I. This surface was once developed across the Tertiary or Quaternary deposits described above, and extends northward across some of the older rocks, as well. It probably is Quaternary in age.

Younger gravels are present as terrace veneers along the Hassayampa River and several of its major tributaries in the district, but nowhere are they extensive. Some of them are partly consolidated, and form small but bold outcrops. Still younger sands and gravels, most of them unconsolidated, underlie the floors of the washes, where they locally are as much as 60 feet thick.

#### STRUCTURAL FEATURES

The structure of the Precambrian rocks is complex, and in part has been obscured by metamorphism. Bedding is nevertheless preserved in some of the sedimentary rocks, as is primary layering in many of the volcanic flows and breccias. These planar features, which appear to be essentially parallel to foliation and schistosity in most places, generally trend northeast to east-southeast, and dip in a northerly direction at moderate to steep angles.

Small-scale folding is visible in many outcrops. Most of the folds are tightly compressed, with amplitudes that are measurable in feet or a few tens of feet. Nearly all the rocks are extensively jointed and sheared, as well, and faults are present in nearly all parts of the district. Displacements along some of these faults probably were large, as suggested by the presence of wholly different rock types on opposite sides of the breaks. No attempt was made in the present investigation to determine the general Precambrian structure of the district, but the observed structural elements are compatible with the concept of two major episodes of faulting and with the pattern of northwest- and northeast-trending folds described by Anderson<sup>9</sup> from areas to

the north and northeast.

The Tertiary volcanic and sedimentary rocks also have been deformed, but to a much lesser extent than the older rocks. They are gently to moderately tilted, and dip northerly in most parts of the district. Folds are present locally, but are not obviously systematic in their distribution or orientation. Faulting is widespread, and numerous steeply dipping breaks are plainly exposed on the walls of the major canyons. In the lower reaches of San Domingo Wash, for example, the Tertiary rocks appear in well defined fault blocks that commonly are less than 1,000 feet wide. Juxtaposition of unlike parts of the Tertiary section suggests that movement along most of the faults must have amounted to at least 100 feet, and possibly was of a much greater order of magnitude.

Several of the faults also transect beds of the younger valley-fill and alluvial-fan sequence, but all of them are covered by the still younger pediment and terrace gravels. Indeed, the blanket of these gravels is so extensively preserved across several of the interstream areas in the southern and southwestern parts of the district that it is impossible to trace most of the faults beyond the walls of the main washes. It also would be difficult, therefore, to establish a reasonably accurate stratigraphic section for the Tertiary rocks in these areas.

#### PEGMATITES

##### DISTRIBUTION AND OCCURENCE

Most of the major pegmatite masses in the district lie within a curving belt, at least ten miles long and one-half mile to about three miles wide, that extends northwestward from points near Trilby Wash and the Castle Hot Springs road to San Domingo Wash, and thence northward and northeastward through the area of Upper Mitchell and San Domingo Washes and into the drainage of Buckhorn Creek (Pl. I). This belt broadens and splits northeastward into two major prongs, and is crescentic in general plan. Its exposed portion is concave toward the east, in part because the Precambrian rocks in the area between the Riley place and Red Picacho are largely concealed by Tertiary rocks (Pl. I).

Numerous dikes and other masses of pegmatite are present in several smaller areas that lie east and north of the main belt. Pegmatite bodies also are exposed in local outliers of Precambrian rocks northeast of the Wickenburg-Phoenix highway and southwest of the area shown in Plate I, and included among them are at least two large masses of lithium-bearing pegmatite. Another area of large pegmatites lies immediately north of the Castle Hot Springs Hotel, approximately 8 miles east of White Picacho. This outlying area is about 3 miles long and 1 mile wide, and is elongated in an east-west direction.

Few large pegmatite bodies are exposed in the areas that fringe the district on the northwest and north, even though Precambrian rocks are well represented there. These rocks

<sup>9</sup>Anderson, C. A., Older Precambrian structure in Arizona: Geol. Soc. Amer. Bull., vol. 62, pp. 1345-2346, 1951.



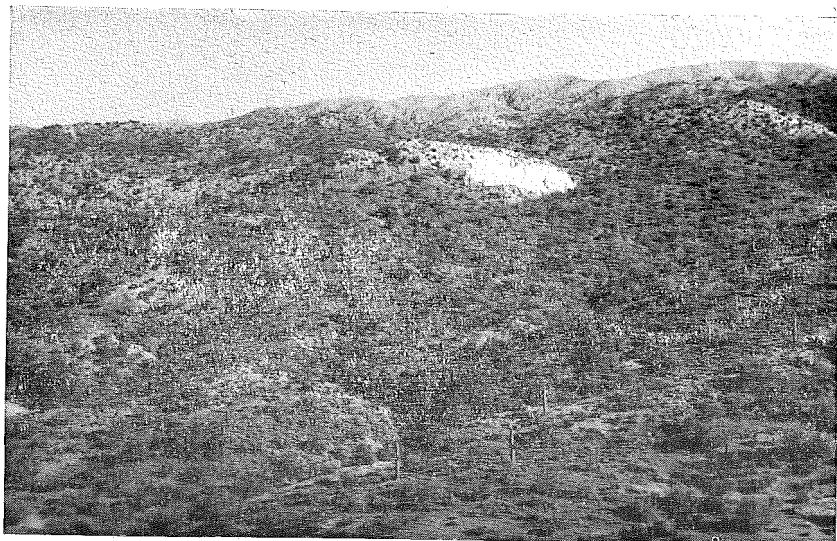


Plate II.—Main cut of the Picacho View mine, looking northwest. The light-colored patches in the foreground and right distance are outcrops of irregular pegmatite bodies.

are mainly granitic, however, in contrast to the dominantly metasedimentary and metavolcanic rocks of the district itself.

The pegmatite masses of principal interest are enclosed by metamorphic rocks, and appear as irregular, light-colored patches in the prevailing darker country-rock terrane (Pls. II, III). In general, the pegmatite is slightly more resistant to erosion than most of the other rocks, and hence is relatively well exposed. The central parts of many individual masses consist of coarse-grained, quartz-rich pegmatite that is much more resistant, and it commonly forms irregular knobs and even some low cliffs (Pl. III). The outer parts of the same masses form more subdued outcrops or are covered by thin mantles of soil and surface wash. Even where no outcrops are present, however, the distribution of float material generally permits location of contacts between pegmatite and country rock within a few feet.

Most of the pegmatite minerals are fairly fresh and unaltered, even at the surface. The only notable exceptions are plagioclase and spodumene, which are recognizably weathered to depths ranging from a few inches to 25 feet. Many of the slopes in pegmatite areas are strewn with irregular blocks and slabs of quartz, coarse perthite, and, locally, amblygonite.

Three general types of pegmatite bodies are present in the district. By far the most abundant are mineralogically simple ones that consist of quartz, potash feldspar, and subordinate sodic

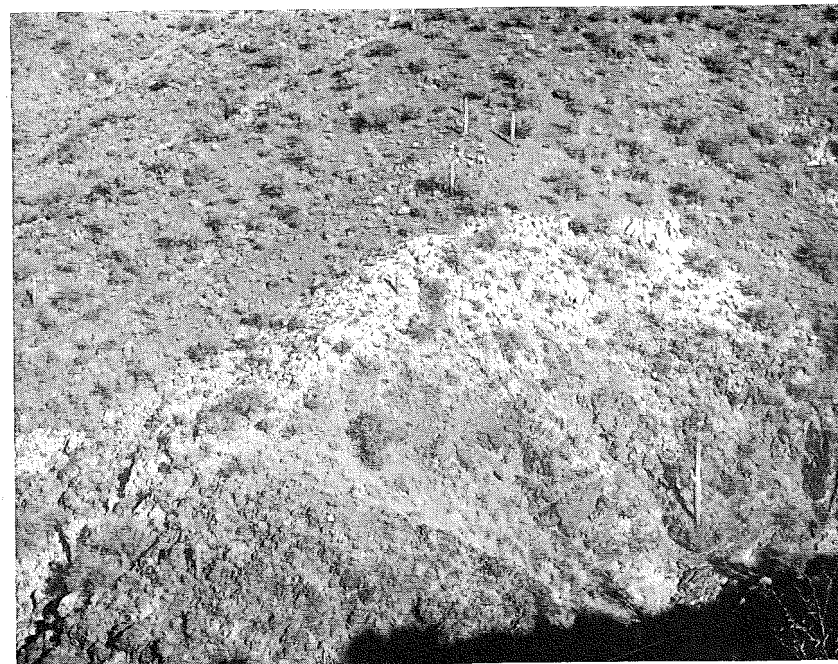


Plate III.—Typical pod-like mass of pegmatite, west side of Mitchell Wash. Note the general excellence of exposure and the contrast between pegmatite and the much darker country rock, here mainly schist and amphibolite.

plagioclase and muscovite, with accessory garnet, biotite, beryl, and black tourmaline (schorl). Graphic granite commonly is present, as well. Some of these bodies are megascopically homogeneous, whereas others comprise two or more contrasting rock types; none of them, however, contains large segregations of exceptionally coarse-grained minerals.

The second type of pegmatite body is similar in bulk composition, but is characterized by somewhat more varied assemblages of accessory minerals. In addition, bodies of this group are distinguished by the occurrence, in their central parts, of segregations of very coarse-grained quartz, potash feldspar, or combinations of these minerals. Individual crystals commonly can be measured in feet or even in tens of feet, and in some bodies they form large aggregates of relatively pure quartz or feldspar.

Lithium-bearing pegmatites, which constitute the third general type, are widespread but numerically subordinate to the other types. They are scattered among the other pegmatites without recognizable pattern, and occur in nearly all parts of the district (Pl. I). These pegmatite bodies are similar to those of the second type described above, in that they contain centrally disposed

segregations of extremely coarse-grained minerals. In addition to quartz and potash feldspar, however, they also contain spodumene, amblygonite and other lithium-bearing phosphate minerals, lepidolite, pink and green tourmaline (elbaite), or combinations of these minerals. The lithium minerals typically are concentrated in the inner parts of the pegmatite bodies, and may well be present in many of the apparently lithium-free bodies whose outer parts are the only ones exposed.

#### FORM, SIZE AND ATTITUDE

The pegmatite bodies include dikes, sills, pods, and irregular, branching masses. Most are distinctly elongate, and all that are not partly concealed by younger rocks plainly are terminated against older rocks in both directions along their strike. Although many simple forms are represented, most of the bodies are highly irregular in detail. Some have broadly rounded ends, but many others taper to long, thin spines or split into two or more branches that commonly change direction as traced along their strike. Lateral projections are characteristic, and range from broad protuberances to thin, irregular apophyses. Some of the apophyses are branching in pattern, others form stockworks in the country rock, and still others connect two or more adjacent pegmatite masses.

Pinch-and-swell structure is widespread, and some masses consist of connected bulges that are arranged like beads on a string. A few highly complex masses, like the Midnight Owl (Pl. XXIV), comprise less systematically disposed bulges and irregular constrictions. The distribution and shape of the major bulges are of considerable commercial significance in most of the pegmatites, as the principal concentrations of feldspar and lithium minerals generally occupy central positions in such bulges (Fig. 3 and Pl. VI).

Some of the pegmatite masses are continuous for distances of 1,000 feet or more, but most are markedly lenticular. Many form groups, or swarms, in which the individual masses show a crude parallelism of attitude. The pegmatites of chief economic interest range in outcrop length from about 50 feet to nearly 2,000 feet, with a general average of slightly less than 400 feet. They range in thickness from less than a foot to about 200 feet, and the average thickness of all major bulges is the order of 40 feet. Ratios of outcrop length to breadth range from slightly less than 2 to 1 to as much as 120 to 1, and reflect variations in form from the thickest and most stubby, pod-like bodies to the longest dikes and other tabular masses.

Despite these numerous irregularities and local variations in attitude, most of the pegmatite bodies show broad consistencies of orientation. In general they trend either north to north-northeast, or east-northeast to east, and their dips are prevailing steep. As traced downward from the outcrop, many of them vary markedly in dip, which commonly passes back and forth through

the vertical. This feature is particularly well shown by the North Morning Star (Pl. XVIII) and the Sunrise pegmatites, the subsurface configurations of which have been explored by means of diamond drill holes.

Some of the more bulbous masses appear to be bottomed at shallow to moderate depth, and hence are truly pod-like in three dimensions. The Lower Jumbo pegmatite, for example, comprises two irregular bulges that are joined by a relatively thin neck, and, as shown in Plate XIX, the lower and larger of these bulges has a well defined keel whose form is complicated somewhat by curving septa of country rock. The results of diamond drilling in this pegmatite body suggest that the axes of both bulges plunge gently, and hence are nearly parallel to the general strike of the body, rather than to its direction of dip.

Detailed studies of pegmatite districts in many other parts of the United States have demonstrated again and again that determination of strike and dip alone commonly does not suffice to establish the true geometrical form of a given pegmatite body, and this applies to the pegmatites of the White Picacho district, as well. Even though many of the tabular masses extend to considerable depths as traced down their dip, others are bottomed at much shallower levels, and hence have the form of flattened lenses whose dips are steep but whose bottoms, or keels, either are horizontal or plunge gently to moderately. The contrast between dikes in which dip is dominant and those in which moderate plunge is dominant is emphasized in Figure 2, and represents an important factor to be considered in commercial development of such dikes.

The more bulbous or otherwise irregular pegmatite bodies are more difficult to appraise in terms of their behavior at depth, but on the average their thickest parts have down-dip dimensions neither very much larger nor very much smaller than their exposed lengths and widths. Surface exposures can be misleading if they are not interpreted with this feature in mind. The impressive dimensions of the Outpost pegmatite, for example, plainly result from the configuration of present topography with respect to the form of the pegmatite body; erosion has stripped the country rock and a little pegmatite from the rounded top, or crest, of a major bulge in this body, and the present outcrop thus gives an exaggerated impression of the true thickness of this bulge (Pl. XXI). Moreover, downward diverging dips on opposite sides of this and similar bulges should be interpreted with caution, as the walls are likely to pass through the vertical and converge at no great depth.

The distribution of pegmatite beneath the outcrop obviously will depend upon the general form of the pegmatite body, and upon the position of the present erosion surface with respect to the body as a whole. Some of the pegmatites in the district have been barely uncovered by erosion, whereas only the roots of

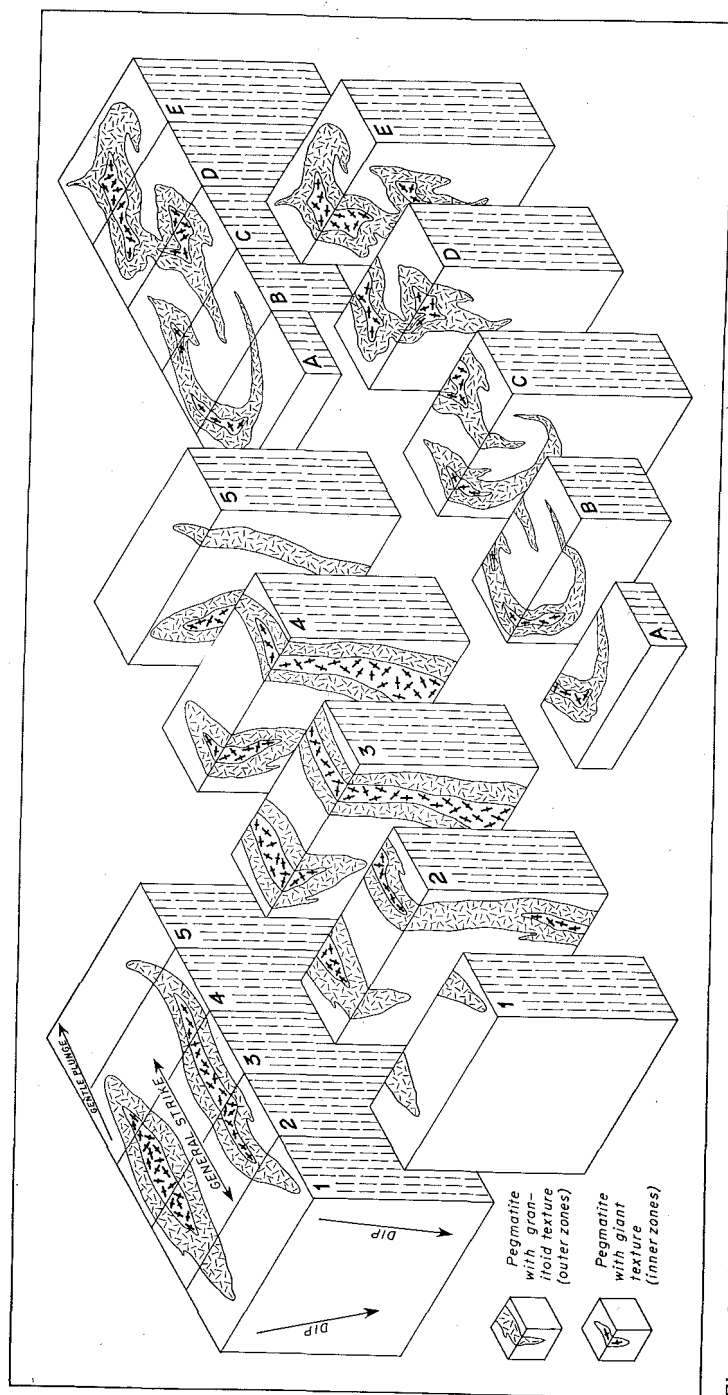


Figure 2.—Exploded block diagrams, showing three-dimensional relations of pegmatite dikes and other bodies.

others remain beneath the present surface. Evaluation of these two major features in advance of subsurface exploration must depend on careful observation and interpretation of pegmatite-country rock contacts, and upon application of an empirical rule that yields surprisingly accurate and useful results, despite some exceptions that must be anticipated. This rule: A given pegmatite body in the White Picacho district, as viewed in cross section, will not differ very greatly, either in dimensions or in general form, from its appearance as viewed in plan.

#### RELATIONS TO COUNTRY ROCK

The general form of the pegmatite bodies reflects, in various ways, major differences in the type of enclosing country rock. The pegmatites that lie in granite and other relatively massive rocks ordinarily are small, thin, and highly irregular in detail. Those in the more thinly foliated varieties of schist, in contrast, commonly are much larger and more bulbous in form. Many of them pinch and swell as traced along their strike, and have one or more subparallel branches. Other gross irregularities are common, as well. Those pegmatites that occur in the schists, gneisses, and greenstones with less well-developed foliation are intermediate in form between the two extremes just cited. Some of the most irregular ones appear locally as stockworks in the country rock, where they evidently were controlled by two or more sets of joints (Pl. V).

Most of the pegmatites are distinctly discordant. Some trend parallel to the strike of the country-rock structure, but diverge markedly from it in dip. A few of the more tabular masses are broadly concordant, but even these transect the structure of the enclosing rock in detail. Many of the tabular pegmatite bodies appear to have been emplaced along joints, whereas others, including most of the bulbous ones, evidently were controlled also by foliation and other planar features in the country rock.

Nearly all the pegmatite-wallrock contacts are sharp, and many are highly irregular in detail (Pls. IV, V). Numerous larger-scale irregularities involve thin septa, screens, and inclusions of schist and gneiss; the foliation in these inclusions commonly lies at distinct angles to their general trend. Many of the pegmatite bodies plainly cut across major folds in the country rock, but numerous plications and small-scale folds appear to have been formed during injection of the pegmatite, especially in the metamorphic rocks that are most thinly foliated.

Much of the country rock seems to have been little deformed or altered adjacent to masses of pegmatite, and remains uniform in texture and mineralogy as traced up to the pegmatite contacts. This uniformity is especially characteristic of the granites and feldspathic gneisses. Some of the more schistose types of country rock, in contrast, have been impregnated with muscovite, potash feldspar, albite, or combinations of these minerals at several localities. The aureoles of impregnation are irregular, and



Plate IV.—Small, cross-cutting mass of pegmatite in feldspathic hornblende gneiss, wall of Mitchell Canyon near Lower Jumbo mine. Note sharpness of pegmatite-wallrock contacts, and abrupt bulging of pegmatite mass.

locally extend for distances of several tens of feet from the pegmatite contacts. In other aureoles much wallrock hornblende has been converted to biotite and in still others the metamorphic rocks are crowded with metacrysts of feldspar. In places the contact between pegmatite and metacryst-rich schist or gneiss is difficult to define.

The widespread type of country-rock alteration associated with the pegmatites is well exposed in the vicinity of the South Morning Star and Midnight Owl bodies. Here broad layers in a terrane of amphibole schist and quartz-rich schist and gneiss have been "flooded" with pale yellowish-green muscovite that forms flakes  $\frac{1}{8}$  inch to  $\frac{1}{2}$  inch in diameter. These flakes are packed into tight mats that are oriented to give the rock a well defined planar structure, and most of the layers are considerably crenulated, plicated, or otherwise contorted on a small scale. Scattered through all of the mica-rich rock are numerous small pods of clear, vein-like quartz.

#### INTERNAL STRUCTURE

##### GENERAL FEATURES

Most of the pegmatite bodies in the district consist of two or more lithologic units, or zones, that are readily distinguishable from one another on the basis of variations in mineralogy, texture, or both features. Inasmuch as the commercially desirable minerals generally are concentrated in certain of these zones



Plate V.—Typical small pegmatite dike, wall of Mitchell Canyon near Lower Jumbo mine. Note thin dikes near top of view and pegmatitic stockworks at right.

within a given pegmatite, the distribution and other characteristics of such units are of great economic significance.

The internal structure of granitic pegmatites has been described and discussed by numerous investigators, who have recognized a remarkably systematic arrangement of mineralogic and lithologic units in many pegmatite bodies. Recently this general topic has been treated in considerable detail by members of the United States Geological Survey,<sup>10</sup> who have proposed the following classification for pegmatite units:

1. *Fracture fillings* are generally tabular bodies that fill fractures in previously consolidated pegmatite.
2. *Replacement bodies* are 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.

All these units, and especially the zones, are related in a definite way to the over-all shape and attitude of the enclosing pegmatite body (Fig. 3); hence an understanding of the gross structure of the body commonly leads to a better appraisal of its individual units in terms of their economic possibilities. The distribution of

<sup>10</sup>Cameron, E. N., Jahns, R. H., McNair, A. H. and Page, L. R., Internal structure of granitic pegmatites: Econ. Geol., Mon. 2, 115 pp., including extensive bibliography, 1949.

individual minerals within each unit also obeys certain rules, although it is irregular in detail. Thus not only do concentrations of economically desirable minerals tend to occur in pegmatite units distinct from adjacent barren units, but many of the individual concentrations take the form of recognizable shoots within the containing unit or units.

Most of the units have well defined borders, and can be distinguished from adjacent units without difficulty. Others, especially those of coarsest grain, have more gradational margins, but even these can be defined in position within 2 feet. Nearly all the zone boundaries in the pegmatites of the White Picacho district are so well defined that they would be assigned virtually identical positions by different geologists working independently, even on maps of very large scale.

A considerable variation in grain size is characteristic of most pegmatite bodies, although many of these variations also are systematic. In connection with all descriptions of pegmatites and pegmatite units in this report, the following grain-size classification is used:

Term	General grain size
Fine	Less than 1 inch
Medium	1 to 4 inches
Coarse	4 to 12 inches
Very coarse, or giant	Greater than 12 inches

#### ZONES

Zones are by far the most important units in the pegmatites of the White Picacho district, as they contain at least 97 per cent of the total pegmatite material and include all the known commercial mineral deposits. These units are perhaps best described according to the following classification, proposed by members of the United States Geological Survey:<sup>11</sup>

1. Border, or outermost, zones.
2. Wall zones.
3. Intermediate zones.
4. Cores, or innermost zones.

**Border zones.**—The pegmatite border zones in the district typically are fine- to medium-grained selvages that range in thickness from  $\frac{1}{8}$  inch to several feet. Most are less than a foot thick, and cannot be shown conveniently on geologic maps, even on those of very large scale. Some of these outermost zones are sharply defined, whereas others fade into the country rock, as already noted. They become coarse grained as traced inward from the wallrock contacts, and in many pegmatite bodies they grade into the adjacent wall zones without a recognizable textural break.

The pegmatite of the border zones generally consists of quartz and sodic plagioclase, with subordinate but widespread black tourmaline (schorl) and perthite. Also present in many of these units are biotite, muscovite, garnet, apatite, and beryl, either

<sup>11</sup>Cameron, E. N., Jahns, R. H., McNair, A. H., and Page, L. R., *op. cit.*, pp. 20-24, 1949.

singly or in various combinations. In general the same mineral assemblages are present in the adjacent wall zones, although the proportions of individual species commonly differ.

A few border zones consist primarily of quartz, and some of these also contain scattered concentrations of schorl, especially in the vicinity of inclusions and septa of country rock. These quartz-rich selvages are particularly well exposed in parts of the Picacho View and North Morning Star pegmatites.

Some border zones contain ill-defined masses of partly digested country rock, which range from thick, dark-colored lenses to barely recognizable micaceous wisps and screens. Biotite and muscovite commonly are present along or near the margins of the pegmatite bodies, and along contacts between pegmatite and some wallrock inclusions, as well. These minerals form numerous irregular concentrations of diversely oriented flakes and plates, and also occur as thin, continuous mats, especially where the adjacent country rock contains abundant mica or amphibole.

Several of the border zones are markedly shistose, and in places this planar structure trends across the pegmatite borders and becomes continuous with that of the surrounding metamorphic rock. Mineralogic layering, which in general is parallel to the zone boundaries, commonly results from systematic variations in the proportion of mica, schorl, or garnet within the pegmatite. Some crystals of tourmaline and mica are oriented with their long dimensions perpendicular or nearly perpendicular to the outer margin of the containing border zone, and locally appear as well defined comb-like fringes.

**Wall zones.**—Most of the wall zones in the White Picacho pegmatites are continuous and well defined, and characteristically are thicker and much coarser grained than the adjoining border zones. They range in thickness from a knife edge to several tens of feet, with averages between 3 feet and 8 feet in most of the pegmatites. With respect to the other zones in a given pegmatite body, they are relatively thinnest around the margins of the most prominent bulges, and relatively thickest in the more constricted parts of the body (Fig. 3).

Where most continuously developed, the wall zones form complete or nearly complete envelopes around the interior portions of the pegmatite bodies, and in many places they constitute almost the entire thickness of exposed pegmatite. Elsewhere they are markedly discontinuous, either because they never were completely formed or because they were formed and then in part removed prior to final consolidation of the containing mass of pegmatite. They are most discontinuous in some of the largest pegmatites of most complex shape, excellent examples of which are the Midnight Owl and the Lower Jumbo.

Fine- to coarse-grained perthite—quartz pegmatite, with subordinate plagioclase, schorl, and mica, is by far the most abundant rock type in the wall zones of the district. The most widely distributed accessory minerals are garnet, apatite, and beryl, and

a few wall zones also contain a little spodumene. The proportions of individual minerals typically vary from one part of the zone to another, especially as traced from one end of the pegmatite body to the other. An excellent example is the wall zone of the North Morning Star pegmatite body, in which the proportion of quartz increases progressively from south to north.

Like the border zones, the wall zones are typically granitoid in texture, and not many of the crystals are markedly coarser than the others. Planar structure occurs locally, but is neither common nor sharply developed. It generally is caused by faint mineralogic layering or by consistently oriented tabular inclusions of country rock, most of which are considerably digested. No segregations of very coarse-grained, relatively pure feldspar or lithium minerals are present in the typical wall zones, and few of the other minerals form concentrations large enough or rich enough to merit commercial attention.

*Intermediate zones.*—An intermediate zone is any zone between the wall zone and the core, which generally occurs at or near the center of the containing pegmatite body. There is no theoretical limit to the number of intermediate zones that could be present in a single pegmatite body, but only a few bodies, like the North Morning Star and the Midnight Owl, contain more than three such units. Many of the pegmatites in the district contain one or two intermediate zones, and many others appear to contain none of these units, and hence consist only of border zones and cores, or of border zones, wall zones, and cores.

The intermediate zones are the least regular of the zonal units, and rarely are as complete as the wall zones. They generally form pods, straight or curving lenses, layers of relatively uniform thickness, or hood-like masses that reflect, to some degree, the gross form of the enclosing pegmatite body (Fig. 3). They range in thickness from a knife edge to a known maximum of nearly 70 feet, and the average thickness of all intermediate zones in the large pegmatites of the district probably is about 6 feet. Abrupt variations are common. In terms of bulk, these units are subordinate to the wall zones in most pegmatite bodies, although the reverse relation is true in many individual bulges.

The composition of the intermediate zones likewise has a wide range, as shown by the typical examples in Fig. 3. In those pegmatites that contain no lithium minerals, individual intermediate zones generally are distinguished by their texture and proportions of quartz and potash feldspar. The most common rock types are massive quartz with scattered giant crystals of perthite; extremely coarse-grained perthite—quartz pegmatite; pegmatite that consists mainly of very coarse, blocky crystals of perthite or of graphic granite; and perthite—quartz—plagioclase pegmatite with very coarse-grained granitoid texture. Ordinarily the intermediate zones of a given pegmatite body become coarser as traced inward from the wall zone to the core, and their content of quartz tends to increase in the same direction.

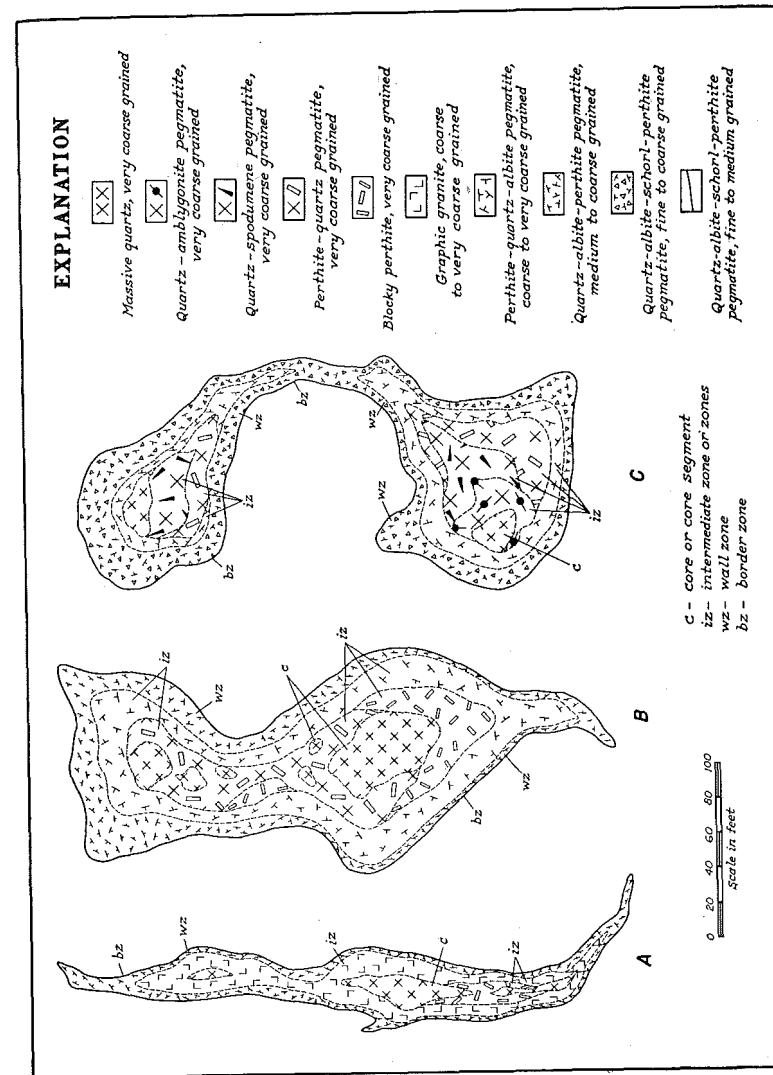


Figure 3.—Generalized plans of typical pegmatite bodies, showing characteristic distribution of zones within them. A. Typical non-commercial pegmatite body. B. Large mass of commercial feldspar. C. Bulbous pegmatite body with concentrations of lithium minerals.

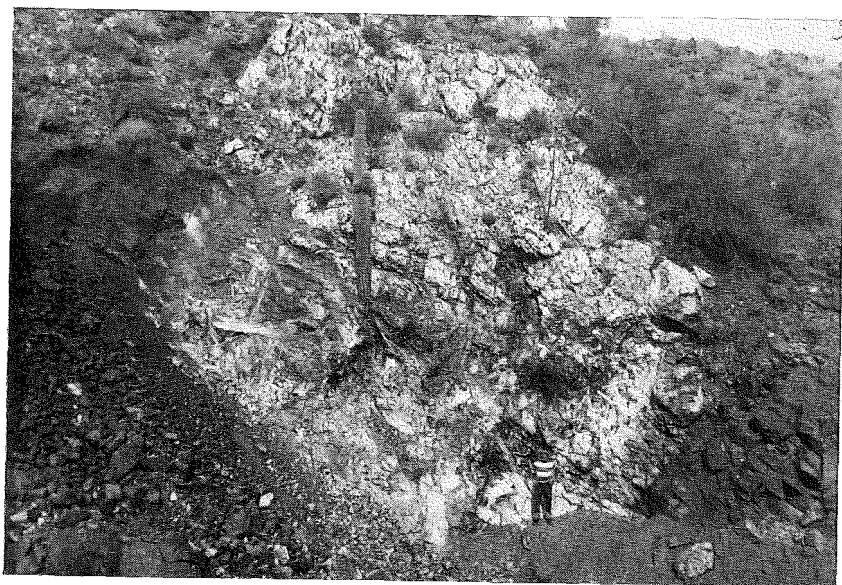


Plate VI.—Main spodumene-bearing bulge in Lower Jumbo pegmatite. Bulge consists chiefly of very coarse-grained quartz-spodumene pegmatite. At right of man is curving wall of bulge. Entire view corresponds to upper part of front vertical section in Plate XIX.

Intermediate zones constitute the major source of lithium minerals in the district, and include such major-mineral combinations as quartz—spodumene, quartz—amblygonite, quartz—perthite—amblygonite, quartz—spodumene—perthite, and quartz—spodumene—amblygonite (Fig. 3). Most of these units are characterized by truly giant textures, and individual crystals commonly are 4 feet or more in maximum dimension (Pls. VI, VII). A few spodumene-bearing intermediate zones, though coarse to very coarse grained, nevertheless are distinctly finer and more even grained than the typical giant-textured units. Such zones occur in the outer parts of several markedly bulbous pegmatites, of which the North Morning Star, Lower Jumbo, and Midnight Owl are good examples.

Other lithium minerals, particularly lepidolite and lithiophilite, also are present in many intermediate zones that lie near the centers of the containing pegmatite bodies. They generally occur as crystals and crystal aggregates that are distinctly smaller than those of the spodumene and amblygonite.

*Cores.*—The cores, or innermost zones, of the pegmatites are even more variable than the intermediate zones in form, position, texture, and mineralogy. Although they generally occur in the central parts of the containing pegmatite bodies, they rarely are symmetrically disposed with respect to the ends of these bodies. The size of the core generally is proportional to the size



Plate VII.—Detail of the pegmatite bulge show in Plate VI. Note the broad, lath-shaped, diversely oriented crystals of spodumene, including the very large crystals to left of man's head and at left base of sahuaro cactus.

of the pegmatite body itself, especially where many zones are present, but numerous exceptions are known.

Many of the cores are single masses, and range in form from thin lenses to nearly spherical pods. Most are shaped like a lima bean, and are straight or gently curved, depending in general upon the shape of the containing pegmatite body. In many pegmatites of relatively complex form, the cores comprise discontinuous segments, each of which occupies the central part of a major bulge (Fig. 3). Some lie in the centers of these bulges, but many others are near one of the ends (Fig. 3C).

In the pegmatites that consist of only two or three zones, the cores are granitoid aggregates of perthite, quartz, and plagioclase, or are small but giant-textured masses of quartz, graphic granite, or perthite—quartz pegmatite. Such pegmatite bodies rarely contain large segregations of very coarse-grained feldspar or lithium minerals, and hence rarely are of commercial interest. Where these cores are large, they generally are granitoid and only slightly coarser than the nearby wall zones.

In those pegmatites with prominent, very coarse-grained intermediate zones, and hence with more complex internal structure, the cores commonly are large and contain crystals of giant size. They are small in bulk, however, as compared with the other zones, and rarely do they constitute more than 3 per cent of the enclosing pegmatite body. The principal rock types represented in the district are massive quartz, quartz—euhedral perthite peg-

matite, perthite-rich pegmatite, and quartz—amblygonite, quartz—spodumene, and quartz—spodumene—amblygonite pegmatite.

These innermost units and some of the adjacent intermediate zones contain the principal commercial concentrations of feldspar and other minerals in the district, and an understanding of their positions within the pegmatite bodies is thus very important. Fortunately, most of them are rich in quartz and hence are well exposed; indeed, many form such prominent outcrops and yield such an abundance of float material that they give the casual observer an exaggerated impression of their size. Due to their relatively small dimensions, the cores, and possibly other zones as well, are not exposed in many pegmatites that have been cut only slightly by erosion; likewise, the cores of many other pegmatites appear to have been wholly removed by erosion.

An added complication is the difficulty of identifying the innermost zones of many pegmatites, for not every core can be seen or even predicted with confidence. Thus a zone identified as a core at one level may prove to be an intermediate zone when the top or edge of the true lens-like core is exposed by subsequent erosion or mining. In general, however, careful study and three-dimensional analysis of the gross structure of even the most irregular mass of pegmatite can lead to some prediction concerning the location and probable composition of its core or core segments, especially if correlated with the form and mineralogy of the other exposed zones.

#### FRACTURE FILLINGS AND OTHER UNITS

Most of the fracture fillings in the pegmatite bodies are thin, irregular, vein-like masses of quartz, albite, muscovite, lepidolite, schorl, or various combinations of these minerals. They form aggregates that typically are much finer grained than the host pegmatite, and range from thin and uniformly tabular masses through more irregular, branching masses to stockworks and groups of irregularly connected pods.

Contacts between the fracture fillings and the enclosing pegmatite ordinarily indicate much corrosion; indeed, there are all gradations between simple open-space fillings and replacement masses whose original fracture control no longer is evident. Well exposed in the Outpost pegmatite body, for example, are all gradations between thin veinlets of albite that form stockworks within aggregates of giant anhedral crystals of quartz, on one hand, and irregular masses of albite, several feet in maximum dimension, that enclose relatively small and ragged residua of quartz, on the other.

Most of the fracture fillings and fracture-controlled replacement masses are tabular in form, and are not more than  $\frac{1}{2}$  inch thick. Many of them show crude parallelism with respect to the zonal structure of the pegmatite body, but most plainly transect this structure, especially in detail, and hence represent material that is younger than the minerals of the adjacent zones.

Milky white to moderately smoky quartz is abundant in all pegmatites as cross-cutting veinlets, most of which range in thickness from a knife edge to about  $\frac{1}{8}$  inch. They characteristically branch and rejoin to form irregular networks, especially within zones that are rich in very coarse-grained perthite. Planar to highly irregular veinlets of sugary quartz are abundant in some of the coarse perthite in the Friction and Picacho View pegmatites (Pl. XII), and thicker tabular masses also are present in these and in other deposits. The largest fracture filling of quartz observed in the district is in the Midnight Owl pegmatite, where it extends from a segment of very coarse-grained quartz—perthite—spodumene pegmatite as an apophysis, 9 feet long and 3 inches to 14 inches thick, into medium-grained perthite—quartz—albite—muscovite pegmatite (Pl. XXIV).

Albite also is widespread as veinlets and as much larger replacement masses, generally in coarse- to very coarse-grained massive quartz and quartz—euhedral perthite pegmatite. It is especially abundant in the Outpost pegmatite, where it forms several mappable units that contain 40 per cent to 95 per cent of sodic albite. One of these large units evidently was once massive quartz, and a second appears to have been developed along the boundary between a very coarse-grained, perthite-rich intermediate zone and a finer-grained wall zone of quartz—perthite—albite—schorl pegmatite (Pl. XXI). Similar but smaller masses of such albite-rich pegmatite are present in the Midnight Owl, White Jumbo, and several other pegmatite bodies, in which they locally obscure the zonal structure.

Muscovite also is widespread in fracture fillings and replacement masses. It forms small flakes and plates in numerous irregular veinlets that are most abundant in coarse-grained potash feldspar and quartz, and also occurs locally as concentrations of thicker books that are  $\frac{1}{2}$  inch to 2 inches in diameter. Most of these books are yellowish green, and are marred by ruling, reeves, warping, and wedge structure. Extremely fine-grained, yellowish green to gray muscovite forms numerous subspherical to turnip-shaped aggregates with smooth margins and a waxy appearance, generally in the interior parts of the largest pegmatite bodies.

Vein-like masses and irregular pods of lepidolite, some of which are 15 feet in maximum dimension, are present in the wall zones and outer intermediate zones of the lithium-bearing pegmatites, as well as in the more central parts, where they are associated with spodumene and amblygonite. Most of the lepidolite occurs as clusters of highly curved and fractured plates, whose color ranges from white to moderately deep lilac. None of these concentrations appears to be of commercial magnitude, but they are very significant as guides to lithium mineralization elsewhere in the enclosing pegmatite body, and hence are particularly important in those bodies whose principal lithium minerals are not exposed at the present surface.

Green, pink, and white tourmaline (elbaite) forms small, pod-like aggregates of crystals along fractures in nearly all of the



lithium-bearing pegmatites. It also occurs as irregular, "bunchy" masses that are similar in general form to the aggregates of lepidolite crystals described above. The maximum dimension of such masses is about 3½ feet.

Bismuthinite and several secondary bismuth minerals fill fractures in quartz and in some coarse-grained perthite in many of the pegmatite bodies. Fracture fillings of other secondary mineral species also are widespread in the district, and occur chiefly in the inner parts of the largest pegmatite bodies. These minerals include hureaulite, strengite, and purpurite derived from earlier lithiophilite-triphyllite; manganese oxides from spessartite and lithiophilite; wulfenite, pyromorphite, mimetite, cerussite, and anglesite from galena; and cuprite, chrysocolla, and malachite from copper-bearing sulfides. Some of these secondary species fill fractures in the minerals from which they were derived, and many of the fillings extend beyond into other pegmatite minerals.

Although the fracture-filling and replacement minerals are very widespread, they represent a trivial amount of the total pegmatite material in the district.

#### MINERALOGY

##### GENERAL STATEMENT

It is not the purpose of this report to discuss fully the minerals of the White Picacho pegmatites, as with few exceptions they are similar in occurrence and properties to pegmatite minerals that have been described in considerable detail from many other parts of the world. It should be pointed out, however, that the pegmatites are distinguished by the presence of several phosphate minerals, including lithium-bearing species, and by the occurrences of tantalum-columbium, tin, uranium-thorium, and rare-earth minerals. Unusually varied assemblages of bismuth, copper, lead, tungsten, and zinc minerals also are present in a few deposits, but detailed descriptions of these occurrences await publication elsewhere. Emphasis in the present report is placed upon those mineralogic features that have greatest bearing upon the economic aspects of the pegmatites, and other features are noted only briefly or are omitted altogether.

The minerals observed in the pegmatites are listed in Table 1, and their abundance is indicated in a general way. Most widespread and abundant are albite, muscovite, perthite, quartz, and black tourmaline (schorl). In addition, many of the pegmatites contain large quantities of amblygonite, lepidolite, spodumene, and colored tourmaline (elbaite). Apatite, beryl, biotite, and garnet are less abundant though very widespread.

The pegmatites are truly granitic in gross composition, and many of them are unusually rich in lithium. Other elements present in noteworthy quantities are beryllium, fluorine, manganese and phosphorous, and, in lesser quantities, bismuth, cesium, columbium, iron, rubidium, and tantalum. Rarer constituents include antimony, copper, lead, molybdenum, rare-earth elements, thorium, tin, tungsten, uranium, vanadium, and zinc.

TABLE 1.—LIST OF MINERALS IN PEGMATITES OF THE WHITE PICACHO DISTRICT

Mineral	General abundance	Not a primary mineral; probably derived from
Albite	XX	_____
Allanite	*	_____
Amblygonite	X	_____
Anglesite	*	Galena, etc.
Apatite	XX	_____
Arsenopyrite	*	_____
Azurite	*	Bornite, chalcopyrite, etc.
Beryl	XX	_____
Beyerite	*	Bismuthinite
Biotite	XX	_____
Bismuth	*	Bismuthinite ?
Bismuthinite	*	_____
Bismutite	X	Bismuthinite
Bornite	*	_____
Calcite	*	_____
Cassiterite	*	_____
Cerussite	*	Galena, etc.
Chalcedony	X	Various sources
Chalcocite	*	_____?
Chalcopyrite	*	_____
Chrysocolla	*	Bornite, chalcopyrite, etc.
Clay minerals	XX	Feldspars, spodumene, etc.
Columbite-tantalite	XX	_____
Cookeite	X	Spodumene
Copper	*	Bornite, chalcopyrite, etc.
Curprite	*	Bornite, chalcopyrite, etc.
Descloizite	*	Galena, etc.
Epidote	X	Various sources
Fluorite	XX	_____
Galena	*	_____
Garnet	XX	_____
Goethite	*	Various sources
Hematite	X	Various sources
Hemimorphite	*	Sphalerite
Hureaulite	X	Lithiophilite and triphylite
Hydrozincite	*	Sphalerite
Lepidolite	X	_____
Lithiophilite-triphyllite	X	_____
Loelligite	*	_____
Magnetite	X	_____
Malachite	*	Bornite, chalcopyrite, etc.
Manganite	X	Lithiophilite, garnet, etc.
Mimetite	*	Galena, etc.
Microcline	XX	_____
Microlite	X	_____
Molybdenite	*	_____
Molybdite	*	Molybdenite and powellite
Monazite	*	_____
Muscovite	XX	_____
Oligoclase	X	_____
Opal	X	Various sources
Powellite	*	_____
Purpurite	*	Lithiophilite and triphylite
Pyrite	X	_____

Mineral	General abundance	Not a primary mineral; probably derived from
Pyrochlore	x	_____
Pyrolusite	x	Lithiophilite, garnet, etc.
Pyromorphite	*	Galena, etc.
Pyrrhotite	x	_____
Quartz	XX	_____
Scheelite	*	_____
Sericite	x	Various sources
Sicklerite	*	Lithiophilite and triphylite
Silver	*	Silver-bearing sulfides
Sphalerite	*	_____
Spinel	*	_____
Spodumene	X	_____
Stewartite	*	Lithiophilite, etc.
Strengite	*	Lithiophilite and triphylite
Tantalite-columbite	x	_____
Tourmaline	XX	_____
Triphylite-lithiophilite	x	_____
Triplite	x	_____
Vanadinite	*	Galena, etc.
Vivianite	*	Triplite
Wulfenite	*	Galena, etc.
Zeolite minerals	x	_____?
Zinnwaldite	*	_____

- XX — Abundant and widespread  
 X — Widespread, or locally abundant  
 xx — Common, or abundant in at least one pegmatite  
 x — Not common  
 \* — Rare

#### ESSENTIAL MINERALS

Microcline, the most abundant mineral in the pegmatites, occurs as white, gray, and flesh-colored to reddish brown crystals that range in maximum dimension from  $\frac{1}{8}$  inch to about 13 feet. These crystals are anhedral to subhedral in the granitoid pegmatite of border zones, wall zones, and some intermediate zones, and subhedral to euhedral in most very coarse-grained pegmatite of intermediate zones and cores. In these interior zones it generally forms large crystals in massive quartz or occurs as nearly pure, blocky aggregates of coarse, poorly formed crystals. The pegmatite that is rich in coarse microcline generally is hard and forms relatively continuous outcrops.

All the observed potash feldspar contains very thin, platy to spindle-shaped subparallel lenses of albite as perthitic intergrowths, and hence is referred to in the following pages as perthite, rather than microcline. The albite lenses ordinarily are less than  $\frac{1}{32}$  inch thick and  $\frac{1}{8}$  inch long, but tend to be larger in the coarsest host crystals of potash feldspar, where some reach thicknesses of nearly  $\frac{1}{8}$  inch and lengths of  $\frac{1}{4}$  inch or more. Some of the perthite contains tabular to spindle-shaped crystals of quartz in crudely graphic orientation, and this graphic granite is similar to that exposed in many other pegmatite districts.

The perthite commonly is weathered somewhat at the pegmatite outcrops, where it has a dull luster and is creamy, tan, or brown in color. Much also is stained by iron oxides. Quartz,

albite, and muscovite, generally in very fine-grained aggregates, vein the coarser types of feldspar in many deposits, and some of the perthite appears to have been brecciated and subsequently cemented with the other minerals.

Albite is present both as fine-grained, sugary, crystalline aggregates and as groups of coarse, platy crystals of the variety cleavelandite. All gradations in habit and size are present between these two extremes. The mineral is typically lustrous and white, but some of the fine-grained aggregates are pale green on freshly broken surfaces, and some of the coarsest cleavelandite is light gray to medium bluish gray. Individual anhedral to subhedral crystals in the sugary aggregates are  $\frac{1}{64}$  inch to  $\frac{1}{16}$  inch in diameter, whereas the larger platy crystals are  $\frac{1}{8}$  inch to 4 inches long,  $\frac{1}{16}$  inch to 3 inches wide, and about  $\frac{1}{4}$  inch in maximum thickness. Average dimensions of the plates are approximately  $\frac{3}{4}$  inch,  $\frac{1}{2}$  inch, and  $\frac{1}{16}$  inch, respectively. Most of these crystals are curved or warped, and the fine, closely spaced ruling of twin lamellae is plainly visible on the edges of many.

Fine-grained cleavelandite and sugary albite are by far the most abundant forms in the pegmatites. They generally occur with quartz, muscovite, schorl, and combinations of these minerals as aggregates that are interstitial to much larger crystals of perthite. They are scattered widely through most of the pegmatite with granitoid texture, and occur also along contacts between perthite crystals, or between crystals of perthite and quartz, in the coarser pegmatite of the inner zones. Much sugary albite also is present along fractures and cleavage cracks in potash feldspar, and commonly shows evidence of having been formed at the expense of the host feldspar crystals. Replacement evidently has progressed much farther in some crystals, and a few pseudomorphs of fine-grained albite after perthite were noted in several of the pegmatite bodies.

Cleavelandite generally is confined to the cores and other interior units of the pegmatites, and characteristically is a late-stage constituent of the rock in which it occurs. In a few pegmatite bodies it is so abundant that it obscures some boundaries between zones. Individual subparallel plates commonly form fringes along fractures in quartz, perthite, spodumene, and muscovite, or along contacts between coarse crystals of such minerals. Other tablets form crudely radial aggregates, the outer surfaces of which are cauliflower-like in general appearance. Some of these comprise successive layers of cleavelandite crystals, and are as much as 4 feet in diameter. A few also contain thin, curving layers of muscovite flakes, with or without similar layers of tiny garnet crystals.

Most of the cleavelandite is light colored, but some is stained deep flesh to dark reddish brown in the immediate vicinity of crystals or masses of pyrochlore, microlite, and columbite-tantalite. Indeed, many spherical zones of discoloration surround centrally disposed crystals or small crystalline aggregates of these

accessory minerals. Where thus discolored, the albite generally is soft and crumbly, and has a dull luster.

Quartz is almost as abundant in the pegmatites as microcline, and is even more widespread. It is present in nearly all the pegmatite units, and evidently was formed during every general stage of pegmatite development. Ordinarily it is milky white to light gray, but a few clear, smoky to colorless crystals are present in some border zones and cores. More than 95 per cent of the quartz forms anhedral crystals that are 1/16 inch to several feet in diameter, and most of the remainder occurs as subhedral spindles, rods, and plates in graphic granite. A little quartz forms tiny prismatic crystals in small, irregular vugs that are present locally in the inner parts of the pegmatite bodies.

The coarsest aggregates of quartz form intermediate zones, cores, or major parts of such units. Most of the large crystals are distinguished by rhombohedral cleavage and coarse, lamellar twinning, and many also show irregularly disposed growth lines and surfaces. Anhedral quartz, generally somewhat less coarse grained, is a major constituent of the granitoid zones that form the outer parts of most pegmatite bodies in the district. Typically it is interstitial to the other minerals, and is associated with albite and muscovite. It also fills numerous fractures in all types of pegmatite, and such fillings range from tiny, irregular stringers in perthite to thick, dike-like masses with dimensions measurable in feet.

#### VARIETAL MINERALS

The mica group is represented in the White Picacho pegmatites by the four major species muscovite, biotite, lepidolite, and zinnwaldite. Of these muscovite is most widespread and abundant, especially in the many pegmatites that do not appear to contain lithium minerals. It is scattered through most border zones and wall zones as small, thin, white to pale green flakes, which are particularly abundant as disseminations in and near partly digested masses of country rock, and as streaks and layers along or near pegmatite-wallrock contacts. Locally these flakes form dense mats that appear as thin, well defined layers. Somewhat larger plates of muscovite, whose maximum dimension is about 2 inches, also occur in quartz-albite aggregates that are interstitial to larger crystals and crystal groups of perthite or graphic granite.

The coarsest muscovite occurs in the central parts of the pegmatites, generally in irregular masses of very coarse-grained anhedral quartz. It forms thick, pale green to yellowish green books that range in diameter from 1/2 inch to 6 inches, with an average of about 1 1/2 inches. Most of the books are scattered uniformly through the quartz, commonly without a preferred orientation; such quartz-muscovite aggregates are very distinctive in appearance, and are termed "burr rock" in many pegmatite districts (Pl. VIII).

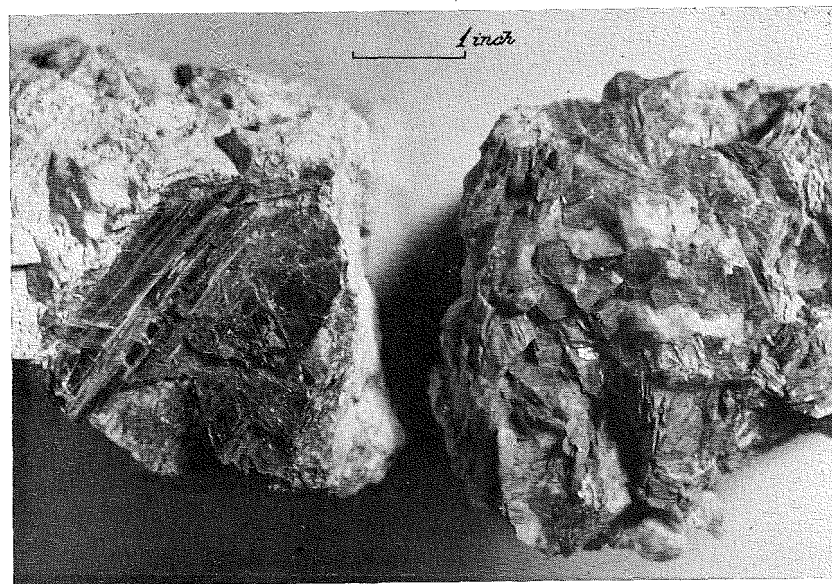


Plate VIII.—Muscovite. *Left.*—Large ruled crystal with ragged edges, in coarse perthite. New Lookout pegmatite. *Right.*—Typical "burr rock," an aggregate of muscovite books and quartz. North Morning Star pegmatite.

Some of the coarsest books occur separately or form irregular clusters. The largest of the clusters comprise diversely oriented and partially intergrown crystals of muscovite, with a little interstitial albite and quartz, and commonly are referred to as "bull mica." Many of these aggregates are localized along contacts between quartz and perthite crystals, or along fractures in aggregates of these minerals.

Muscovite also forms aggregates of much finer grain size. Some are nearly pure, but others also contain much schorl, albite, and quartz. These fine-grained masses are 1 inch to 5 feet in maximum dimension, and generally lie along fractures or along boundaries between pegmatite zones. Other, still finer-grained aggregates of pale greenish, grayish, and yellowish green muscovite occur in several of the pegmatites, and are locally abundant in the Picacho View, Outpost, and Midnight Owl bodies. They are waxy in appearance, tabular to pod-like in form, and rarely exceed 8 inches in maximum dimension. Like the slightly coarser-grained aggregates, they commonly are localized along fractures or intersections of fractures in the central parts of the pegmatite bodies.

Pink muscovite also is present as very fine-grained aggregates, mainly along fractures and cleavage cracks in crystals of spodumene. This material resembles some of the finest-grained varieties of lepidolite, but the lepidolite generally can be distinguished

because of its more bluish color.

Biotite is a quantitatively minor constituent in most of the pegmatites. It occurs almost wholly in their outer parts, chiefly the border zones, and is associated with plagioclase, black tourmaline, and quartz. It is especially abundant along some pegmatite-wallrock contacts and within partly digested inclusions and septa of mafic country rock, where much of it plainly is pseudomorphous after hornblende.

The biotite generally forms lustrous flakes  $\frac{1}{4}$  inch or less in diameter. Many of these are scattered individually, but others form dense, compact aggregates. Also present are some much larger, thin plates and blades, mainly in the perthite-rich wall zones of a few pegmatites, where the mineral is associated with graphic granite. Many of these crystals clearly fill fractures in graphic granite, perthite, and in granitoid aggregates of perthite and quartz. A little coarse, fracture-filling biotite also occurs in the quartz-rich inner units of a few pegmatite bodies.

Lepidolite, the lithium mica, is present in the central parts of some pegmatites, where it generally is associated with albite and with spodumene, amblygonite, and other lithium minerals. It is most abundant along the margins of very coarse-grained, quartz-rich zones, and also occurs with albite and quartz as irregular fracture fillings in these units and in some of the outer zones, as well. Its most common form is compact aggregates of flakes, foils, or thick, diversely oriented plates (Pl. IX), and it varies considerably in grain size. Some of the largest plates are 4 inches to 7 inches in diameter and as much as 2 inches thick, although the average dimensions of the coarse crystals are approximately 2 inches and  $\frac{1}{4}$  inch, respectively. In contrast, some aggregates of flakes are so fine grained that they resemble the waxy muscovite already described. Such aggregates occur mainly as fracture-filling veinlets and as small, rounded pods.

The lepidolite ranges in color from light pinkish gray to a moderately deep lilac or lavender, and where fresh is readily distinguished from the other micas. Near-surface books are bleached, however, and at the outcrop most of them have separated into light gray cleavage plates with a pearly luster. Even where fresh and unweathered, the crystals are considerably broken, warped, crenulated, and ruled (Pl. IX), and they yield ragged cleavage plates that are distinctly brittle. The lepidolite commonly is intergrown with sugary albite, which also veins many of the larger books. Some crystals of the mica are embedded in much larger prisms of spodumene, and locally appear to have been formed by replacement of the spodumene.

Zinnwaldite, the lithium-iron mica, is a very rare constituent of the inner pegmatite zones, and is associated there with quartz, albite, lepidolite, spodumene, berly, and fluorite. It forms thick, stubby crystals that generally are less than  $\frac{1}{2}$  inch in maximum dimension. These crystals are very dark in color, but yield cleavage flakes that are golden brown.

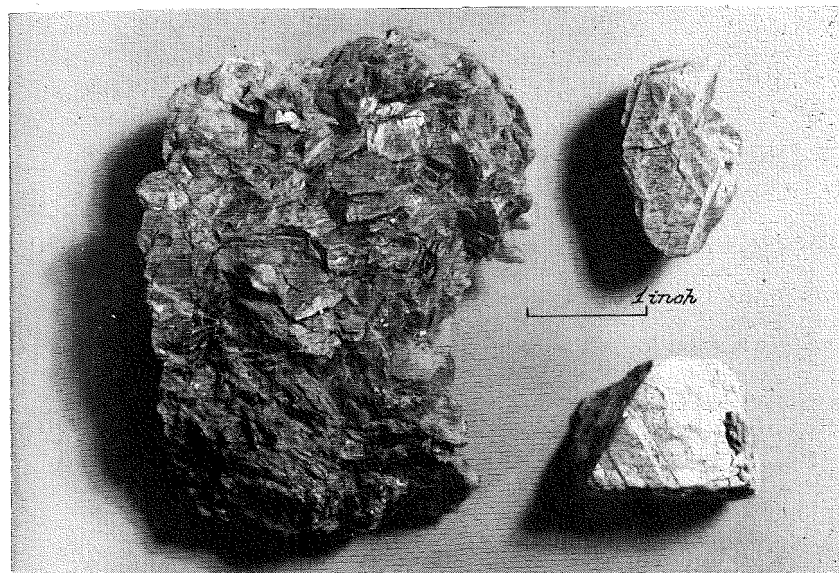


Plate IX.—Lepidolite. *Left*.—Aggregate of diversely oriented plates on quartz. North Morning Star pegmatite. *Right*.—Thick cleavage fragments, much ruled and with warped faces. Specimen at top is analyzed Sample A, Table 4. Sunrise pegmatite.

Spodumene is moderately abundant in nearly all of the lithium-bearing pegmatite, in which it is a constituent of intermediate zones and, rarely, of cores. The coarsest crystals are lath- to log-shaped, and are 2 feet to 21 feet long, 3 inches to  $4\frac{1}{2}$  feet wide, and  $\frac{1}{4}$  inch to 7 inches thick. Average dimensions are about 4 feet, 8 inches, and  $\frac{3}{4}$  inch, respectively. Most of the crystals are marked by striations, grooves, and elongate pits that are parallel to the longest axis, and nearly all are broken along irregular crosswise fractures. The coarse spodumene typically is associated with giant-textured aggregates of anhedral quartz, in which it forms jackstraw-like networks of diversely oriented crystals. Perthite, amblygonite, or both these minerals also are major constituents in some of the aggregates.

Finer-grained spodumene occurs in the outer intermediate zones of a few pegmatites, notably the North Morning Star and the Midnight Owl. The crystals are rough prisms that typically are less flattened than the larger crystals described above, and many have the form of stubby wedges. They are  $1\frac{1}{2}$  inches to 24 inches long and  $\frac{1}{8}$  inch to 6 inches thick. The most common of the associated minerals are quartz, perthite, albite, lepidolite, and, locally, amblygonite.

Considerable variations in general appearance are characteristic of the spodumene, and evidently reflect differences in degree of alteration. None of the material is transparent in the

hand specimen, but some is fresh and moderately lustrous on newly broken surfaces, which appear pearly white to greenish or bluish gray (Pl. X). Some is distinctly pinkish, and at least a part of such color appears to be caused by disseminated tiny flakes of lepidolite and muscovite. Most of the spodumene is buff to greenish gray, and is sufficiently altered to appear dull or even earthy (Pl. X). Increase in the proportion of alteration products, mainly albite, muscovite, and clay minerals, is accompanied in a given crystal by corresponding decreases in specific gravity, hardness, and luster; of considerable economic significance is an attendant decrease in the proportion of lithium present. Most of the crystals are not as thoroughly altered as their appearance might suggest, although some are little more than pseudomorphs of extremely fine-grained alteration minerals after the original spodumene. Variations in appearance and lithium content of the spodumene are discussed in greater detail in the section on economic features of the pegmatite minerals.

Amblygonite, lithium-aluminum fluo-phosphate, occurs in only a small proportion of the pegmatite bodies, but locally is present in considerable abundance. It forms large, irregular masses and crudely faced crystals, and generally is associated with quartz, or with quartz and spodumene, in intermediate zones and cores. Many of the crystals are well exposed in the outcrops of such pegmatite bodies as the North Morning Star, Sunrise, and Midnight Owl, and the mineral also is represented in the pegmatite float at these and several other localities. Individual crystals range in diameter from a few inches to about 6 feet, and several aggregates of crystals are as much as 15 feet in maximum dimension.

In general the amblygonite resembles some types of coarse potash feldspar, but it is markedly heavier and, where weathered, develops distinctive hard, grayish outer surfaces that are pitted, grooved, and cellular in appearance (Pls. XI, XII). Most is white to very pale bluish white where fresh, and has a characteristic pearly luster. Many cleavage surfaces are broadly curved, and some are markedly uneven in detail. Nearly all the crystals are considerably fractured, and in places they are brecciated on a small scale; the breaks generally are healed with finely fragmented amblygonite that is much more bluish or greenish than the main mass of the crystal (Pl. XI). Many of the fracture-bounded blocks show cleavage surfaces whose orientations are different from those of adjacent blocks, as if the fragments had been juggled slightly prior to healing.

Two general varieties of tourmaline, schorl and elbaite, are present in the pegmatite bodies. Schorl, the dark-colored iron tourmaline, is widespread and locally very abundant. It forms nearly equidimensional, subhedral to anhedral crystals that appear as dark chunks in most of the border and wall zones, and also occurs as coarse, stubby prisms in the interior parts of many pegmatite bodies. In addition, some forms crudely graphic intergrowths with coarse-grained quartz.

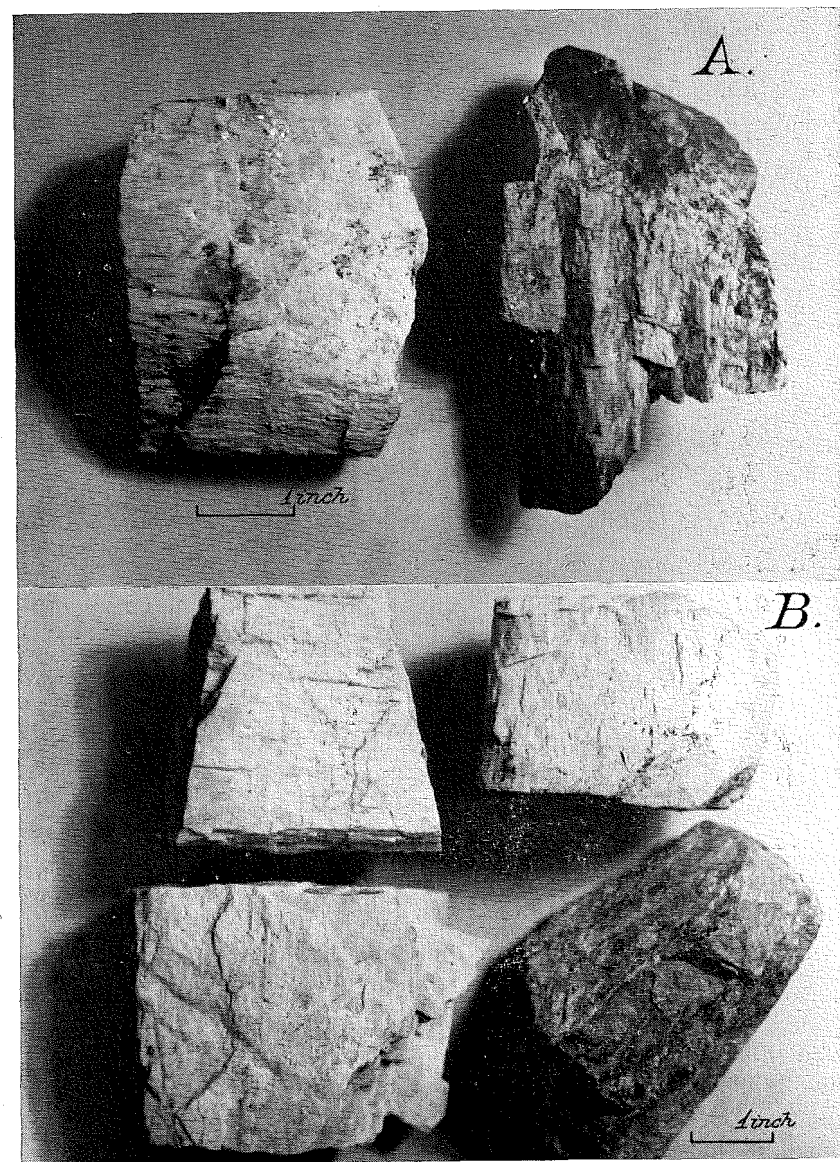


Plate X.—Spodumene. A. *Left*.—Fragment from hard, lustrous crystal. Sample A, Table 3. Lower Jumbo pegmatite. *Right*.—Fragment from soft, weathered crystal. Sample B, Table 3. Sunrise pegmatite. B. *Top*.—Fragments from hard, lustrous crystals. Lower Jumbo pegmatite. *Lower left*.—Similar fragment from Midnight Owl pegmatite. *Lower right*.—Fragment from soft, greenish gray crystal. Sample D, Table 3. Midnight Owl pegmatite.

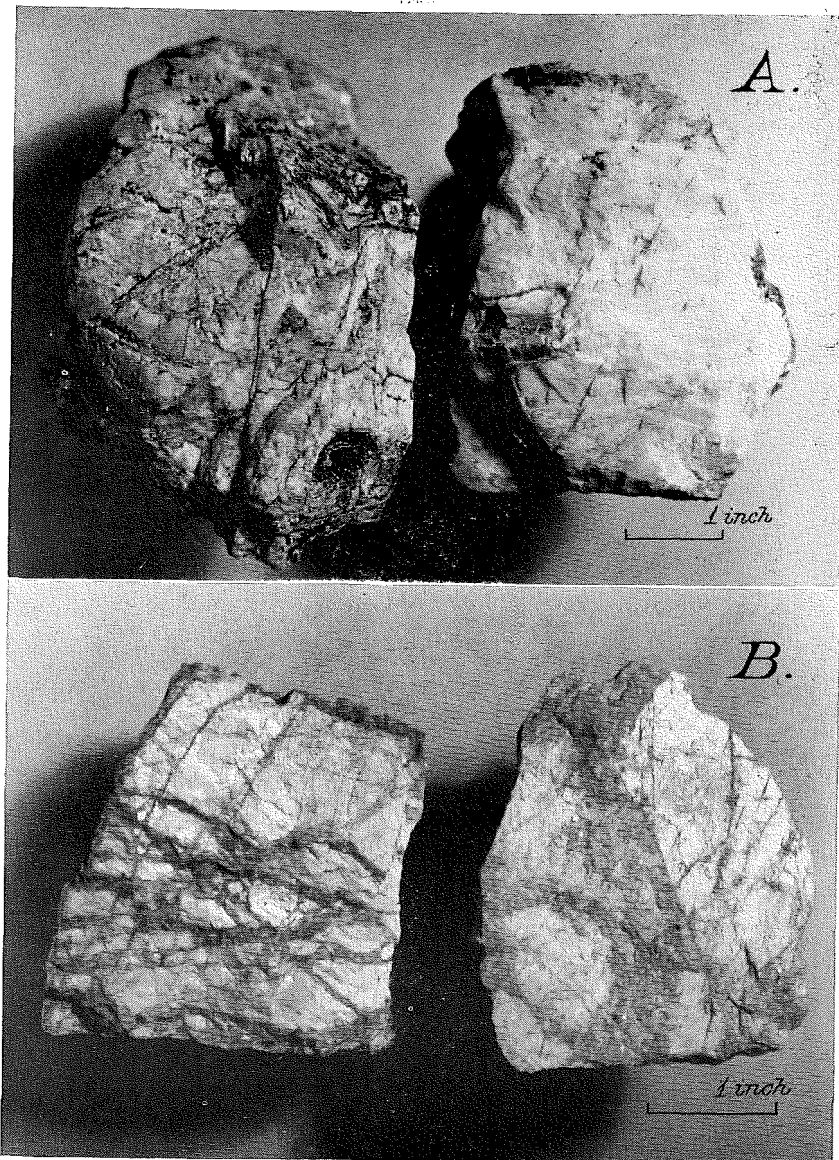


Plate XI.—Ambygonite. A. Fragments showing typical weathered and freshly broken surfaces. North Morning Star pegmatite. B. Cleavage fragments showing typical fracturing and brecciation of coarse ambygonite, and veining by very fine-grained, sugary ambygonite. Note the slightly diverse orientations of the cleavage in individual fragments. Sunrise pegmatite.

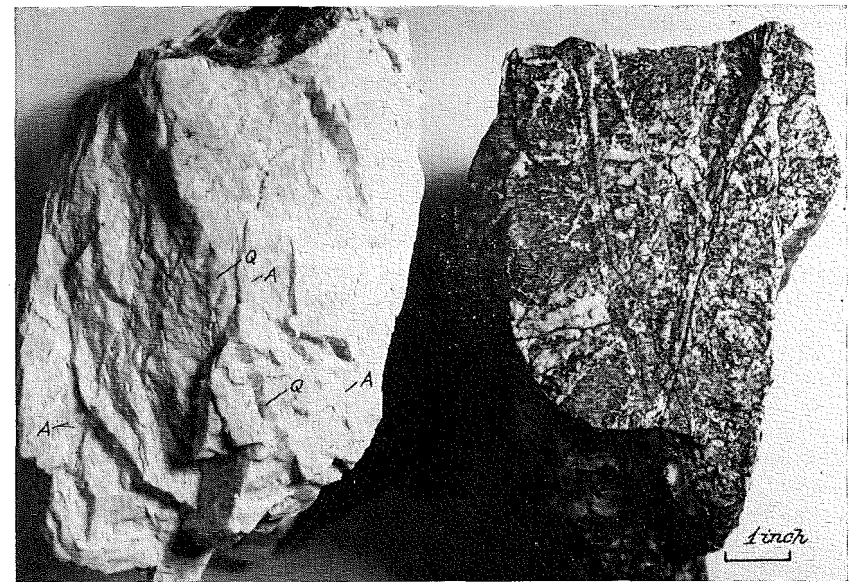


Plate XII.—Veining of perthite and ambygonite. *Left.*—Large cleavage fragment of perthite, showing typical thin veinlet of quartz (Q), which is parallel to numerous elongate, light-colored plates of perthitic albite (A). Picacho View pegmatite. *Right.*—Weathered and stained surface of ambygonite crystal fragment, showing veining by sugary ambygonite. Sunrise pegmatite.

The crystals in the outer zones are  $\frac{1}{8}$  inch to about 6 inches in diameter. They are extremely dark blue and green in the thinnest fragments, but appear black in the hand specimen. They are characteristically much sheared and fractured, and many of the breaks are cemented with very fine-grained tourmaline and mica. Most of the crystals also show a crudely developed basal parting. Nearly all of the schorl is somewhat altered, and in general appearance resembles some dull-lustered varieties of coal. Many of the crystals are coated with scaly aggregates of muscovite.

The more euhedral crystals of the interior zones and cores are  $\frac{1}{8}$  inch to 3 inches in diameter and  $\frac{1}{2}$  inch to 8 inches long. They commonly form bundles of subparallel prisms, as well as radial aggregates, and some groups of prisms are slightly divergent from what appears to be a common base. Many crystal groups have maximum dimensions as great as 12 inches. The individual crystals have rough but well defined faces, including terminations, and are much grooved and striated parallel to their c-axes. Nearly all are dull in appearance, even on newly broken surfaces, and are considerably fractured. Most are partly altered

to mica and clay minerals, and are enclosed by thin, firm layers of overlapping muscovite flakes. The schorl in some deposits contains abundant inclusions of euhedral pyrite.

Schorl also occurs in the interior parts of many less coarse-grained pegmatite bodies that have relatively simple zonal structure, and in them is characteristically associated with irregular pod-like masses of quartz. Most of the crystals are pencil-like, and ordinarily appear much fresher and more lustrous than those described above. The largest of them are about 3 inches in maximum dimension. Some of the schorl forms graphic intergrowths with quartz, and these aggregates locally resemble the quartz-muscovite "burr rock" in general structure.

Elbaite, which comprises the lighter-colored types of tourmaline in the pegmatites, is virtually restricted in its occurrence to the inner parts of a few pegmatite bodies. It characteristically forms rough prisms  $\frac{1}{4}$  inch to 7 inches long and  $\frac{1}{16}$  inch to  $1\frac{1}{2}$  inches in diameter. These are present in both zones and fracture-controlled replacement bodies, where they typically are associated with albite, lepidolite, muscovite, quartz, and spodumene. The mineral also occurs as inclusions in crystals of lepidolite, where it forms longitudinally striated blades and needles.

The crystals of elbaite are euhedral, but most are so severely altered that their faces are pitted and roughened, and most of the characteristic striations and grooves have been obliterated. The mineral is typically opaque, lusterless, and soft, and jackets of fine-grained muscovite and lepidolite are present on many of the crystals. Despite all this alteration, the color is well preserved in much of the elbaite. Green, pink, and pale yellow are most common, and many of the prisms are color zoned, either longitudinally or concentrically about their c-axes. A few of the concentrically zoned crystals are typical "watermelon" tourmaline, in that their green outer rims surround thin colorless layers, which in turn enclose pink cores.

#### ACCESSORY MINERALS

Nearly seventy minerals have been recognized as minor constituents of the pegmatites in the district, and more than half of these can be classed as primary accessory species. The others are mainly of secondary origin, and replace, or fill fractures in, pre-existing pegmatite minerals and included wallrock material. The most widespread of the accessory species are apatite, beryl, bismuth minerals, columbite-tantalite, fluorite, garnet, lithiophilite-triphyllite, magnetite, microlite and pyrochlore, pyrite and other sulfides, and triplite. Other, rarer accessories, generally noted in only a few pegmatites, include allanite, cassiterite, monazite, scheelite and powellite, and spinel.

Apatite occurs chiefly in border zones, wall zones, and locally along the outer margins of massive-quartz units. It forms gray to dark green and dark blue prismatic and tabular crystals with poorly developed faces. Most individuals are less than 1 inch in maximum dimension, and their average dimension probably is

slightly less than  $\frac{1}{4}$  inch. Apatite also is abundant locally in the central parts of lithium-bearing pegmatite bodies, both as stubby prisms and as thin, continuous gray rims on crystals of lithiophilite and triphylite.

Beryl is present in almost all the pegmatite zones. It occurs in border zones and wall zones as pale yellowish, greenish, and bluish gray anhedral crystals that are  $\frac{1}{8}$  inch to  $2\frac{1}{2}$  inches in maximum dimension, and locally is abundant. Most of the crystals are very irregular in form, and do not show marked elongation. In general they are not readily distinguished from some quartz and feldspar, although they have a characteristic greasy luster that can be recognized by a practised eye. Much larger crystals with rough faces occur in many of the inner zones, generally as thick prisms 2 inches to 11 inches long. These are pale greenish gray to pinkish, and commonly are associated with lithium minerals.

Several bismuth minerals are locally abundant in the Outpost pegmatite, and are widespread but very minor constituents of quartz-rich inner zones in many other pegmatite bodies. They are characteristically associated with quartz, albite, muscovite, cassiterite, and lead minerals. The chief primary mineral appears to be bismuthinite, which forms irregular, fibrous to columnar masses  $\frac{1}{8}$  inch to 6 inches in diameter. Some occurs with subordinate quartz and albite as bunched aggregates that are 2 inches to 7 feet in diameter. Individual crystals of the bismuthinite are considerably broken, and some even are brecciated.

Much more abundant is bismutite, a bismuth carbonate, which typically forms veins and stockworks in quartz, albite, and bismuthinite, and which also occurs as chunky pseudomorphs after bismuthinite. It ranges in color from gray through greenish and yellowish gray to bright green and canary yellow, and is distinguished by a dull and earthy luster, and by very high specific gravity. Native bismuth forms irregular masses, and also occurs as thin flakes in the other bismuth minerals. It is typically silvery to pinkish on freshly broken surfaces. One mass, said to have weighed  $2\frac{1}{2}$  pounds, was encountered during mining of the East bulge in the Midnight Owl pegmatite. Beyerite, a calcium-bismuth carbonate, forms grayish green films on the bismutite and bismuth. It also occurs as dense masses and as pearly white flakes in small cavities.<sup>12</sup>

Columbite-tantalite is present mainly in quartz-rich inner zones, where it forms thin to moderately thick tablets  $\frac{1}{8}$  inch to  $2\frac{3}{4}$  inches in maximum dimension. Much larger crystals are present locally in the Midnight Owl and a few other pegmatite bodies, where they reach maximum dimensions of about 5 inches. Both these and the smaller, thinner tablets commonly are warped or curved. The mineral is characteristically black, with dull-appearing outer surfaces. Many of the crystals are coated with flakes of very pale yellowish green muscovite. The columbite-tantalite

<sup>12</sup>Fron del, Clifford, personal communication, 1953.

is easily mistaken for triplite and some schorl, but is heavier than these minerals, and is distinctly more lustrous on freshly broken surfaces.

Fluorite is widespread, generally as small, inconspicuous gray crystals in outer zones and as larger subhedral masses in mineralogically complex cores and intermediate zones. It commonly is associated with schorl, especially near the borders of the pegmatite bodies. The coarsest crystals,  $\frac{1}{4}$  inch to 2 inches in diameter, are white to faintly greenish gray. Cleavage is very well developed, and many of the smaller crystals appear sugary under the hand lens. These commonly weather out from pegmatite outcrops to yield numerous small pits in the rock.

Garnet is present in all the pegmatites observed, and ordinarily is widely distributed in each pegmatite body. All the specimens checked were spessartite, the manganese-aluminum garnet. The mineral ranges from tiny, rounded, orange red to deep red crystals in outer zones to larger, sharply faced, salmon pink to red crystals in the central parts of the pegmatites. The largest crystals are about  $\frac{1}{2}$  inch in diameter. Some garnet forms graphic intergrowths with quartz, and locally resembles the quartz-schorl intergrowths already described.

Associated with the amblyonite and spodumene in the inner parts of several lithium-bearing pegmatites are lithiophilite, lithium-manganese phosphate, and triphylite, lithium-iron phosphate. These minerals form equant to stubby prismatic crystals with rough faces, and range in maximum dimension from  $\frac{1}{2}$  inch to 6 inches. A few clusters of coarse crystals are as much as 24 inches in diameter. Freshly broken surfaces are lustrous, and range in color from pale bluish gray through flesh to salmon pink. Manganese oxides form prominent black stains around the margins of the crystals, and along fractures within them (Pl. XIII), and nearly all the observed crystals are coated with thick crusts of manganite and pyrolusite.

Several rare manganese and iron phosphate minerals appear to have been formed directly or indirectly from the lithiophilite and triphylite, and their relations are similar to those described from several other phosphate-bearing pegmatites in the Black Hills region of South Dakota,<sup>13</sup> the Pala district of southern California,<sup>14</sup> and the Boliden area of Sweden.<sup>15</sup> Sicklerite, iron-manganese-lithium phosphate, forms thin, discontinuous rims on

<sup>13</sup>Fisher, D. J., Preliminary report on the mineralogy of some pegmatites near Custer: South Dakota Geol. Survey, Rept. Inv. No. 50, esp. pp. 43-47, 1945.

<sup>14</sup>Jahns, R. H., and Wright, L. A., Gem- and lithium-bearing pegmatites of the Pala district, San Diego County, California: California State Div. of Mines, Special Rept. 7-A, pp. 40-41, 1951.

<sup>15</sup>Quensel, Percy, Minerals of the Varuträsk pegmatite. 1. The lithium-manganese phosphates: Geol. Fören. Stockholm Förh., vol. 59, pp. 77-96, 1937.

Mason, Brian, Minerals of the Varuträsk pegmatite. 23. Some iron-manganese phosphate minerals and their alteration products: Geol. Fören. Stockholm Förh., vol. 63, pp. 134-155, 165-175, 1941.

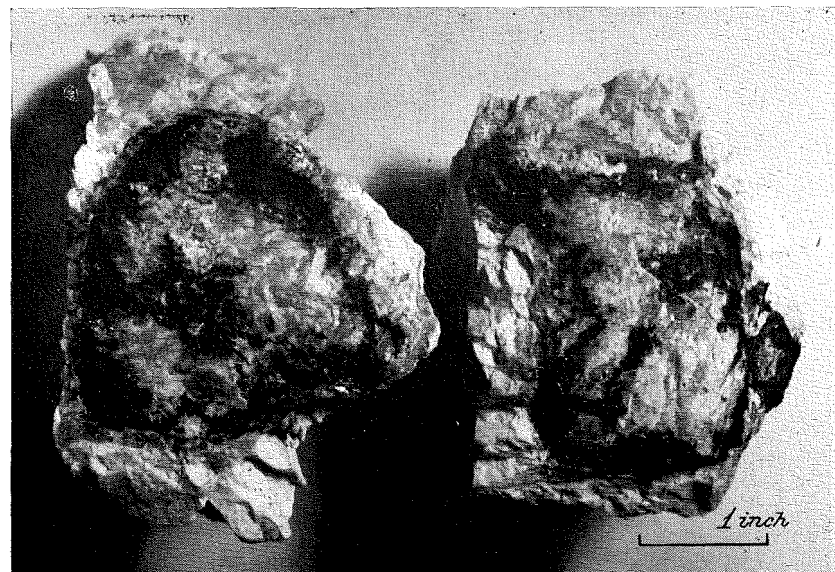


Plate XIII.—Lithiophilite. Freshly broken surfaces of large, salmon-pink crystals, showing dark stains of manganese oxides. Both crystals are thinly rimmed by light gray apatite. Midnight Owl pegmatite.

a few of the crystals. These are dark reddish to mahogany brown, and their cleavage surfaces are continuous with those of the lithiophilite and triphylite. Hureaulite, a hydrous manganese phosphate, occurs locally between the cores of the crystals and the sicklerite as crystalline aggregates, and also is present along fractures in the cores. It is amber to flesh colored, and in general is distinctly lighter in color than the adjacent lithiophilite, and more yellowish than the triphylite.

Tiny needles and plates of purpurite, hydrous iron-manganese phosphate, and strengite, hydrous iron phosphate, form crusts and cavity fillings, mainly within the masses of manganese oxides. Most appear as small, felted aggregates with distinctive pinkish, lavender, and deep reddish color. Stewartite, another hydrous manganese phosphate, forms numerous pale yellow films in the other minerals. It also occurs as finely crystalline aggregates that cement microbreccias of hureaulite and lithiophilite, and as thin, subparallel fibers along irregular fractures in other minerals, mainly strengite and purpurite.

Also associated with the spodumene, amblygonite, and lithiophilite-triphylite is triplite, a fluo-phosphate of iron and manganese. It occurs in quartz and albite as roughly-faced tabular crystals,  $\frac{1}{4}$  inch to 7 inches in maximum dimension, that are either separate or in groups of slightly diverging individuals (Pl. XIV). It resembles some schorl and columbite-tantalite, but has moder-

Plate XIV.—Triplite.



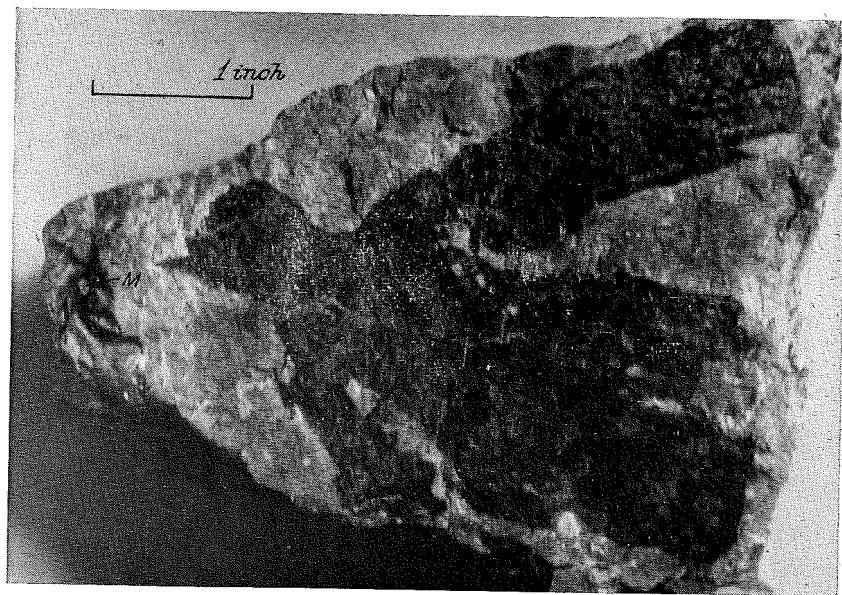


Plate XIV.—Triplite. Edge-on view of coarse, tabular crystals in quartz, perthite, and flesh-colored albite. Small crystal of microlite (*M*) at left. Midnight Owl pegmatite.

ately good cleavage and is more brownish than either of these minerals. Too, freshly broken surfaces are resinous and are not as lustrous as those of the columbite-tantalite. Rough chemical tests indicate a moderately high ratio of manganese to iron, and in this respect the mineral resembles the triplite noted by Galbraith<sup>16</sup> from the Eureka district to the north. Most is coated and veined with manganese oxides, and locally contains films of finely crystalline, bluish gray vivianite.

Monazite, a phosphate of the rare-earth elements, is a very minor associate of the tantalum-columbium minerals in the quartz-rich interior parts of several pegmatites. Its crystals are small, well faced, and pale reddish brown to honey yellow in color. Many have mica coatings like those on the tantalite-columbite.

Magnetite forms small, lustrous crystals and grains in many of the pegmatite units. It is widespread but nowhere abundant. Most is finely disseminated in border zones and in the schorl-bearing parts of some perthite-rich intermediate zones.

Microlite and pyrochlore, essentially tantalate-columbates of calcium, occur sparingly in the intermediate-zone quartz and perthite of the Outpost, Midnight Owl, Picacho View, and several other large pegmatite bodies. They form tiny, olive green to dark brown and black crystals with sharply defined octahedral

and dodecahedral faces. The feldspar that surrounds such crystals generally is darkened and lusterless, and contains tiny disseminated flakes of muscovite.

Scheelite and powellite are scattered sparsely through some quartz-rich inner zones, generally as small, roughly faced crystals and as very thin veinlets and stringers in the quartz. Larger and richer concentrations of both minerals occur in separate masses of vein-like quartz that are not directly associated with any of the pegmatite bodies.

Allanite, a rare-earth-bearing member of the epidote group, forms a few pencil-like crystals in the coarse-grained quartz of several inner zones. These crystals are  $\frac{1}{2}$  inch to 4 inches long, and are dark brown to black in color. They are very lustrous, in contrast to most of the black tourmaline, and are deeply and finely striated longitudinally.

Cassiterite is locally common in fractured and brecciated quartz of several pegmatite bodies, and is especially abundant in the Outpost pegmatite, where it is associated with bismuth, lead, and copper minerals. It forms tabular crystals with well defined faces, many of them finely striated. These crystals are  $\frac{1}{8}$  inch to  $1\frac{1}{2}$  inches in diameter, with an average of about  $\frac{3}{8}$  inch. They are honey yellow to very dark brown, and some are zoned, with dark rims and lighter-colored cores. A few of the lightest-colored crystals are dull in appearance, but the remainder have a high luster. Nearly all are broken along numerous irregular fractures.

Gahnite, a zinc-bearing member of the spinel group, is present in the interior parts of the pegmatites, generally as small, blue-gray to deep green octahedral crystals in very coarse-grained quartz. Many of these crystals are distributed along fractures. They commonly are associated with columbite-tantalite, and locally with pyrochlore and cassiterite. The spinel pleonaste, magnesium-iron aluminate, was noted in the border zones of two pegmatites, where it forms small crystals in partly digested masses of amphibolite. It is greenish black, with a bright luster.

Arsenopyrite, bornite, chalcopyrite, galena, loellingite, molybdenite, pyrite, pyrrhotite, and sphalerite are sparsely scattered through the coarse-grained inner units of most pegmatites in the district, and locally are present in surprising abundance. They are mainly disseminated through aggregates of perthite, quartz, and albite, and are localized along crystal boundaries or along fractures within large crystals or crystal groups of quartz and feldspars. Some are included in schorl and muscovite, and some form crystalline aggregates,  $\frac{1}{8}$  inch to 7 inches in maximum dimension, that appear as irregular "clots" in masses of coarse, blocky perthite. Pyrite and molybdenite are locally abundant along well defined fractures in massive quartz.

Pyrite is by far the most abundant of the sulfide minerals, and pyrrhotite and loellingite are locally abundant, as well. These minerals also have the widest distribution in the cores and intermediate zones of the pegmatites. The copper, lead, molybdenum,

<sup>16</sup>Galbraith, F. W., *Minerals of Arizona* (2nd edition): Univ. of Arizona, Bur. of Mines, Bull. 153, p. 56, 1947.

and zinc minerals, in contrast, are more restricted to the innermost parts of the pegmatite bodies. Many of these minerals are oxidized in near-surface parts of the pegmatites, and their abundance and even their presence in some exposures cannot be estimated with confidence. It is likely that at depth these species are present in greater abundance than the surface exposures might suggest.

Oxidation of pyrite and pyrrhotite has led to development of iron-oxide pseudomorphs, which are particularly common in the perthite and schorl of the Picacho View, Outpost, and several other large pegmatite bodies. Some of the feldspar deposits are considerably stained by iron oxides derived from these minerals. Much of the molybdenite, in contrast, is very fresh within a few inches of the surface, and only the material at the outcrop is coated with thin yellow films and ochreous crusts of molybdate. Some molybdate also appears to have been derived from powellite.

The copper-bearing hypogene species have yielded supergene azurite, malachite, chrysocolla, native copper, cuprite, and probably some chalcocite; the sphalerite has yielded hemimorphite and hydrozincite; and the galena similarly has contributed to supergene development of anglesite, cerussite, desclowitzite, mimetite, pyromorphite, wulfenite, vanadinite, and a little native silver. Most of these secondary minerals are rare, even though they form rather spectacular occurrences in a few places. Coarsely crystalline supergene copper and lead minerals, for example, are present in the quartz—albite—bismutite masses in the Outpost pegmatite as brightly-colored veinlets, pods, and individual crystals. It is not clear how much of this supergene mineralization was genetically related to those copper-lead-zinc minerals that are indigenous to the pegmatites.

#### OTHER MINERALS

Epidote is widely distributed in all parts of the pegmatites, but nowhere in more than trivial amounts. In the border zones it forms dark green to brownish green crystals that generally appear as fine-grained veinlets and irregular mats. They are especially abundant in and adjacent to partly digested septa and inclusions of mafic wallrock, where they are associated with garnet and biotite. In many other parts of the pegmatite masses epidote occurs as fine-grained, pale grassy green films that coat fractures and shear planes in the coarse-grained minerals.

Calcite occurs as thin veinlets that commonly are associated with epidote, and also forms some anhedral crystals,  $\frac{1}{8}$  inch to  $\frac{3}{4}$  inch in maximum dimension, that are interstitial to quartz, perthite, albite, spodumene, amblygonite, and other species in the central parts of the Midnight Owl, Sunrise, and a few other large pegmatite bodies. This anhedral material may represent a very late stage of hypogene mineral development in the pegmatites.

Clay minerals are widespread in the near-surface parts of all the pegmatite bodies. Most were formed by weathering of feldspars, and they coat and vein crystals of perthite and albite. Some also were developed from spodumene by weathering processes. These supergene clay minerals are white to gray, and are typically earthy in appearance. Many are stained by iron and manganese oxides.

Some clay minerals of possible hypogene origin also form very fine-grained, white to pinkish, vein-like masses in spodumene, lepidolite, amblygonite, and tourmaline. Similar material is scattered as cloudy aggregates through many crystals of spodumene and tourmaline, and well-defined pseudomorphs of clay minerals after spodumene are present in a few places. Some or all of these aggregates may have been developed through alteration of the lithium minerals under hypogene conditions, as suggested for similar material in the Pala pegmatites of southern California.<sup>17</sup> This type of clay has been encountered in excavations and in drill holes at depths well beneath the lower limit of noteworthy weathering in the feldspars, and is associated with unaltered pyrite and other sulfide minerals.

Sericite forms gray to very pale greenish gray vein-like masses, films, and coatings in all the other major minerals. It is associated with muscovite, and the distinction between the two minerals is somewhat arbitrary, as there are all gradations in grain size and appearance between them.

Cookeite, a micaceous lithium-aluminum silicate, forms rare coatings on lepidolite and spodumene, and also fills fractures in the interior parts of several lithium-bearing pegmatites. It occurs as white to very pale pink flakes and foils, which commonly are grouped in felt-like aggregates.

Several species of the zeolite group form fracture fillings in other minerals, and generally are associated with epidote and chalcedonic silica. They are earthy to finely crystalline, and appear to be simple open-space fillings that were not developed by alteration of the immediately adjacent minerals.

Crusts and highly irregular fracture fillings of opaline and chalcedonic silica are widespread and locally abundant. They occur in massive quartz and in quartz—perthite pegmatite, and also are present in the innermost parts of several lithium-bearing pegmatite bodies. They are most abundant as cementing material in fractured and brecciated masses of coarse quartz and feldspar, as in the central parts of the South Morning Star and White Jumbo pegmatites.

As already noted, both iron and manganese oxides are widespread. Hematite and goethite, the principal iron oxides, were formed mainly by alteration of pyrite and other iron-bearing sulfides, garnet, biotite, schorl, magnetite, and ferromagnesian minerals in the adjacent country rock. A little hematite also was developed as skeletal crystals within the largest crystals of muscovite, presumably by exsolution. The manganese oxides

<sup>17</sup>Jahns, R. H., and Wright, L. A., *op. cit.*, p. 39, 1951.

were derived mainly from garnet, several of the phosphate minerals, and in very small quantities from tourmaline and spodumene. They form crusts, veinlets, stockworks, and disseminated specks and spots in these and many of the other minerals, and also occur as films and dendrites along cleavage surfaces in feldspars, spodumene, and amblygonite.

#### SEQUENCE OF MINERAL FORMATION

The spatial relations between adjacent mineral grains and between adjacent zones and other lithologic units in the pegmatite bodies indicate a general sequence of mineral development that is remarkably consistent from one pegmatite body to another. It is complicated, and locally even obscured, by some irregularities of detail, but the basic pattern is easily recognized in all of the pegmatite bodies.

A broad sequence of textures also is characteristic, in that the general grain size of the major minerals increases from the walls of the containing pegmatite body inward toward its center, or from its border zone to its core. The border zones, wall zones, and some intermediate zones are granitoid or, rarely, porphyritic in texture, and the mineral grains are anhedral to subhedral. The inner zones, in marked contrast, are typically giant textured, and, with the single exception of quartz, their constituent major minerals are subhedral to euhedral. The fracture fillings and replacement bodies generally are much finer grained than the enclosing zonal pegmatite, and their occurrence as corrosion rims, veinlets, groups and networks of veinlets, and as larger, more irregular masses plainly is superimposed on the structural and textural pattern of the pegmatite zones.

The general age-abundance relations of the principal pegmatite minerals are shown diagrammatically in Figure 4. The relative amounts of these minerals being formed at various stages are indicated very roughly by the relative heights of the corresponding ruled areas. The range of mineral development has been arbitrarily divided into five general stages, which are listed from left to right in order of decreasing age. As implied by the arrangement of the columns, there is much overlap in time between the stages of zone formation, on one hand, and the more extended period during which fracture fillings and masses of replacement material were developed, on the other. Thus, some cross-cutting veinlets of albite and muscovite appear to have been formed in the wall zone of a given pegmatite body during the same period in which the inner intermediate zone was being developed, and later veinlets of albite and muscovite were formed in this intermediate zone during the period of core development.

The generalizations on abundance presented in Figure 4 are based on visual estimates and on eighty-six quantitative determinations of minerals in various pegmatite units, especially the very coarse-grained inner zones. The general age relations were determined chiefly on the basis of occurrence of a given mineral:

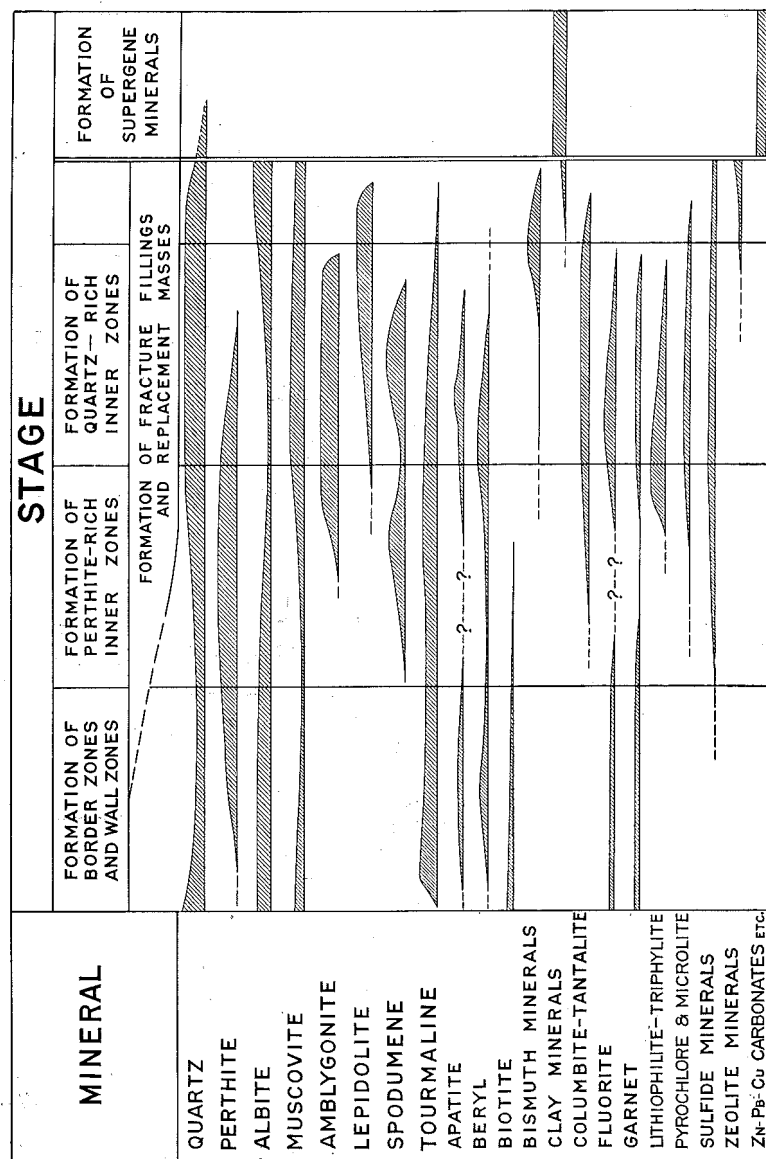


Figure 4.—General age-abundance relations of principal minerals in the pegmatites.

1. Consistently in a zone or other pegmatite unit whose age relations are known, generally through structural evidence.
2. As a filling of cleavage cracks or other fractures in an earlier mineral or mineral aggregate.
3. As a pseudomorph of an earlier mineral, where the existence and identity of the earlier mineral can be established by means of crystal form, cleavage patterns, other characteristic structural features, or by the preservation of residual material.

Additional criteria, not individually diagnostic but commonly of value when used in combination with one another or with those noted above, include the occurrence of a given mineral consistently along contacts between other minerals, as jackets around crystals of another mineral, as inclusions oriented along cleavage or other crystallographic directions in the host mineral, as embayments or other forms that suggest the corrosion of an earlier mineral, and in or consistently with another mineral whose age relations are known.

The pegmatite zones evidently were developed successively inward from the walls of each containing pegmatite body, as demonstrated by the detailed relations of many mineral grains and especially by the presence in some zones of fracture-filling offshoots from other, younger zones. Quartz, albite, and muscovite were formed throughout the general period of zone development, and the range of perthite crystallization was only slightly less extensive (Fig. 4). Tourmaline, apatite, beryl, fluorite, and garnet also were formed over a wide range, whereas biotite was relatively early and many of the rarer accessory constituents were relatively late in the over-all sequence. The lithium minerals were formed mainly during late stages of zonal development, and only spodumene appears to have made an appearance soon after the close of wall-zone formation in most pegmatites.

Several mineral species show progressive variations in composition and physical properties as traced through their periods of formation within a given pegmatite body. Thus schorl was developed during crystallization of border zones, wall zones, and several of the intermediate zones in most of the pegmatites, but gave way to elbaite during the final stages of crystallization in the lithium-bearing pegmatites. And within several pegmatite bodies in which tests were made, the alkali content of the beryl, the lithium content of the elbaite and most of the micas, the tantalum-columbium ratio in the pyrochlore-microlite and columbite-tantalite, the manganese-iron ratio in the columbite-tantalite and lithiophilite-triptylite, and the sodium-calcium ratio in the albite increase from the earliest- to the latest-formed crystals.

#### GENESIS OF THE PEGMATITES

The pegmatites are among the youngest of the Precambrian rocks in the district, and perhaps are related genetically to the

masses of granite that are widely exposed in areas to the north. Both of these rocks postdate the metasedimentary and metavolcanic rocks of the Precambrian terrane, and are overlain with marked unconformity by the sediments and flows of Tertiary and Quaternary age. Both are widespread in their occurrence, and the pegmatite is present within the granite and in the surrounding older rocks, as well. Thus the pegmatites may represent a very late stage in the igneous cycle that gave rise to the masses of granite, although such a relation cannot be proved on the basis of the present studies.

The pegmatite solutions evidently were introduced along fractures, bedding and foliation planes, and along contacts between different units in the country-rock terrane. Observed structural relations suggest that emplacement was accomplished chiefly by mechanical injection of liquids, and that this was accompanied locally by some replacement of the most susceptible types of country rock. The pegmatite-wallrock contacts generally are sharp, and, despite irregularities of detail, many of them plainly represent surfaces of fractures that were present in the older rock.

It can be demonstrated, through detailed stratigraphic analysis, that the foliated rocks that flank some pegmatite bodies were split apart and forced away from the space now occupied by pegmatite. Further, the more schistose rock types commonly are warped, plicated, or even tightly crumpled along the pegmatite contacts, as if they had been disturbed by injected liquids. And finally, the pegmatite bodies plainly crystallized progressively inward from their walls to their centers, a sequence that is difficult to explain in terms of pegmatite formation by replacement, *in situ*, of country rock. That some replacement of wallrock did occur is demonstrated by the presence of hybrid rocks within and along the margins of border zones in many pegmatite bodies, but the quantitative importance of this process appears to have been small.

The postemplacement history of the pegmatite bodies evidently was similar to that of zoned pegmatites in many parts of the world. The various theories that have been advanced to account for the characteristic structural, textural, and compositional features of such pegmatite bodies have been summarized by Kemp,<sup>18</sup> Johannsen,<sup>19</sup> and Landes,<sup>20</sup> and the reader is referred to these publications for a detailed review of the general problem.

The zones in each of the White Pichacho pegmatites are thought to have been developed by crystallization of magma progressively inward from the wallrock contacts, under conditions approaching those of a closed system, and the lithologic differences between

<sup>18</sup>Kemp, J. F., The pegmatites: *Econ. Geol.*, vol. 19, pp. 697-723, 1924.

<sup>19</sup>Johannsen, Albert, A descriptive petrography of the igneous rocks, Vol. II, The quartz-bearing rocks, pp. 74-84, The Univ. of Chicago Press, Chicago, Illinois, 1932.

<sup>20</sup>Landes, K. K., Origin and classification of pegmatites: *Amer. Mineral.*, Vol. 18, pp. 41-56, 1933.

adjacent zones seem best attributed to fractional crystallization and incomplete reaction between successive crops of crystals and rest-liquid. This is the view expressed earlier by Cameron, et al.,<sup>21</sup> on the basis of detailed studies of pegmatites in many parts of the United States, and most recently it has been discussed by Flawn<sup>22</sup> and Jahns.<sup>23</sup> It reflects, wholly or in large part, the much earlier conclusions of Brögger,<sup>24</sup> Crosby and Fuller,<sup>25</sup> Warren and Palache,<sup>26</sup> Kemp,<sup>27</sup> Landes,<sup>28</sup> Shaub,<sup>29</sup> and other investigators.

The magmatic origin of the minerals that are indigenous to the pegmatite zones is indicated most strongly by the following features of occurrence:<sup>30</sup>

1. Widespread structural evidence for emplacement of original pegmatite fluid by mechanical injection, in many instances accompanied by some digestion of country rock.
2. Consistent evidence for a sequence of zone development from the walls of the containing pegmatite body inward to its center.
3. Remarkable correspondence in sequence of mineral assemblages from one zoned pegmatite body to another.
4. Correspondence of the sequence of essential-mineral development in zoned pegmatites with the sequence of the same mineral species in normal igneous rocks; the sequence of major minerals in zoned pegmatite bodies is basically that of Bowen's reaction series.
5. Intrinsic similarities of pegmatite fabrics to those of many normal igneous rocks, despite the marked differences in grain size.
6. Lack of evidence that zones in a given pegmatite body were developed by successive replacement of pre-existing pegmatite.
7. Strong concentrations of rare elements in some masses of pegmatite, and the general accordance, in occurrences thus far investigated, of rare-element distribution from

<sup>21</sup>Cameron, E. N., Jahns, R. H., McNair, A. H., and Page, L. R., Internal structure of granitic pegmatites: *Econ. Geol.*, Mon. 2, pp. 97-106, 1949.

<sup>22</sup>Flawn, P. T., Pegmatites of the Van Horn Mountains, Texas: *Econ. Geol.*, vol. 46, pp. 163-192, 1951.

<sup>23</sup>Jahns, R. H., The genesis of pegmatites. I. Occurrence and origin of giant crystals: *Amer. Mineral.*, in press, 1953.

<sup>24</sup>Brögger, W. C., Die mineralien der syenitpegmatitgänge der Sudnordwegischen augit und nephelinsyenite: *Zeit. Kryst. Min.*, vol. 16, p. 230, 1890. (Translated into English by Evans, N. N., *Canadian Rec. of Sci.*, vol. 6, pp. 34-46, 61-71, 1894.)

<sup>25</sup>Crosby, W. O., and Fuller, M. L., Origin of pegmatite: *Tech. Quart.*, vol. 9, pp. 326-56; *Amer. Geol.*, vol. 19, pp. 147-280, esp. p. 157, 1897.

<sup>26</sup>Warren, C. H., and Palache, Charles, The pegmatites of the riebeckite-aegerite granite of Quincy, Massachusetts: *Amer. Acad. Arts Sci., Proc.*, vol. 47, p. 146, 1911.

<sup>27</sup>Kemp, J. F., *op. cit.*, pp. 708-09, 772, 1924.

<sup>28</sup>Landes, K. K., *op. cit.*, pp. 53-55, 1933.

<sup>29</sup>Shaub, B. M., On the origin of some pegmatites in the Town of Newry, Maine: *Amer. Mineral.*, vol. 25, pp. 684-88, 1940.

<sup>30</sup>Jahns, R. H., *op. cit.*, 1953.

zone to zone with the distribution predicted for such elements on theoretical grounds.

The process of zone development must have involved corrosion and partial or complete resorption of many early-formed crystals, partial or complete replacement of some minerals by others, and the invasion of some earlier, outer zones by apophyses from later, more centrally disposed zones. The activities of reacting and replacing solutions undoubtedly increased as crystallization progressed and the proportion of hyperfusible constituents in the rest-liquid increased, and they must have reached a climax during crystallization of the innermost zones, when the pegmatite bodies in effect "stewed in their own juices" and the attendant deuteric reactions obscured and locally even obliterated some of the results of primary crystallization. Thus fracture-controlled replacement masses of lepidolite were developed along the boundary between the massive-quartz core and the quartz-spodumene intermediate zone of the North Morning Star pegmatite, and fracture-controlled albitization obscured several contacts between zones in the Outpost pegmatite.

The effects of the replacement processes are not easily evaluated in quantitative terms, but in general the proportion of material formed at the expense of earlier pegmatite minerals appears to be small. The replacing solutions probably were not derived from sources outside the pegmatite bodies, but instead appear to have coursed outward from the central parts of these bodies along fractures and other, less obvious channels of escape.

On the basis of accessible exposures, it cannot be demonstrated that all of the supergene copper-lead-zinc minerals that appear in the pegmatites were derived from primary minerals in the same pegmatite bodies. Indeed, it seems possible that they may have been derived in large part from hypogene minerals whose formation was not genetically related to the pegmatites.

## ECONOMIC FEATURES OF THE PEGMATITE MINERALS

### FELDSPARS

#### USES, CLASSIFICATION, AND MARKETING DATA

Commercial feldspar is used mainly as a ground raw ingredient of glasses, glazes, pottery, and other ceramic products. It also is employed as an abrasive in soaps, scouring powders, and sweeping compounds; as a binder and filler in harder abrasive blocks and wheels; as poultry grit and roofing granules; and in various ways as a filler, building material, and high-temperature coating and cementing agent. During wartime periods coarsely ground feldspar serves effectively as an extinguishing agent for magnesium incendiary bombs.

Nearly half of the annual production of domestic feldspar is used in the manufacture of glass, to which it contributes the alumina that is required to retard devitrification and improve the viscosity and melting-range characteristics. Feldspar for this and most other fused products generally is graded on the basis

of its content of free silica and its freedom from iron, manganese, and other discoloring agents. Quartz ordinarily is regarded merely as a diluent, although it does lower the market value of the product if present in proportions much greater than 1 per cent. Biotite, garnet, tourmaline, and other iron-bearing minerals are far more objectionable, and tolerances for such impurities are very low, generally 0.03 per cent to 0.05 per cent, for nearly all ceramic uses.

Commercial feldspar is a mixture of microcline (or orthoclase) and sodic plagioclase, and in most material the potash feldspar is the dominant constituent. Much of the plagioclase forms perthitic intergrowths within larger crystals of potash feldspar; in addition, the potash feldspar ordinarily contains appreciable amounts of soda in solid solution, and the plagioclase similarly contains some potash. The  $K_2O-Na_2O$  ratio in typical commercial potash feldspar ranges from about 3:1 to about 4:1. The best commercial grades of feldspar contain less than 5 per cent of quartz, and the poorest acceptable material contains about 30 per cent of quartz. Thus graphic granite, or "corduroy spar," most of which contains 15 per cent or more of free silica, commands a relatively low price in those areas where it can be marketed at all.

For many years pegmatite deposits yielded a very large proportion of feldspar produced in this country each year, generally as coarsely broken material obtained by hand sorting at the mine. This product was shipped to near-by plants for grinding and blending. Later on, substantial amounts were obtained by direct processing of aplites and other rocks with very low proportions of dark minerals. During recent years, concentration by froth flotation has yielded increasing amounts of both feldspars and salable by-products from several large masses of pegmatite and finer-grained igneous rocks in the eastern United States, and this method holds attractive possibilities for future operations in the western states, where the distance of most deposits from the principal centers of demand makes it economic to produce and ship only the best grades of material.

Prices for western feldspar at or near the mine range from about \$3.50 to \$12 or more per long ton, with a general average of about \$6 per ton for all material marketed during the past twenty-five years. Ground feldspar, chiefly in the minus-200-mesh range, has commanded prices of \$18 to \$45 per short ton in bulk lots during recent years at various manufacturing centers along the Pacific Coast. It is used mostly in the ceramic industry, where competition from talc, tremolite, and feldspathic glass sands is particularly keen. Some extremely pure potash feldspar, used mainly for special abrasives and ceramic products, yields returns of \$1 or more per pound, but the demand for such material fluctuates widely and never is very large. Producers, grinders, and buyers of feldspar have been tabulated by the U.S. Bureau of Mines.<sup>31</sup>

<sup>31</sup>For footnote, see p. 59.

## OCCURENCE

Several of the pegmatite bodies in the White Picacho district contain concentrations of coarse perthite that are of potential economic importance, and among those studied during the course of the present investigation are the North Morning Star, Picacho View, Outpost, Friction, and Midnight Owl. None of the concentrations of albite appear to be sufficiently extensive or free from impurities to sustain an operation for soda feldspar, although albite would be a significant constituent of any potash feldspar mined from the district.

The feldspar of highest grade occurs as giant crystals and crystal aggregates in the cores and intermediate zones of the largest pegmatite bodies. A few of the perthite individuals must weigh as much as 80 tons, and many others amount to 5 tons or more; all of these represent material that would be readily recoverable by hand sorting. Most of the very coarse perthite is associated with massive quartz, and either flanks cores and intermediate zones of such material or surrounds large, irregular pods of quartz. In a few deposits, the perthite is associated with very coarse-grained lithium minerals, as well.

Several intermediate zones consist mainly of large perthite crystals, and form masses that weigh hundreds, and locally thousands of tons. A little interstitial quartz ordinarily is present, and some of the perthite is veined by quartz, finer-grained silica, albite, muscovite, or combinations of these minerals. The chief objectionable impurities in the perthite of all these deposits are schorl, sulfide minerals, and garnet. Many of these impurities are removable by selective mining, and all could be eliminated by the usual methods of magnetic separation.

Perthite also is abundant in the outer parts of the pegmatite bodies, particularly in the outer intermediate zones of bodies with complex internal structure. It is considerably less pure than the more centrally-disposed material just described, however, and would not yield as high-grade a product by simple hand sorting. Quartz, the most widespread impurity, forms interstitial grains and masses, and in some deposits is intimately intergrown with the feldspar to form graphic granite. Schorl, garnet, biotite, and local grains of sulfides are present in most of these rock masses, and commonly are so widespread that removal by some mechanical means would be necessary to obtain a marketable product.

Economic maps of three perthite-rich pegmatite bodies, the Picacho View, Outpost, and Friction, are presented in Plates XX, XXII, and XXIII. These show, in a general way, the distribution of feldspar deposits by grade, and demonstrate the close relationship between these deposits and the zonal structure of the peg-

<sup>31</sup>Metcalf, R. W., Marketing feldspar: U.S. Bur. Mines, Inf. Circ. 7184, pp. 7-13, 1941.  
Metcalf, R. W., Feldspar: U.S. Bur. Mines, Minerals Yearbook for 1948, pp. 511-12, 1950.

matite bodies. The masses of highest grade contain coarse, clean perthite that can be easily separated from the other constituents (chiefly quartz) by selective mining and hand sorting. Iron- and manganese-bearing impurities are relatively sparse or are restricted to a few local concentrations.

The masses classed as medium grade would yield, by similar methods of separation, a product with a higher proportion of quartz and muscovite, and in most instances it would be necessary to remove iron-bearing impurities by magnetic separation. The low-grade masses probably could not be worked economically under present market conditions, due principally to the abundance and wide distribution of other minerals. Both these and some of the noncommercial masses, however, would merit consideration as sources of feldspar and other salable products if bulk mining methods were used to supply feed for a mill designed to separate feldspar, quartz, micas, and possibly other minerals, as well.

#### QUARTZ

Quartz, an expectable by-product from any feldspar operations in the district, might well be marketed in quantities determined largely by western demands for abrasive and ceramic material. A product meeting all normal specifications for these uses could be readily obtained by hand sorting, but its low value of \$2 to \$6 per ton would seriously reduce any economic margin of operation for deposits located so far from major centers of demand.

Some quartz of fusing grade, which ordinarily commands prices of \$100 to \$150 per ton, could be produced from many of the deposits, but the total annual demand for such material is variable, and in most years is not very large. None of the pegmatites appears to contain quartz that is suitable for gem or piezoelectric uses.

#### LITHIUM MINERALS

##### USES AND MARKETING DATA

Spodumene, amblygonite, and lepidolite are the lithium minerals of chief commercial interest in the White Picacho district. Lepidolite is widely used in glass making, as it not only is an excellent fluxing material, but it increases the luster, weather resistance, and strength characteristics of finished glasses, while reducing their coefficients of expansion. Such glasses are in great demand for high-pressure gages, X-ray and electronic tubes, and other devices subject to mechanical stresses or sudden temperature changes. Lepidolite also is an ingredient of many high-quality porcelains and enamels, in which it is an effective opacifier. It increases their resistance to corrosion and stain, and improves their bonding characteristics where they are applied as coatings on metals.

Spodumene also can be employed directly in the manufacture of glass to neutralize shrinkage during cooling, and is an ingredient of other ceramic products, as well. Most spodumene, how-

TABLE 2.—COMPOSITION OF COMMERCIAL LITHIUM MINERALS FROM PEGMATITES

Mineral	Simplified formula	Theoretical content of Li <sub>2</sub> O, per cent	Proportion of Li <sub>2</sub> O in most marketed concentrates, per cent
Spodumene	LiAlSi <sub>2</sub> O <sub>6</sub>	8.05	> 6.0 <sup>a</sup>
Lepidolite	KLi <sub>2</sub> AlSi <sub>4</sub> O <sub>10</sub> F <sub>2</sub> <sup>b</sup>	7.65 <sup>b</sup>	> 2.5
Amblygonite	LiAlFPO <sub>4</sub>	10.10	> 8.0
Zinnwaldite	LiKFeAl <sub>2</sub> F <sub>2</sub> Si <sub>3</sub> O <sub>10</sub>	3.40	> 1.5
Triphylite	LiFePO <sub>4</sub>	9.47	> 3.5
Lithiophilite	LiMnPO <sub>4</sub>	9.52	> 3.5
Petalite	LiAlSi <sub>4</sub> O <sub>10</sub>	4.89	> 3.0

<sup>a</sup>Concentrates containing as little as 4 per cent Li<sub>2</sub>O are sometimes marketed in special lots.

<sup>b</sup>For polyolithionite end member.

ever, is processed into lithium carbonate and other lithium compounds, and amblygonite and a little lepidolite also are converted to such compounds. Salts of lithium are used in pharmaceuticals, storage batteries, flares and fireworks, fluxes, soaps, waxes, low-temperature lubricants, refrigerants, deodorants, bleaching agents, fungicides, beverages, plastics, special cements, luminous paints, and photographic chemicals, and serve as catalysts in various organic reactions, as moisture- and gas-absorption agents in air-conditioning equipment and other devices, and as desulfurizing agents in petroleum refining and steel manufacture. They also are used in the purification of helium and other inert gases, in the manufacture of textiles, ceramics, and special refractories, and in the smelting of iron ore.

Lithium hydride has been employed as a transporter of hydrogen in self-inflating rafts, balloons, and other devices. The metal is variously used as a scavenger in the refining of certain other metals. It also is a minor constituent of several special-purpose alloys, especially for bearings and castings, and generally is added to aluminum, copper, lead, magnesium, nickel, silver, zinc, or combinations of these metals. In addition, it is a major constituent of some newly developed magnesium alloys. Lithium has several important potential uses in the fields of nuclear physics, jet propulsion, and underwater propulsion.

The composition of several commercial lithium minerals from pegmatites is indicated in Table 2. The average price quoted for spodumene during recent years is about \$30 per short ton of clean cobbled or milled material, generally with a minimum acceptability limit of 6 per cent contained Li<sub>2</sub>O. This represents a range in price of \$4 to nearly \$9 per short-ton unit of lithium oxide. The highest prices were quoted during the period of World War II, when foreign supply was uncertain and domestic production facilities were not adequate in terms of demand.

Prices for amblygonite, which contains a higher proportion of lithium, have ranged from \$35 to \$110 per short ton, with a general average between \$40 and \$50. The market is somewhat limited, mainly because of fluctuations and uncertainties in the

supply situation. Lepidolite containing 3 per cent of  $\text{Li}_2\text{O}$  has commanded prices of \$15 to \$50 per short ton at the mine, and some material with 4 per cent or more of  $\text{Li}_2\text{O}$  has been sold for as much as \$80 per ton.

The chief commercial specification for all lots of crude lithium minerals is the proportion of lithium oxide that is present, and impurities are otherwise insignificant with respect to most uses. An important exception involves the ceramic industry, for which material must contain very little iron; the tolerance generally is 0.03 per cent or less.

Recovery of lithium minerals from the host pegmatite ordinarily is a simple matter, involving hand cobbing and picking. Few of the minerals are difficult to recognize, and many crystals and crystal aggregates of spodumene and amblygonite are so large that they can be broken and shipped with a minimum of sorting. In some places these minerals are intimately intergrown, and can be marketed as mixed lithium-bearing material. Other occurrences require mechanical separation, as the lithium minerals are intergrown with lithium-free species that are present in abundance. Lithium minerals have been recovered by milling at several localities during recent years. A large flotation plant near Kings Mountain, North Carolina, yielded commercial spodumene concentrates during the period 1943-1945, later was redesigned and reactivated, and has been in operation since 1951. A heavy-media method of separation has been used in a second mill at Keystone, South Dakota.

Marketing data for lithium minerals have been summarized by the U.S. Bureau of Mines,<sup>32</sup> and some of the industrial aspects of lithium and lithium compounds have been discussed in detail by Osborg.<sup>33</sup> The demand for lithium minerals has increased markedly during the past half century, due mainly to the development of new uses, and reached a peak in the wartime year 1944, when 13,339 short tons of crude concentrates was produced in this country. A substantial portion of this output was in the form of di-lithium sodium phosphate, containing about 22 per cent of  $\text{Li}_2\text{O}$ , that was recovered from brines at Searles Lake, California; most of the remainder was spodumene obtained from several pegmatite districts. It has been estimated in a recent summary by Landolt<sup>34</sup> that potential industrial demand might amount to as much as 100,000 tons of concentrates (5 per cent  $\text{Li}_2\text{O}$ ) per year, exclusive of direct war uses, as compared with demands of 10,000 to 20,000 tons per year during World War II and an average annual demand of 5,500 tons during the period 1946-1950.

#### DETERMINATION OF GRADE

It always is desirable, and for obvious reasons, to maintain adequate grade control on lots of commercial concentrates of

<sup>32</sup>Houk, L. G., Marketing lithium minerals: U.S. Bur. Mines, Information Circular 7225, 1942.

<sup>33</sup>Osborg, Hans, Lithium, theoretical studies and practical applications, 68 pp., The Electrochemical Society, New York, 1935.

<sup>34</sup>Landolt, P. E., Lithium: Mining Eng., vol. 3, pp. 1045-48, es. p. 1047, 1951.

lithium minerals shipped from any given property. Rough appraisals of  $\text{Li}_2\text{O}$  content can be made for crude amblygonite concentrates without serious difficulty, as they can be based mainly on estimates of the amount of amblygonite relative to the other minerals that are present. A simple calculation then suffices to establish the over-all grade of each lot; as the lithium content of the amblygonite in the White Picacho pegmatites does not vary over a wide range.

The problem is considerably more difficult with respect to the lepidolite and spodumene in the pegmatites, because both of these minerals show large variations in lithium content. Moreover, not all of the variations are easily correlated with the general appearance of the materials in question. Casual inspection during hand sorting already has led to bitter disappointments among mine owners and operators in this and nearby districts, as several lots of spodumene—including two of carload size—have been received by eastern firms, tested, and then rejected as too low in grade to be usable.

Some assay control, even if only approximate, should be applied to shipments of the spodumene and lepidolite, especially if they are large. This is done as a matter of course with other mineral commodities, including many for which such data are not nearly so critical, and should be equally routine for the lithium minerals. Fortunately, it also is possible to make preliminary estimates of grade by critical visual appraisal of the material itself, as shown by the results of tests made during the present investigations.

Although some of the spodumene in the district contains 7 per cent or more of  $\text{Li}_2\text{O}$ , and hence is of reasonably high grade, much has been altered to varying degree, with attendant decreases in the proportion of lithium present. The intensity of alteration to fine-grained albite, muscovite, and other minerals varies from deposit to deposit, and also varies considerably from crystal to crystal within a given deposit. Correlations between lithium content and some physical properties are shown in Table 3 for four selected samples that represent the major types of spodumene crystals (and pseudomorphs) from the district.

The spodumene of highest lithium content is characteristically fresh in appearance, with a light gray to white color and a glistening, pearly to silky luster. It is readily cleavable into somewhat splintery laths and blades. This material is weathered in near-surface exposures to much white and softer masses that appear chalky; they commonly contain many elongate, subparallel fragments of relatively fresh spodumene that are separated from one another by the altered material. The lithium content of such weathered crystals generally is about as great as that of the wholly fresh-appearing crystals.

The spodumene from which all or a part of the original lithium has been extracted is somewhat different in appearance. Some is hard and light to medium gray in color, and some is much



TABLE 3.—VARIATIONS IN PROPORTION OF MAJOR ALKALI ELEMENTS IN SAMPLES OF SPODUMENE FROM THE WHITE PICACHO PEGMATITES

Sample of Spodumene	General description	Proportion of major alkali constituents*		
		Li <sub>2</sub> O	Na <sub>2</sub> O	K <sub>2</sub> O
A.	Hard, fresh-appearing crystal that breaks into pearly gray to very pale greenish gray fragments with shining to glistening luster; weathers chalky white; excellent cleavage. See Plate XA.	7.81	0.64	0.25
B.	Soft, weathered crystal from surface exposure; chalky white on faces and along many fractures, but elsewhere light pearly gray, with glistening luster; excellent cleavage. See Plate XA.	8.02	0.47	0.94
C.	Hard crystal from surface exposure; rough, light gray, enamel-like faces appear sugary under the hand lens; light to medium gray, with glimmering luster, on newly broken surfaces, which show some tiny faces of albite and muscovite; cleavage very poor.	4.16	7.00	0.46
D.	Moderately soft, light greenish gray crystal with glimmering, waxy luster; fair cleavage, with surfaces that appear to have been smoothed by rubbing or shearing. See Plate XB.	Tr.	Tr.	4.50

\*G. L. Cheney, analyst.

softer and more greenish, depending upon whether the principal alteration products are albite (C, Table 3) or micaceous minerals (D, Table 3), respectively. All types have duller luster than that of the unaltered spodumene, and are distinctly waxy in appearance. Some cleavage commonly is apparent, especially in crystals that are not completely altered, but in general it is not possible to split unbroken masses of the material into smoothly bounded cleavage fragments. This is perhaps the most useful and reliable means for distinguishing by inspection this lower-grade spodumene from the unaltered spodumene described above.

The lepidolite, too, is difficult to appraise by casual inspection, not only because of variations in its lithium content, but because it resembles some types of lithia muscovite that also are present in the deposits. As shown in Table 4, the true lepidolite is of reasonably high grade, whereas the lithium content of the muscovite is well below all commercial specifications. The lepidolite is lilac, lavender, or gray in color, and the lithium-bearing muscovite is pink to gray. Both micas weather light gray to white, and hence cannot be distinguished at the outcrop on the basis of color alone. The lepidolite is distinctly more brittle than the

TABLE 4.—LITHIUM CONTENT OF LEPIDOLITE AND PINK MUSCOVITE FROM THE WHITE PICACHO PEGMATITES

Sample	General description	Proportion of Li <sub>2</sub> O	Proportion of other constituents	
			Na <sub>2</sub> O	K <sub>2</sub> O
A.	Large, lilac-colored plates; very slightly flexible. Sunrise pegmatite. See Plate IX.	3.92 <sup>a</sup>	0.20 <sup>a</sup>	2.54 <sup>a</sup>
B.	Small, lilac-colored plates; slightly flexible. Sunrise pegmatite.	3.78 <sup>b</sup>	N.D.	
C.	Small, lavender to bluish-gray plates; moderately flexible. White Jumbo pegmatite.	4.49 <sup>b</sup>	N.D.	
D.	Large, pale pink plates; flexible. Sunrise pegmatite.	0.31 <sup>b</sup>	N.D.	
E.	Small, pale pink to gray plates; flexible. White Jumbo pegmatite.	0.17 <sup>b</sup>	N.D.	
F.	Large, thin, pinkish gray plates; flexible. Midnight Owl pegmatite.	< 0.10 <sup>c</sup>	N.D.	
G.	Small, thick, very pale pink to gray plates. Midnight Owl pegmatite.	< 0.10 <sup>c</sup>	N.D.	

<sup>a</sup>G. L. Cheney, analyst.<sup>b</sup>R. H. Jahns, analyst.<sup>c</sup>Determined spectrographically.

muscovite, and can be cleaved into thin plates only with considerable difficulty. These plates, moreover, are not nearly so elastic as those split from the crystals of muscovite. Finally, the lepidolite is readily fusible, whereas the muscovite is not. The edges of thin flakes of lepidolite can be fused to small globules of glass if held over the flame of an ordinary match.

## OCCURRENCE

The spodumene and amblygonite form very large crystals in the central parts of several pegmatite bodies in the district, where they are associated with very coarse-grained, anhedral quartz in cores and intermediate zones. They also occur as much smaller crystals in some other intermediate zones that contain abundant perthite, as well as quartz. Other minerals commonly are present in subordinate amounts, but in general these are of much smaller grain size. Quartz—spodumene and quartz—amblygonite aggregates form separate zones in some pegmatite bodies, like the North Morning Star and the Sunrise, whereas in others, like the Midnight Owl, the two lithium minerals are present in the same zones and hence could be recovered in the mining of single blocks of ground. In a few pegmatite bodies of complex mineralogy, feldspar, beryl, and other minerals are potentially recoverable by-products. Both beryl and columbite-tantalite, for example, have been sorted from spodumene-bearing pegmatite at the Midnight Owl mine.

Much of the amblygonite forms such large masses that it can be separated from the adjacent minerals by hand picking, as already pointed out. The coarsest spodumene also can be handled in this way, although its relatively thin, lath-like habit makes efficient recovery much more difficult. In addition, a large

proportion of the total spodumene in most of the lithium-bearing pegmatites is present as crystals whose maximum dimensions are less than 2 feet, and high yields of such material could be obtained at reasonable cost only through the use of mechanical methods of separation. Although no wholly satisfactory estimates can be made on the basis of data now available, it is suggested that only about half of the amblygonite and less than one-fourth of the spodumene in the district could be recovered by hand sorting at reasonable costs.

The amblygonite commonly is so coarse and so "bunchy" in its distribution that, for all practical purposes, the proportion of this mineral ranges from nil to 100 per cent in large parts of the pegmatite zones in which it occurs. More meaningful estimates of grade can be made, however, if each zone is considered in its entirety, or if it is arbitrarily separated into only a few very large blocks of ground. Blocks of 2,000 tons or more contain 0.5 per cent to nearly 12 per cent of amblygonite in several of the pegmatite bodies, and the average in the best deposits probably is about 4 per cent.

The spodumene is more uniformly distributed, and hence its abundance is more readily estimated by measurement of present exposures. Several of the large, spodumene-rich zones contain 2 per cent to 23 per cent of this mineral, with an apparent average of about 8 per cent. As exposed late in 1951 on the main quarry face in Mitchell Wash, the quartz—spodumene core of the Lower Jumbo pegmatite (Pls. VI, VII) contained an average of 9 per cent spodumene, and the faces developed during subsequent stages of mining have shown that the spodumene content of this zone is remarkably uniform. Mining operations in the east bulge of the Midnight Owl pegmatite (Pls. XV, XXIV) have yielded spodumene that amounts to about 6 per cent of the total rock removed from the pit, and the principal spodumene-bearing zone in the west bulge appears to contain about 8 per cent of this mineral in the form of large crystals.

Considerable thicknesses of spodumene-bearing pegmatite were penetrated by several diamond-drill holes during recent exploration of the North Morning Star, Lower Jumbo, Sunrise, and Midnight Owl deposits, but most of the corresponding drill cores were found to contain less than 0.2 per cent of  $\text{Li}_2\text{O}$ . Such low values may be somewhat misleading, however, as the cores may not represent this type of rock within satisfactory limits.

In the drilling of several pegmatite bodies in other districts during recent years, core recoveries were found to be relatively low wherever quartz-spodumene pegmatite was penetrated, as high proportions of spodumene were carried off in the sludges. Moreover, the quartz-spodumene ratio in most recovered fragments of core was unduly high, as much spodumene was selectively plucked and torn away by the drill bit before the cores were delivered at the surface. In the light of these factors, therefore, it would seem best to employ the drill-hole data primarily

as guides to the distribution of spodumene-bearing pegmatite at depth (Pls. XVIII, XIX), and to rely mainly upon extrapolation from the best surface exposures for estimates of the spodumene content of such pegmatite.

The lepidolite is not a major constituent of any pegmatite zone in the district, nor does it form very large, fine-grained masses like those that have been mined in several other districts in the Western States. Instead, it occurs as much smaller, very irregular, tabular to pod-like masses that appear to have been developed by replacement of earlier pegmatite minerals. These masses are most abundant along margins of zones that are rich in very coarse-grained quartz, or quartz with amblygonite or spodumene, and generally consist of platy crystals of lepidolite with subordinate quartz and albite. They range in maximum dimensions from several inches to about 25 feet, and few of them contain more than 10 tons of lepidolite.

It would be difficult to hand-sort this type of material to a concentrate containing as much as 3 per cent of  $\text{Li}_2\text{O}$ , mainly because the lepidolite is so closely associated with other minerals. It seems likely that lepidolite could be recovered commercially from the White Picacho pegmatites only as a by-product from operations for feldspar, spodumene, or amblygonite, and some mechanical means of separation probably would be required to obtain a satisfactory product. Even then, the total yield from the known deposits might not exceed a few hundred tons. And finally, lepidolite is most abundant in those deposits in which many of the spodumene crystals are considerably altered, and hence are so low in grade that they are of relatively little economic interest.

Lithiophilite, triphylite, and zinnwaldite, though present in several pegmatites, are nowhere sufficiently abundant to be regarded as significant sources of lithium-bearing mineral concentrates.

#### BERYL

##### USES AND MARKETING DATA

Beryl is the present commercial source of beryllium metal and beryllium compounds, which are used in ceramics and refractories, 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 also is used in nuclear physics, chiefly as a source of neutrons and as a moderator for fast neutrons. In addition, it is alloyed with zinc, aluminum, magnesium, iron, and nickel, but for many years the major demand has been for copper-base alloys, which are exceptionally resistant to fatigue and wear, are responsive to hardening treatments after being worked soft, and are harder and otherwise superior to copper in structural characteristics. Further, they are good electrical conductors, non-magnetic, and nonsparking. Alloys of the beryllium-copper group

are used, for example, in non-sparking tools and in springs, contact plates, bushings, shims, and corrosion-resistant parts of motors and gages. They also are employed for parts in precision instruments and machines.

For several years prior to 1941, prices for clean-cobbed domestic beryl were quoted at \$30 to \$35 per dry short ton, or at \$2.75 to \$3.60 per dry short-ton unit in sampled and analyzed lots. The unit price rose during World War II to a maximum of \$14.50 for ore containing 8 per cent or more of BeO. Postwar prices declined sharply, but later began a steady rise that carried them well above the previous wartime high. As of January 1, 1953, some domestic beryl was being sold directly to the General Services Administration of the Federal Government at the rate of \$400 per dry short ton for visually inspected lots presumed to contain not less than 8 per cent of BeO, or on a sliding scale of \$40 to \$50 per unit, the specific price depending upon the grade of each lot as determined by sampling and chemical analysis. The remainder of the domestic output was sold on the open market, some at prices as high as \$58 per unit, and some low-grade material at prices of \$25 to \$40 per unit.

Beryl is produced commercially from most deposits in the United States as a by-product of mining operations for feldspar, lithium minerals, mica, or other pegmatite commodities. It is recovered from the host rock by rough cobbing and hand sorting, and hence only deposits that contain coarse crystals and masses of the mineral have been of major economic interest. A great deal of laboratory testing has been done in an effort to devise some means of mechanical separation of beryl from other pegmatite minerals, and the results obtained from several of these tests seem to offer considerable promise; at present, however, no commercial production is being obtained by means of flotation, heavy-media separation, or other types of milling.

#### DETERMINATION OF GRADE

Ordinary inspection, even if carefully made, does not suffice to determine the BeO content of a given lot of commercial beryl concentrates, due mainly to variations in the BeO content of the beryl itself. These variations have the same economic effect as those in the Li<sub>2</sub>O content of the spodumene, which already have been described, but fortunately are of lesser magnitude and are much more systematic. They appear to reflect primary differences in composition of the mineral, and in general the beryl within a given pegmatite body in the district shows progressive increases in alkali content—and attendant decreases in BeO content—as traced in its occurrence from the walls inward to the core. The maximum observed variation, in the beryl of the Midnight Owl pegmatite, amounts to approximately 1.8 per cent of BeO; this corresponds to a difference of \$75 to \$100 in the per-ton value of clean concentrates, as determined from price schedules in effect during the winter of 1952-53.

The BeO content of pure beryl ranges from about 10 per cent to a theoretical maximum of nearly 14 per cent. Although satis-

factory analytical methods have been developed for the determination of beryllium in ores,<sup>35</sup> they are time consuming and expensive. Spectrochemical analysis, which is rapid and only moderately expensive, has been used for numerous BeO determinations, especially in low-grade ores,<sup>36</sup> but requires laboratory facilities and costly equipment. The simplest, most rapid, and least expensive method of analysis thus far available is based upon determination of the ordinary (w) index of refraction of the beryl, which decreases with increasing beryllium content. The effects of composition on index of refraction have been determined by Schaller and Stevens<sup>37</sup> on the basis of detailed studies of seventy-two different beryls, and it was found that a simple curve shows the relation between the BeO content and ordinary index. Thus, once the index of refraction of the sample is established, generally by study of crushed fragments under a microscope, the corresponding proportion of BeO can be read directly from this curve.

All the beryl tested from the White Picacho pegmatites has been found to contain more than 12.0 per cent of BeO, and most appears to contain 13.0 per cent or more. The crystals with highest index of refraction, and hence of lowest beryllium content, occur in the cores and inner intermediate zones of such mineralogically complex lithium-bearing pegmatites as the North Morning Star, Sunrise, and Midnight Owl.

#### OCCURRENCE

The coarsest beryl in the district occurs in the inner parts of the pegmatite bodies, where it generally is associated with massive quartz. Coarse perthite also is present in some deposits, and other associated minerals include albite, muscovite, lepidolite, spodumene, and amblygonite. Columbite-tantalite, fluorite, lithiophilite-triphylite, and triplite also occur with beryl in the east bulge of the Midnight Owl pegmatite, where the beryl constitutes approximately 1.1 per cent of the intermediate zone that has been mined in a small quarry. Similar beryl-bearing inner zones in six other pegmatite bodies contain 0.08 per cent to 1.6 per cent of this mineral, with an average of about 0.7 per cent. Many other zones, however, appear to be completely barren of beryl.

The largest masses of the beryl are only about a foot in maximum dimension, but they can be separated economically from the broken rock by hand methods, especially by persons who have learned to recognize the characteristic pale colors and somewhat greasy luster of the mineral. The much smaller anhedral

<sup>35</sup>Stevens, R. E., and Carron, M. K., Determination of beryllium in ores: U.S. Geol. Survey, Bull. 950, pp. 91-100, 1946.

<sup>36</sup>Marks, G. W., and Jones, B. M., Method for the spectrochemical determination of beryllium, cadmium, zinc, and indium in ore samples: U.S. Bur. Mines, Rept. Investig. 4363, 1948.

<sup>37</sup>Schaller, W. T., and Stevens, R. E., A study of beryl, manuscript in preparation, 1953.

crystals in the outer zones of several pegmatite bodies probably could not be recovered economically except by some mechanical means. These crystals represent a potentially important reserve of marketable material, and in some border-zone deposits, like those in the Midnight Owl pegmatite, they constitute 3 per cent to 8 per cent of rock masses that amount to 50 tons or more.

#### MICA

##### CLASSIFICATION, USES, AND MARKETING DATA

Commercial muscovite that is flat or nearly so, and is large enough and sufficiently free from structural defects to be used in some types of electrical equipment and certain other manufactured articles generally is known as sheet mica. It must yield trimmed sheets at least 1½ inches by 2 inches in size. Punch mica yields somewhat smaller trimmed or punched sheets, generally at least 1 inch in diameter. Scrap mica includes all material that is too small or that in some other way is not acceptable for sheet or punch uses.

Most sheet and punch mica is employed as an electrical insulating material, either directly as cut, stamped, or punched pieces, or as a wide variety of built-up forms made by cementing numerous splittings of mica with an appropriate bonding medium. The properties most desired in material of superior quality are flatness, uniform splitting characteristics, reasonable hardness and flexibility, elasticity, transparency, freedom from inclusions of other minerals, and freedom from various structural imperfections.<sup>38</sup> Such mica requires a considerable amount of processing after it is removed from the deposit in which it occurs. In general it is split and sorted several times, trimmed and/or punched one or more times, and is carefully graded and classified at least once before it reaches the end-use stage.

Prices for sheet mica fluctuate widely in response to changes in demand, and vary according to the size and quality of the material. The ranges for clear mica are great, and during a thirty-year period the price for 3 by 3 inch trimmed sheets in the Southeastern States, the major producing area in this country, ranged from \$0.58 to \$2 per pound, and that for 1½ by 2 inch trimmed sheets ranged from \$0.12 to \$0.60 per pound. Prices characteristically reach very high levels during war periods, and for several months in 1944, for example, a flat price of \$8 per pound was in effect for full-trimmed sheets 2 by 2 inches and larger.<sup>39</sup> Subsequent purchasing schedules were scaled down

<sup>38</sup>For discussions of these and other significant features of commercial muscovite, see:

Sterrett, D. B., Mica deposits of the United States: U.S. Geol. Survey, Bull. 740, pp. 11-28, 1923.

Albertson, J. M., Hammond, W. E., and Blackly, C. D., Mica: U.S. Tariff Comm., 89 pp., 1947.

Jahns, R. H., and Lancaster, F. W., Physical characteristics of commercial sheet muscovite in the southeastern United States: U.S. Geol. Survey, Prof. Paper 225, pp. 4-28, 1950.

<sup>39</sup>For more detailed information on prices, see Jahns, R. H., and Lancaster, F. W., *op. cit.*, pp. 27-28, 1950.

considerably, and again were based upon size and quality of the prepared sheets. During recent months, however, prices once again experienced a general rise, and by the end of 1952 were back in the general range of the World War II period.

Scrap mica ordinarily is processed by grinding, and is classified on the basis of its mechanical purity and the color and coarseness of the ground product. Most ground mica is prepared by dry methods, and is used in asphalt shingles and other roofing materials, refractories, foundry facings, decorative concrete, stuccos and plasters, paints, plastics, and in the manufacture of rubber products and various types of molded insulation. It also is used in the insulation of buildings, and modest quantities are processed into Christmas-tree snow, greeting-card decorations, and other specialized products. Wet-ground mica, which ordinarily is much finer grained, is employed extensively in the manufacture of rubber, wallpaper, paints and other protective coatings, lubricants, textiles, and plastics. It is an effective filler and bonding medium, and commonly increases the resistance of the products to corrosion, heat, and fatigue.

The domestic demand for scrap mica has grown steadily during the past two decades, and annual production has reached levels in excess of 30,000 tons, most of which represents mica from pegmatitic sources. Prices during recent years have ranged from \$25 to \$55 per ton for most raw scrap mica, from \$30 to \$80 per ton for dry-ground mica, and from \$125 to \$170 per ton for wet-ground material. Additional marketing data and discussions of the mica-grinding industry are available in publications of the U.S. Bureau of Mines.<sup>40</sup>

#### OCCURRENCE

Muscovite is abundant in many parts of the district, and especially in a widespread group of pegmatite bodies that are exposed on both sides of the drainage divide between Buckhorn Wash on the north and Trilby and San Domingo Washes to the south (Pl. I). It is scattered as small books through many of the border zones and wall zones, in some of which it amounts to 20 per cent or more of the rock. Locally, as in the Long Dike deposit, it forms as much as 80 per cent of the rock, but no very large masses of such material appear to be present anywhere in the district. Inasmuch as all of this outer-zone mica forms small flakes, plates, and books, it is of commercial significance as scrap-grade material only.

Larger crystals of muscovite are abundant in the cores and intermediate zones of some pegmatite bodies, where they are embedded in masses of very coarse-grained quartz or are clustered around the margins of such masses. Numerous occurrences of

<sup>40</sup>Myers, W. M., Mica: U.S. Bur. Mines, Inf. Circ. 6205, pp. 7-8, 14-18, 1929.  
Horton, F. W., Mica: U.S. Bur. Mines, Inf. Circ. 6822, pp. 10-12, 28-30, 1935 (revised 1941).

Gwinn, G. R., Strategic mica: U.S. Bur. Mines, Inf. Circ. 7258, pp. 15-17, 1943.

this type are well exposed in the irregular pegmatite dikes at the head of Independence Gulch, west of the Midnight Owl mine (Pl. I). Some masses of intergrown books, commonly with associated minor albite and quartz, are as much as 8 feet in maximum dimension. More abundant, however, are somewhat larger masses of rock that contain less mica and considerably more quartz.

This coarser-grained muscovite is light green in color, clear, hard, and free splitting. Most is severely ruled and fractured (Pl. VIII), however, and the largest books are marred by "A"-structure. Warping, wedging, and intergrowths with adjacent books further reduce the amounts of high-quality material that might be recovered by careful splitting and trimming. Thus, despite the satisfactory size-range of the largest books, the proportion of punch and small-sheet mica that could be obtained from them probably does not exceed 0.1 per cent, and nearly all of the deposits are best viewed as sources of scrap mica only.

The muscovite yields an excellent white product when ground, and should find a ready market. Unfortunately, it is not closely associated in the pegmatites with many other minerals that could be recovered as commercial by-products in a separation and grinding mill. Quartz and possibly a little beryl might be obtained during processing of the pegmatite masses with the highest mica content, but the potential yield of columbite-tantalite and other accessory minerals would be negligible. Large quantities of muscovite are not present in any of the lithium-bearing pegmatites thus far observed.

#### COLUMBIUM-TANTALUM MINERALS

The domestic market for columbium and tantalum minerals generally is excellent, owing to demands based on uses of the metals in radio and electronic equipment, corrosion-resistant tools and other devices, special glasses, and numerous alloys. In addition, tantalum is employed in the manufacture of synthetic rubber, and is uniquely satisfactory as a surgical metal. Prices quoted for columbium-tantalum ores vary according to the total content of  $\text{Cb}_2\text{O}_5$  and  $\text{Ta}_2\text{O}_5$ ; in addition, the most desirable ores are low-tantalum columbite and low-columbium tantalite. Prices during 1952 ranged from \$2 to nearly \$7 per pound of contained  $\text{Ta}_2\text{O}_5$  or  $\text{Cb}_2\text{O}_5$  for most concentrates, with the highest values applied to tantalite with 75 per cent or more of  $\text{Ta}_2\text{O}_5$ . Most lots of tantalum or columbium concentrates are marketed under specific agreements between the producer and purchaser.

The wide range in the price scale for columbite-tantalite makes assays in advance of sorting and shipping a practical necessity. Quantitative determinations of tantalum and columbium oxides by chemical analysis is a slow and very costly process, but it is possible to make approximate though rapid estimates for members of the columbite-tantalite series on the basis of the consistent relation between specific gravity and  $\text{Ta}_2\text{O}_5$  content. In general the gravity rises with increasing proportion of tantalum oxide. The specific gravity of most columbite ranges from 5.2

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.

Columbite-tantalite is present in several of the White Picacho pegmatites, and locally in sufficient concentrations of coarse crystals to be economically recoverable by hand sorting. Small lots already have been obtained during operations for beryl and lithium minerals at the Midnight Owl mine, and it seems likely that a modest yield of by-product material can be anticipated from most mining operations in the large and mineralogically complex pegmatites. Unfortunately, much of the columbite-tantalite and all of the other columbium-tantalum minerals in the district are too fine grained for effective recovery by hand methods, although they do merit consideration as potentially valuable by-products in the event that appropriate milling facilities become available.

#### BISMUTH MINERALS

Most domestic bismuth is obtained as a by-product from the smelting of lead ores, but a limited market exists for concentrates of raw bismuth minerals, and especially for those that are free from arsenic and antimony. Bismuth metal and bismuth compounds are used mainly in special alloys, pharmaceuticals, phosphors, and catalysts. The average value of ores sold during recent years is about \$0.50 per pound, and the metal has commanded an average price of slightly more than \$2 per pound.

Bismutite and other bismuth minerals form minable concentrations in a few of the pegmatite bodies, notably the Outpost and the Midnight Owl. They are spotty in their distribution and extent, but almost invariably occur in zones that are rich in massive quartz.

More than 10 tons of bismutite-bismuthinite concentrates were obtained from one large, pod-like mass at the Outpost mine, and reportedly were marketed at an average price of \$1.25 per pound. This occurrence was of course exceptional, but a few others like it might well be encountered during future mining for feldspars and lithium minerals in the district. The bismuth minerals seem best viewed as potential by-products that are readily recoverable by hand picking wherever they are encountered in large enough quantities, but whose major occurrences cannot be predicted in advance of mining.

#### MINING AND PROSPECTING

##### METHODS AND PAST DEVELOPMENTS

The pegmatites of the White Picacho district were visited and examined from time to time over a period of many years, mainly by prospectors in search of gold, copper, or tungsten deposits. Their potential value as sources of nonmetallic commodities does not seem to have been recognized until 1947, when they were

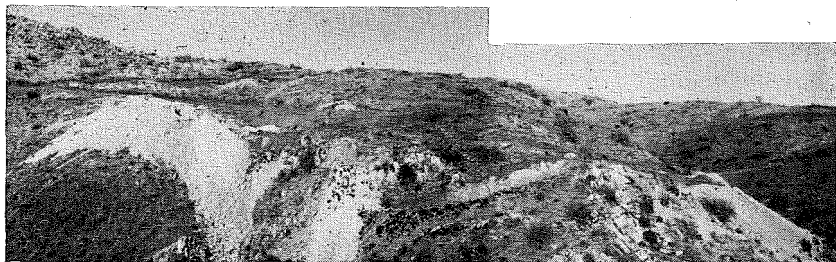


Plate XV.—View of Midnight Owl pegmatite, looking north. The Upper cut, at left, is in the west bulge of the pegmatite body; the Lower cut, at right, is in the east bulge (see Plate XXIV). Note bold outcrops of pegmatite in center and right foreground.

noted during an aerial reconnaissance for deposits of high-grade feldspar by the Whitehall Company of Keene, New Hampshire. The largest pegmatite bodies, as well as those containing abundant massive quartz, are particularly conspicuous when viewed from the air, and their positive identification thus was easily accomplished. The locations of both these and other masses of pegmatite were plotted on maps during the initial reconnaissance, and the airplane map then was used as a guide for location and examination of each pegmatite on the ground.<sup>41</sup>

During 1947 several of the most promising pegmatites were further exposed by stripping with a bulldozer, and were explored for deposits of feldspar and lithium minerals by means of trenches, cuts, test pits, and shallow drill holes. Numerous short access roads were built, and quarries were developed in the Picacho View, Outpost, and Friction deposits in order to test them more fully as sources of commercial feldspar. The entire exploration program was well planned and effective. It quickly focused attention on the deposits of greatest economic potential, and yielded valuable information concerning their form, extent, and grade.

During this time, several small lots of bismutite and bismuthinite were obtained from the Outpost pegmatite by Earl F. Anderson and Sidney B. Anderson of Mesa, who developed an open cut and short appended incline in a small but rich occurrence of bismuth and copper minerals that had been exposed during stripping operations by the Whitehall Company. A nearly pure concentrate of shipping material was recovered by careful hand picking during 1947 and 1948.

The Anderson brothers then turned their attention to the Midnight Owl pegmatite, which they explored and mined on a small scale for amblygonite, spodumene, beryl, and columbite-tantalite. Open cuts were developed in two major bulges of the pegmatite body (Pls. XV, XXIV), and these operations yielded several ship-

<sup>41</sup>Whitney, R. J., How a bird's-eye view from a plane makes prospecting easier: *Eng. and Min. Jour.*, vol. 153, no. 3, pp. 84-86, 1952.

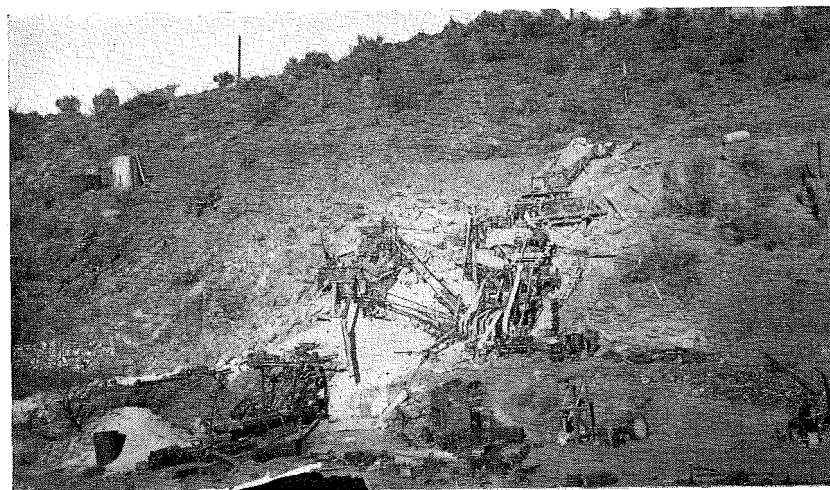


Plate XVI.—Anderson mica mill, in upper part of San Domingo Wash.

ments of marketable material. Mining was being continued, chiefly in the Lower cut, when the property was last visited in June, 1952. Additional quantities of amblygonite and spodumene were shipped in 1951 from the North Morning Star property, wholly from two open cuts that were developed in the main dike (Pl. XVII). The rock excavated from one small cut near the north end of this dike yielded 17 tons of coarse amblygonite.

The most recent operations for lithium minerals in the district were begun in the Lower Jumbo pegmatite late in 1951 (Pl. VI), and have yielded at least one carload shipment of marketable spodumene.

During 1950 the Anderson brothers mined moderate quantities of muscovite-bearing pegmatite, chiefly from deposits near the head of Independence Gulch (Pl. I). Some were shipped to a mill at Aguila for separation and grinding, and the remainder was processed in a small mill that was built in San Domingo Wash about a mile east-northeast of the Riley place (Pls. I, XVI). This mill effected the separation of a rough scrap mica product by several stages of crushing and screening, and it is reported that a small air-separation unit also was tested for a short period of time. The mill has been idle since 1951.

Nearly all the deposits of pegmatite minerals that have been mined in the district were discovered through inspection of outcrops or through the tracing of float material to its source. Loose fragments of quartz, which are strewn over many ridges and slopes, have proved to be good indicators of feldspar, amblygonite, and spodumene deposits high on the slopes, and close inspection of the float commonly has revealed fragments of these minerals in association with the blocks of quartz. It seems likely that examination of these float occurrences and the available outcrops

of pegmatite should lead to recognition of most near-surface concentrations of economically desirable minerals in the district.

Most exploration and mining thus far has been confined to surface excavations, and the typical sequence of operations has been outlined in earlier paragraphs. A few deposits, like the Picacho View, have been tested by means of short tunnels and shallow shafts, and the North Morning Star, Sunrise, Lower Jumbo, and Midnight Owl pegmatites were diamond drilled by the Pacific Coast Borax Company in 1952. Future mining operations probably will follow the course taken in most other pegmatite districts, in which widespread open-cut work has led to underground mining in many of the best deposits.

A little stripping has been required to expose fully the outer surfaces of some deposits, but the surficial overburden rarely is more than 3 feet thick. Nearly all of the pegmatite is hard and unweathered, so that drilling and blasting are necessary in mining. Some mica has been recovered by milling of pegmatite that was mined in bulk, but all other production thus far has resulted from somewhat selective mining, followed immediately by hand cobbing and picking of the desired minerals.

Where overlying masses of country rock would necessitate a change to underground methods if mining were extended to deeper levels, no unusual problems should be encountered in the support of the workings. Little timbering should be needed except perhaps at the portals of some openings. Ground water also would be no problem in most mines, especially those that lie well above the levels of nearby major washes.

#### PRODUCTION

The production data for pegmatite minerals during the initial five-year period of active mining in the White Picacho district are summarized in Table 5. These modest totals comprise the output from a few small mines and an additional yield of material recovered during exploration of several pegmatite bodies. They represent a combined value of approximately \$45,000, a substantial portion of which applies to the bismuth minerals obtained from the Outpost mine. It is not possible to estimate the quantities or value of feldspar mined from the major deposits, although the total amount certainly exceeds 2,000 tons. Only a few test lots actually were shipped, and the remainder lies in several dumps and stockpiles.

#### FUTURE POSSIBILITIES

The recent recognition of the White Picacho pegmatites as possible sources of commercial feldspar and other mineral commodities may well prove to be of considerable economic significance, particularly in view of the markedly declining discovery rate for domestic deposits of pegmatite minerals during the past few decades. The White Picacho district is one of the few in which discovery and exploration are far ahead of development and exploitation, a situation that promises to continue for a

TABLE 5.—PRODUCTION OF PEGMATITE MINERALS FROM THE WHITE PICACHO DISTRICT, 1947-1952

Mineral	Deposit	Quantity (tons)	Grade (per cent)
Feldspar	Picacho View	Large lots for testing	No. 1
	Outpost		
	Friction		
	Midnight Owl		
Amblygonite	North Morning Star	26	8.5 Li <sub>2</sub> O
	Midnight Owl	62	7.4 Li <sub>2</sub> O
Spodumene	North Morning Star	20*	5* Li <sub>2</sub> O
	Lower Jumbo	55	
	Midnight Owl	None shipped	2-3 Li <sub>2</sub> O
Beryl	Midnight Owl	13	11-12 BeO
Bismutite	Outpost	12	—
Muscovite	Several deposits	100*	—
Columbite-tantalite	Midnight Owl	< 1	Not known

\*Approximate

period of a decade or more. The immediate future of the district therefore will depend not so much upon continued search for additional deposits as upon appraisal and development of those that are known. The effectiveness of such work will be governed in turn by the degree to which all significant geologic and economic factors are recognized and properly evaluated.

The development of several deposits in the district during the past five years reveals the general pattern that might be expected for any future operations based upon selective mining and hand sorting of salable minerals. Plainly the major possibilities lie in the production of high-grade feldspar, several large deposits of which are known and have been explored. Reserves of recoverable material probably amount to at least 70,000 tons, and might prove to be considerably greater after further exploration of the largest pegmatite bodies. The chief problems attending commercial operations for feldspar would be economic rather than geologic, at least in the early stages. They would require careful analysis of mining, sorting, and hauling costs, as well as the appraisal of present and potential market conditions, especially in the industrial areas of the Pacific Coast region.

Reserves of lithium minerals in the district probably amount to at least 8,000 tons, and production of very coarse-grained spodumene and amblygonite might well reach modest levels. Operations would be handicapped by the great distance of the deposits from the principal eastern centers of demand, and perhaps to a much greater degree by the relatively low average lithium content of the spodumene that could be obtained. Further, substantial proportions of the spodumene and amblygonite in the district could not be recovered effectively by hand sorting from the pegmatite in which they occur.

Future production of beryl, mica, quartz, and other minerals could be continued on the basis of small-scale mining and hand

picking, especially under favorable market conditions like those obtaining at the present time. Much of this output probably would be in the form of by-products recovered during operations for feldspar and lithium minerals.

The broader, long-term outlook for the district might be brightened considerably if a mill were erected for treatment of pegmatite in large quantities. The net value of the mined rock could be materially increased by mechanical recovery of several marketable minerals, and columbite-tantalite, pyrochlore, and some of the other accessory minerals could be concentrated as by-products, even though they are not sufficiently abundant in any one ore body to be considered as a primary basis for exploitation. In addition, milling of pegmatite would encourage the adoption of low-cost bulk methods of mining, and might shift attention from high-grade, pockety deposits to more extensive and continuous deposits of lower grade.

Grinding plants for feldspar and scrap mica might be operated in conjunction with the mill, and the products shipped to areas of demand as fully prepared material. Neither mill nor grinding plants should be built, however, in advance of adequate data on available reserves of near-by pegmatite material and a careful analysis of all economic factors involved.

The commercial potentialities of individual pegmatite bodies should be appraised before any attempts at full-scale mining are begun. The exploration program of the Whitehall Company satisfied the need for surface and near-surface data on extent and grade of several major deposits, and the more recent program of the Pacific Coast Borax Company demonstrated 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. Geologic data on these and several other deposits in the district are presented in the following section of this report, and are aimed mainly at providing mineralogic and structural information of greatest potential economic usefulness. Applications of such data have been discussed on previous pages, and in addition have been treated in more general terms in the published record.<sup>42</sup>

#### DESCRIPTIONS OF SELECTED MINES AND PROSPECTS MORNING STAR PROSPECTS

The Morning Star pegmatites (1, Pl. I) are irregular, steeply dipping dikes that are exposed on a prominent ridge about half

<sup>42</sup>See, for example,

Cameron, E. N., Larrabee, D. M., McNair, A. H., Page, J. J., and Shainin, V. E., Structural and economic characteristics of New England mica deposits: *Econ. Geol.*, vol. 40, pp. 369-93, 1945.

Jahns, R. H., Mica deposits of the Petaca district, Rio Arriba County, New Mexico: *New Mexico School of Mines, Bur. of Mines and Min. Res. Bull.* 25, pp. 39-51, 261-64, 1946.

Cameron, E. N., Jahns, R. H., McNair, A. H., and Page, L. R., Internal structure of granitic pegmatites: *Econ. Geol.*, Mon. 2, esp. pp. 106-07, 1949.

Jahns, R. H., Geology, mining, and uses of strategic pegmatites: *Amer. Inst. Min. and Met. Eng., Trans.*, vol. 190, pp. 45-59, 1951.

a mile west-southwest of the Riley place, in the western half of sec. 16, T. 7 N., R. 3 W. White quartz and coarse potash feldspar form several bold outcrops along the crest of a ridge that rises steeply on the northwest side of San Domingo Wash, and these have contributed abundant float to the slopes below. Pegmatite also appears along low cuts made during recent construction of a truck road, and in several shallow prospect pits and trenches, as well.

The country rock in this general area is thinly foliated to slabby amphibole schist, quartz-biotite schist, and quartz-biotite-muscovite schist, most of which is medium dark gray in color. These rock types are intimately interlayered, and locally contain lenses of amphibolite and epidosite. Most appear to be of volcanic origin, and several thick, tabular masses of agglomerate and breccia are clearly recognizable. Both foliation and layering strike west-northwest to west, and dip 45° to 55° north. The general structure is rather uniform, but the rocks are much crumpled and contorted in detail. Here and there the schist is cut by quartz veins and by dikes of fine-grained, very dark gray amphibolite.

Near the pegmatite contacts the schist has been impregnated with abundant potash feldspar and flakes of pale green muscovite. All transitions between amphibole- or biotite-rich schist and nearly pure muscovite schist are visible on a small knob immediately north of the thickest part of the south pegmatite dike. Most of the muscovite forms thin flakes 1/8 inch to 1/2 inch in diameter, and both these and the gross foliation of the rock are much contorted in detail.

The south prospect is in a large, somewhat bulbous dike with a general outline like that of a bowling pin. It trends east, and appears to dip steeply north. It is about 300 feet long and 70 feet in maximum outcrop breadth, and its broadest part forms a distinct topographic knob. Several stubby projections extend southward on both sides of the ridge.

The pegmatite body consists of five readily distinguishable zones. The poorly exposed border zone, which ranges in thickness from a knife edge to 1 1/2 feet, is a medium-grained granitoid aggregate of quartz, plagioclase, and scattered muscovite. In most places it is rich in quartz, some of which is veined by very fine-grained aggregates of plagioclase and mica. Coarser muscovite, chiefly in stubby crystals 1/8 inch to 1/2 inch in diameter, is scattered through the rock, and locally is associated with small prismatic crystals of very dark green to black tourmaline. The continuity of the zone is broken here and there by wisps and slabs of schist, and by pod-like aggregates of coarse hornblende, some of which has been altered to biotite.

The wall zone, a discontinuous unit about 6 feet in maximum thickness, is a medium- to coarse-grained granitoid aggregate of perthite, plagioclase, and subordinate quartz, with moderate amounts of fine-grained plagioclase. A little muscovite and



garnet also is present. This unit grades into an outer intermediate zone, 6 inches to 8 feet thick, that is composed chiefly of coarse-grained, subhedral to anhedral perthite with subordinate interstitial quartz. Some of the potash feldspar contains quartz in crudely graphic intergrowths.

The inner intermediate zone, the most conspicuous unit in the dike, is 2 feet to 28 feet thick. It consists almost wholly of coarse- to very coarse-grained, subhedral perthite, and some of the crystals are as much as 7 feet in maximum dimension. Most are considerably fractured, and locally are brecciated on a small scale. Many thin shear zones are present, and several curving, roughly grooved surfaces of movement resemble the grooved surfaces that are so common in some basaltic rocks. The feldspar is white to bluish gray, but weathers to a creamy tan color. Some is stained by manganese oxides, and a little by chrysocolla, as well. Interstitial quartz is present in only a few places, and constitutes less than 3 per cent of the rock. Fine-grained plagioclase occurs in some of the fractured and brecciated crystals of perthite.

Irregular pods of massive quartz, 6 inches to 9 feet in maximum dimension, form a segmented core in the thickest part of the dike. Well formed crystals of perthite, a few of them as much as 3 feet in diameter, are scattered sparsely through the outer parts of the largest core segments. Both the perthite and the quartz are locally sheared and brecciated, and are veined with muscovite and fine-grained, lustrous white albite. Aggregates of muscovite, in pale yellowish green crystals  $\frac{1}{8}$  inch to 2 inches in diameter, occur as thin, discontinuous fringes around most of the quartz pods.

A small, quartz-rich dike is exposed on the hill slope across a small gully to the northeast. It is teardrop shaped, and contains a conspicuous core of quartz that in places is much fractured and brecciated. A wall zone of coarse, blocky perthite, also much fractured, is 6 feet to 12 feet thick in the southwest part of the dike, but elsewhere is 18 inches or less in thickness. In places it appears to be absent altogether.

Neither of these dikes contains large amounts of highest-grade feldspar, but a modest reserve of coarse perthite does exist in the thickest part of the south dike, where the inner intermediate zone is most broadly developed.

#### NORTH MORNING STAR MINE

The North Morning Star mine, about 600 feet N.  $10^\circ$  E. of the prospects described above, is in a steeply dipping pegmatite dike that trends north-northeast to northeast along the same prominent ridge (Pls. I, XVII). Some spodumene has been obtained from the Main cut, a large, trench-like opening developed across a saddle between two elongate knobs of massive quartz, and coarse amblygonite has been recovered commercially from a smaller cut at the thick northeast end of the dike (Pl. XVII).

The pegmatite body is about 50 feet in outcrop breadth in the vicinity of the Main cut, and broadens northeastward to a maximum of nearly 100 feet. Prominent branches extend eastward and northwestward beyond the mapped area (Pl. XVII). The country rock is thinly foliated, light to medium gray quartz-biotite-muscovite schist. Its well developed planar structure trends west-northwest and dips north-northeast at moderate to steep angles. The rock is cut by several dikes of fine-grained, dark gray amphibolite, and also contains numerous quartz veins. The pegmatite-wallrock contacts are sharp, and in places the outer part of the pegmatite body is complicated by tabular inclusions and elongate septa of schist. Several of these are exposed in the Main cut, and others were penetrated by drill holes during recent exploration of the property (Pls. XVII, XVIII).

The pegmatite dike is remarkably well zoned, and is distinguished by prominent inner zones with giant texture. The segmented core consists almost wholly of very coarse-grained anhedral quartz. The two largest segments are pod-like, and form irregular knobs whose summits are about 120 feet apart on the crest of the ridge. Many float blocks of white quartz are strewn over the broad slope to the southeast. Fine-grained white albite forms some fracture-filling veinlets in the core, but constitutes an extremely small proportion of the rock.

Five distinctive intermediate zones appear to enclose or partly enclose the principal core segments. The innermost intermediate zone is a very coarse-grained aggregate of quartz and amblygonite, and grades inward into the massive quartz of the core. It crops out only on the ridge north and northeast of the north quartz knob, and evidently extends for a considerable distance down the steep dip of the dike (Pls. XVII, XVIII).

The amblygonite is scattered through the quartz as crudely formed crystals and irregular masses, some as much as 5 feet in diameter. Weathered surfaces of these masses are buff colored and somewhat cellular in appearance, and are easily distinguished from weathered surfaces of coarse feldspar. Fresh surfaces are white to very pale greenish buff, and show a somewhat pearly luster. Much of the amblygonite has been fractured and brecciated on a small scale, and the breaks have been "healed" with fine-grained, breccia-like aggregates of pale greenish to bluish amblygonite.

Quartz-spodumene pegmatite forms the next intermediate zone, the inner part of which contains some amblygonite. This unit, which appears to be relatively continuous, is exposed on the rubble-strewn surface of the saddle between the two quartz knobs, and also is very poorly exposed high on the slopes that flank the knobs. The spodumene occurs as rough prismatic crystals that range in thickness from less than  $\frac{1}{2}$  inch to 6 inches, and in length from  $1\frac{1}{2}$  inches to at least 24 inches. It is buff to bluish gray in color, and, though opaque, does not appear to be much altered or leached. Most of the near-surface material, however, is considerably weathered, and locally is stained

by oxides of iron and manganese.

Black, green, and pink tourmaline, as well as lepidolite, apatite, columbite-tantalite, and some muscovite, occur in the spodumene-bearing pegmatite, generally in association with albite. The black tourmaline is scattered through the outer parts of the zone, whereas the elbaite forms local pod-like concentrations of rough, prismatic crystals. Most of these green and pink crystals are  $\frac{1}{2}$  inch to 5 inches long, and are considerably altered. Much smaller, more sharply faced crystals form inclusions in some of the coarsest books of lepidolite. Thin tablets of columbite-tantalite,  $\frac{1}{8}$  inch to  $1\frac{1}{2}$  inches in maximum dimension, are associated with the tourmaline, spodumene, and quartz, and are most abundant in and near the Main cut. Anhedral crystals of dark bluish gray apatite are scattered sparsely through the entire zone.

Lepidolite occurs in both the spodumene- and amblygonite-bearing units as fine-grained aggregates and as scattered coarse books, some of which are as much as 5 inches in diameter. The mica is pale pinkish to gray where exposed at the surface, but crystals obtained from depths of 3 feet or more have a moderately deep lilac color. The coarsest plates are severely ruled, and many are distinctly curved. Most are associated with coarse-grained cleavelandite. As exposed on the two knobs and in small prospect pits on the northwest slope of the ridge, the fine-grained aggregates of lepidolite form irregular fracture fillings and fracture-controlled stockworks in the much coarser quartz and spodumene. Some of the large quartz crystals are veined with aggregates of lepidolite so fine grained that they appear waxy.

The middle, or third, intermediate zone is a very coarse-grained aggregate of quartz and euhedral crystals of perthite. It appears as a hood-like mass in the north part of the dike, and is best exposed on the slope about 50 feet west of the Amblygonite cut (Pl. XVII). The feldspar crystals are about 10 inches in average diameter, but some are as large as  $4\frac{1}{2}$  feet. The ratio of perthite to quartz ranges from about 2:1 to as much as 10:1. Aggregates of lepidolite and cleavelandite are present locally, especially in and immediately adjacent to fractures, and some sugary albite is scattered irregularly through the rock.

Flanking the middle intermediate zone is a much more continuous unit of coarse- to very coarse-grained quartz and subhedral perthite, with subordinate albite and schorl. This rock is similar in composition to that of the middle intermediate zone, but is distinctly less giant textured and is characterized by higher perthite-quartz ratios. Further, the crystals of perthite are markedly less euhedral.

The outer intermediate zone is a medium- to coarse-grained aggregate of quartz, albite, perthite, spodumene, and muscovite, with minor accessory garnet and schorl. It is exposed only along the northwest side of the dike in and near the Main cut, where it flanks an elongate septum of schist (Pl. XVII), and nowhere is it more than 8 feet thick.

Medium- to coarse-grained perthite-quartz-albite pegmatite forms a very poorly exposed wall zone that appears to be about 3 feet in average thickness. The border zone is distinctly finer grained, and contains a much higher proportion of quartz. Associated with the quartz are albite, schorl, perthite, and some muscovite. Like the wall zone, the border zone is covered by talus and soil in most places.

The deposit seems to offer some promise as a source of lithium minerals. Amblygonite forms 6 per cent to 10 per cent of the inner intermediate zone, as determined by traverse measurements. This unit is exposed only in the northern part of the dike, but may well have a moderately large vertical dimension (Pl. XVIII). It is estimated that about 160 tons of amblygonite is present to a depth of 100 feet, and that the reserves of this mineral in the entire dike may well exceed 500 tons. The tonnage of spodumene present to the same depth undoubtedly is much larger, but the major spodumene-bearing unit is even more poorly exposed than the inner intermediate zone, and hence specific estimates cannot be made. At least 500 tons of very coarse-grained potash feldspar of good quality should be present to a depth of 30 feet in a small area just west of the Amblygonite cut and north of the north quartz knob, and substantially greater reserves may well exist elsewhere in the dike.

#### SUNSET PROSPECT

The Sunset dikes (2, Pl. I) are on a ridge immediately east and northeast of the Riley place, in the NE  $\frac{1}{4}$  of sec. 16, T. 7 N., R. 3 W., and the sinuous outcrop of the main dike is plainly visible from San Domingo Wash to the south. This dike trends N.  $40^{\circ}$  E., dips steeply, and is approximately 530 feet long. It is 2 feet to 18 feet thick, but most of it ranges in thickness from 8 feet to 14 feet.

The country rock is dark greenish gray amphibole schist and amphibole-rich breccia that appear to be of volcanic origin. The layering in these rocks trends N.  $65^{\circ}$  E. and dips steeply north-northwest along the east side of the pegmatite, but strikes N.  $80^{\circ}$  E. and dips  $70^{\circ}$  N. beyond the ends of the dike.

The pegmatite in the main dike is distinctly different from that of the Morning Star dikes. It contains no lithium minerals, but includes abundant muscovite, schorl, and graphic granite. It is chiefly a fine- to medium-grained aggregate of potash feldspar, quartz, and muscovite, with minor plagioclase, schorl, and garnet, and its central part is marked by elongate masses of quartz 8 inches to 24 inches in thickness. These core segments of quartz are most abundant where the dike is relatively thin; where it is thicker, its central part consists chiefly of medium- to coarse-grained graphic granite with abundant scattered prisms of schorl.

The grain size of the pegmatite varies considerably from place to place, even within the units that are rich in graphic granite. Relatively coarse crystals and crystal aggregates of perthite are

scattered through much finer-grained perthite-rich pegmatite, much as the quartz core segments are scattered through the central part of the dike. Some of the feldspar is almost free from quartz, especially where it lies along the flanks of these core segments. Clots of quartz and coarse schorl, locally in graphic intergrowth, also are scattered through the inner parts of the dike.

All the minerals are considerably fractured and crackled, and many of the fractures are filled with aggregates of fine-grained, sugary albite. This feldspar also is present along contacts between crystals of potash feldspar, and is there associated with flakes of yellowish green muscovite. Coarser books of muscovite occur locally as fringes around segments of the quartz core.

The border of the dike consists of fine- to medium-grained quartz-plagioclase-perthite pegmatite through which are scattered abundant crystals of schorl. In the south, relatively thin part of the dike, several tabular masses of fine- to coarse-grained quartz transect the other minerals, and some of them clearly cut across the perthite and quartz of graphic-granite masses. Sugary albite locally is intergrown with this late-stage quartz.

Other, smaller dikes of pegmatite crop out lower on the slope to the west. Several prospect pits expose rock similar to that in the main dike, and no lithium minerals are visible. The country rock is chiefly amphibole-rich schist that contains some chlorite- and epidote-rich layers.

#### LOWER JUMBO MINE

The Lower Jumbo mine (3, Pl. I) is in the lower, canyon-like part of Mitchell Wash, about half a mile north-northeast of the Riley place. It lies near the SE corner of sec. 9, T. 7 N., R. 3 W. The principal opening, a small "stripping quarry" on the wall of the canyon, was developed during 1951 and 1952 by Earl F. Anderson of Mesa. A carload of hand-sorted spodumene was shipped from the deposit late in 1951.

The quarry face exposes a thick, bulge-like pegmatite mass that contains abundant spodumene in very large crystals (Pls. VI, VII). This mass is a part of a very irregular dike that trends north to north-northeast and dips steeply westward. It is enclosed by hard, fine-grained, greenish gray feldspathic hornblende gneiss that is thin and regularly layered. This rock weathers to a dark grayish brown, essentially the color of desert varnish. Its well developed foliation strikes N. 85° W. and dips 45° to 60° N.

As shown in Plate XIX, the pegmatite body is a connected pair of elongate bulges whose major axes plunge very gently in a northerly direction. The upper bulge, which appears to contain little or no spodumene, is dominant at the surface, where its exposure is about 170 feet long and 30 feet to 50 feet wide. The results of diamond-drill exploration, however, indicate that the lower, spodumene-rich bulge probably is much larger. It is about 60 feet in maximum thickness where exposed in the quarry (Pl. VI), and its general surface trace on the steep canyon wall

is represented on the upper part of the front plate in the isometric diagram (Pl. XIX). It thickens considerably northward along its plunge, and its keel appears to be complicated by one or more large, curving septa of country rock. Only one end of this bulge is exposed at the surface, but it was penetrated by several of the drill holes, and must be at least 200 feet long.

The pegmatite body does not extend across the narrow canyon, but instead thins abruptly in the canyon bottom and bends sharply westward to join a subparallel dike nearby. This second dike, which is 8 feet to 15 feet thick, is separated from the main dike by 20 feet to 45 feet of country-rock gneiss. As traced north-eastward, it joins the upper bulge of the main dike high on the canyon wall (Pl. XIX).

Like most of the other lithium-bearing pegmatites in the district, the main dike is spodumene-rich in its thickest part, but is perthite-rich elsewhere. As exposed on the canyon wall, its upper bulge comprises three zones. A fine-grained border zone, which ranges in thickness from about 1/8 inch to 5 inches, consists of perthite, albite, quartz, schorl, muscovite, and a little pale bluish-gray beryl. Where this selvage is thickest, it contains numerous prisms of schorl, 1/2 inch to 3 inches long, that are graphically intergrown with quartz and subordinate feldspars. The wall zone, which is 6 inches to 8 feet thick, is mainly a medium-grained aggregate of perthite, quartz, albite, schorl, and muscovite. It characteristically weathers to hard, light-gray surfaces that give the rock a deceptively fine-grained appearance. A few scattered, irregular crystals of greenish-gray beryl, 3 inches to 5 inches in maximum dimension, also appear in this zone.

The central part of the bulge is occupied by a thick unit that is similar to the wall zone in mineralogy, but in general is distinctly coarser grained. Most of its minerals are about 4 inches in average diameter. The rock coarsens perceptibly toward the center of the bulge, particularly near its south end. Much of the coarsest quartz is veined and partly replaced by albite, which locally forms well-defined stockworks.

The quarry face (Pl. VI) provides an excellent and complete wall-to-wall exposure of the main, or lower, bulge. Here the border zone, about 6 inches in average thickness, consists of fine-grained perthite—albite—quartz—schorl—muscovite pegmatite. As in the exposures higher on the hill, it contains a little beryl. Scattered small crystals of spessartite also are present. Immediately inside this border zone in most parts of the bulge is a medium- to coarse-grained layer of perthite—albite—quartz—spodumene—muscovite pegmatite that is about 15 inches in average thickness. This unit, which probably is an intermediate zone, dies out as traced upward along the margins of the large, spodumene-bearing core; in the upper flanks of the bulge, it is separated from the border zone by a thin layer of wall-zone pegmatite similar to that in the upper bulge (Pl. XIX).

The bulk of the lower bulge is composed of giant-textured spodumene—quartz pegmatite. The intermediate zone described above grades into this unit with a rather abrupt increase in the size and amount of contained spodumene crystals. These crystals are lath-like in form, and some are as much as 5 by 10 inches in section and 16 feet in length. Most, however, are 4 feet to 6 feet long. These laths, which are scattered through the very coarse-grained quartz as giant jackstraws (Pls. VI, VII), are typically bent, fractured, and even broken apart; where broken, most have been "healed" by quartz.

Spodumene and quartz constitute about 98 per cent of this unit, which is the core of the dike. The only other minerals present are albite, which forms scattered veinlets and irregular concentrations, and a few crystals of garnet and very pale pinkish beryl. Much of the spodumene is partly altered, especially in the outer parts of the core, and such crystals are relatively soft and chalky. They range in color from brownish gray through yellowish to pale greenish gray. In contrast, most of the spodumene in the central part of the core appears to be quite fresh. It is hard, very pale greenish gray, and is transparent on the thinnest edges.

Spodumene forms about 20 per cent of the rock in which it is most concentrated, but over the entire quarry face its average proportion is about 9 per cent. It is least abundant toward the center of the core, where the largest crystals occur. Reserves of spodumene-bearing pegmatite in the lower bulge must amount to at least 20,000 tons, and this rock may well be present in considerably greater quantity.

The smaller, northwesterly dike is similar to the main dike, except that its central unit consists of massive quartz with gigantic crystals of light to dark gray perthite. Some of these crystals are as much as 7 feet long. A little medium-grained spodumene is present along the margins of this zone. Both pegmatite dikes contain many tabular inclusions of country rock, none of which appear to be systematically oriented. These inclusions are scattered at random through the dikes, and even appear near the center of the core. Five of them are exposed in the quarry face.

#### WHITE JUMBO PROSPECT

The White Jumbo lithium pegmatite (4, Pl. I) is on a southwest-trending ridge about a mile northeast of the Riley place, and lies in the east half of the SW  $\frac{1}{4}$  of sec. 10, T. 7 N., R. 3 W. It has been exposed by means of bulldozer stripping, chiefly along the crest of the ridge and on a small knob, and also appears in several shallow cuts high on the west side of the ridge.

The pegmatite body is a dike that trends N. 75° to 85° E., and probably dips south-southeast at moderate to steep angles. It forms almost a dip slope immediately northeast of the stripped area. The dike is more than 40 feet in outcrop breadth in the vicinity of the prospect openings, but splits into two prongs

east-northeast of the stripped area. The northern prong tapers out about 50 feet beyond the point of separation, but the southern prong appears to be more continuous.

The country rock is a dark greenish gray, fine-grained hornblende-biotite schist, with interlayered coarse-grained amphibole schist. A distinct foliation trends N. 70° E. and dips 65° NNW.

The pegmatite dike contains a core of massive quartz that forms a small but distinct topographic knob immediately south of the stripped area, and also appears as another segment to the east-northeast. The quartz is much sheared, brecciated, and cemented with finely crystalline quartz and opaline to chalcedonic silica. It also contains numerous small vugs that are lined with prismatic crystals of quartz, and some of these cavities are marked by molds of calcite crystals. The entire rock looks not unlike a mass of vein silica.

A thin and poorly exposed inner intermediate zone consists chiefly of quartz and spodumene. The spodumene occurs both as small, wedge-shaped crystals and as much longer laths, some of which are 20 inches in maximum dimension. Both minerals form individual fragments in brecciated and sheared zones similar to those in the adjacent core. Associated with the spodumene is some bluish to light gray amblygonite, as well as minor lithiophilite, apatite, and lepidolite. A small prospect pit on the ridge immediately north of the main quartz knob exposes a highly weathered aggregate of spodumene, amblygonite, quartz, and perthite, which is veined by stringers of pink clay minerals.

An outer intermediate zone, which fringes the core and the lithium-bearing inner intermediate zone, consists of coarse, blocky perthite with minor quartz. This unit ranges in outcrop breadth from less than a foot to about 30 feet, with an average of slightly less than 10 feet. The relatively continuous wall zone is a coarse-grained aggregate of potash feldspar, quartz, and subordinate plagioclase and muscovite. The border zone is considerably richer in quartz, and also contains locally abundant plagioclase and schorl.

The proportion of lithium minerals and the aggregate tonnage of lithium-bearing rock in the deposit are not great, but moderately large concentrations of potash feldspar are present. Much of this feldspar, however, is veined with finely crystalline quartz, and nearly all the near-surface material is stained with manganese and iron oxides.

#### SUNRISE PROSPECT

The Sunrise lithium pegmatites (5, Pl. I) are about 2,500 feet northwest of the White Jumbo prospect and a mile north-northeast of the Riley place, and lie near the northwest corner of the SW  $\frac{1}{4}$  of sec. 10, T. 7 N., R. 3 W. The main pegmatite body is exposed along a nearly flat-crested ridge that trends northeast. Not far to the northwest is a second, somewhat smaller dike, which forms a small topographic knob where it crosses a westerly trending ridge (Fig. 5). Both dikes are locally rich in

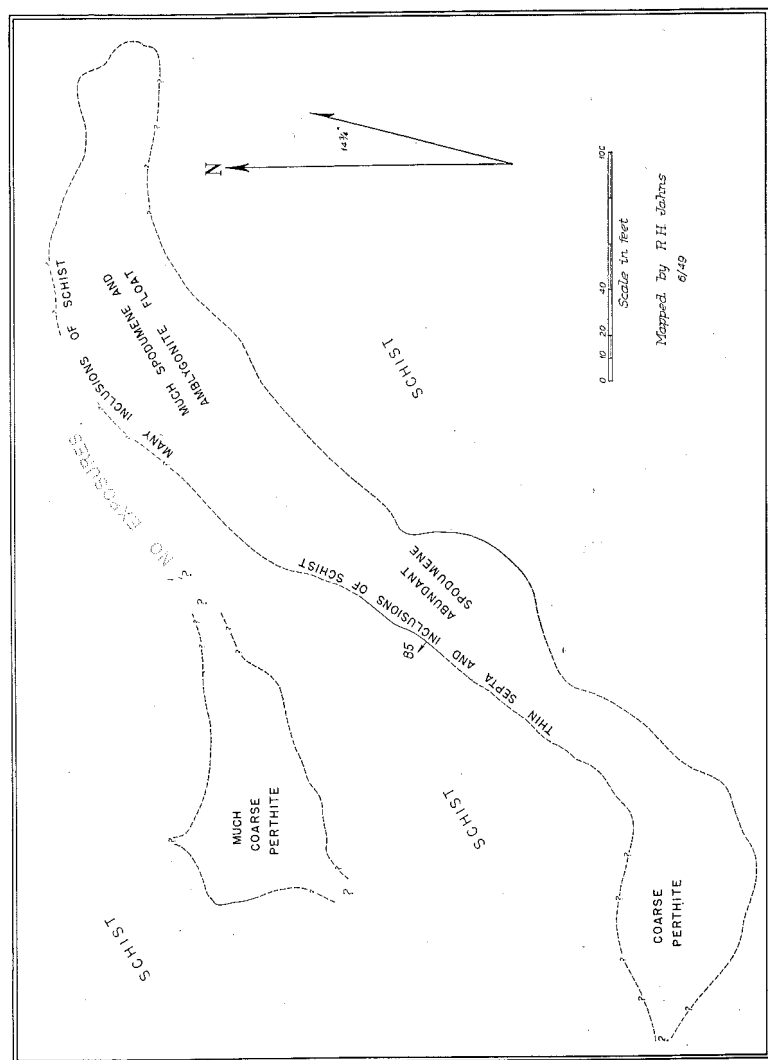


Figure 5.—Sketch map of the Sunrise pegmatite bodies.

lithium minerals, and have been prospected by means of several small, shallow cuts. In addition, an extensive area along the ridge was stripped with a bulldozer by the Whitehall Company in 1948.

The main dike trends northeast, and appears to dip steeply. It is roughly propeller-shaped in plan, and its northeastern part has a gently curving trace that is concave toward the southeast. It is more than 500 feet long, and in most places is at least 30 feet in outcrop breadth. Prominent bulges, 45 feet to 60 feet in outcrop breadth, are present near the middle and near both ends of this dike (Fig. 5). The other dike is poorly exposed, but contains one well defined bulge that is about 100 feet long and 60 feet in maximum width.

The country rock is mainly light gray to greenish gray, thinly foliated quartz-muscovite schist. Much of the muscovite and feldspar appear to have been introduced during injection of the pegmatite material, as the rock grades into more massive quartz-biotite-amphibole schist away from the pegmatite contacts. The mica-impregnated schist locally is much crenulated and plicated. Inclusions and septa of this rock are abundant along the northwest margin of the main pegmatite dike.

The outer parts of both dikes are largely concealed by surface accumulations of quartz blocks and other detritus, but appear to be lithologically similar to the border zone and wall zone of the White Jumbo pegmatite. The inner zones, in contrast, are locally well exposed. A large core segment of massive quartz lies near the northeast end of the main pegmatite, and smaller pods crop out elsewhere in both dikes. Surrounding or flanking these core segments are intermediate zones of quartz—amblygonite pegmatite, quartz—amblygonite—spodumene pegmatite, quartz—spodumene pegmatite, and quartz—euhedral perthite pegmatite. The quartz—amblygonite pegmatite is best developed as a fringe around the largest mass of quartz, and also appears to form isolated concentrations elsewhere in the central part of the dike. Spodumene-bearing pegmatite is most abundant farther southwest on the ridge (Fig. 5).

The amblygonite occurs as coarse, rough crystals and groups of crystals. It is gray to bluish gray, and locally is veined with sugary aggregates of more bluish amblygonite (PI XII B). Much of the spodumene forms light gray, log-shaped crystals that range in maximum dimension from 2 inches to 6½ feet. In contrast, the crystals that are nearest the walls of the dike are distinctly smaller, and are short, stubby, and commonly wedge-like in form. Most are less than 4 inches long and 1 by 2 inches in section.

Coarse crystals of lepidolite are scattered through the inner zones, and typically are associated with spodumene. Individual books are ⅛ inch to about 4 inches in diameter, and most are marked by closely spaced ruling and tiny crenulations. Some of the crystals form tangled intergrowths, and when broken yield stubby fragments that are bounded by cleavage and parting

planes. The mineral is tough but brittle, and cannot be readily cleaved into thin flakes. It is white to light gray at the outcrop, but the color becomes more typical pink and lavender with increasing depth beneath the surface.

Accessory constituents include small, tabular crystals of columbite-tantalite, dark blue masses of apatite, scattered tiny crystals and rare large masses of spessartite, and a few prisms of green tourmaline. Irregular masses of lithiophyllite, some of them as much as 5 inches in diameter, are exposed in three places along the crest of the main ridge. Most of these masses are rimmed with flesh-colored hureaulite, and are stained along fractures by manganese oxides. Manganese-oxides crusts surround some of the lithiophyllite, and contain small cavities that are partly filled with tiny crystals of pinkish to lavender purpurite and strengite.

Although lithium minerals appear to be abundant and widespread in the inner parts of the dike, the exposures are too incomplete to permit an appraisal of their commercial possibilities. Coarse-grained, blocky perthite is locally very abundant in the intermediate zones of both dikes, but these units appear to be too thin to constitute a significant commercial reserve of feldspar.

#### PICACHO VIEW MINE

The Picacho View feldspar mine (7, Pl. I) is on a ridge crest about  $\frac{1}{4}$  mile northeast of Mitchell Wash, and lies in the east half of the NW  $\frac{1}{4}$  of sec. 10, T. 7 N., R. 3 W. Recent operations by the Whitehall Company have led to development of a large, bench-like open cut on the southeast slope of the ridge (Pl. II), several smaller cuts higher on the ridge to the west, and a long, narrow bench on the north end of the ridge (Pl. XX). Extensive stripping also has been done. The large Main cut is 120 feet long, about 40 feet wide, and 18 feet to 27 feet deep along its northwest face. Stockpiled feldspar and dump material from this opening now conceal an adit and a shaft that were previously developed in showings of lead, zinc, and gold. These and other old prospect openings along the opposite side of the ridge are chiefly in schist and gneiss.

The main pegmatite body is a large, irregular mass that is essentially rectangular in plan (Pl. XX). It is about 240 feet long, 140 feet in maximum outcrop breadth, and trends N. 55° E. Its northwest side dips 35° to 55° southeast, and much steeper southeastward dips along its opposite side suggest a marked downward thinning of the entire mass. The steep dip of the contact at the southwest end of the Main cut may reflect only a local roll, however, as the same contact dips 35° southeast where exposed just beyond the cut, as well as in the nearby adit that is now beneath the dump (Pl. XX).

The country rock is thinly foliated quartz-mica schist and quartz-mica-amphibole schist, with interlayered epidosite and chlorite-rich rocks that appear to include both pyroclastic and intrusive types. The foliation and layering trend east-northeast to east, and dip 30° or less in both northwesterly and southeast-

erly directions. Local variations are common, especially near the borders of the main pegmatite mass.

Many stringers, dikes, and large, irregular pods of pegmatite are scattered through the older rocks, and a curving pegmatite dike about 160 feet long and 30 feet to 40 feet wide forms a small ridge southwest of the main dike. A larger dike is exposed farther northwest, outside the mapped area (Pl. XX). The pegmatite-wallrock contacts are very sharp in most places, and locally show much evidence of shearing. Small-scale "feathering" of pegmatite into schist is common, and larger irregularities appear in a few places. One prominent curving septum of schist, exposed in a pit near the southwest end of the main ridge (Pl. XX), is about 30 feet long and 6 feet to 8 feet thick. Other septa and inclusions of country rock are exposed in the Main cut, especially on the floor and low on the principal face. They are bounded from the pegmatite by shear planes in most places.

The main pegmatite body comprises five well defined zones. A discontinuous outer selvage, approximately 8 inches in maximum thickness, is a fine- to medium-grained aggregate of quartz, albite, perthite, muscovite, and schorl. The outer half inch of this unit is rich in fine-grained mica, but elsewhere quartz is by far the most abundant mineral. Mica-rich partings and other types of mineralogic layering give the rock a distinctly platy appearance where it is exposed along the western margin of the dike.

The wall zone is 2 feet to 55 feet in exposed breadth, and is most extensively developed at the north end of the pegmatite. It is composed mainly of coarse-grained perthite and quartz, with scattered albite and flake muscovite. Its outer parts are rich in quartz and schorl, and are distinguished from the adjacent border zone solely on the basis of grain size. Quartz constitutes the bulk of several septa that extend into the country rock from the main dike. These are thinly ribboned and vuggy, and the quartz resembles typical vein material.

Quartz is not particularly abundant elsewhere in the wall zone, and forms less than 10 per cent of the entire unit. It occurs both as interstitial material and as  $\frac{1}{16}$ -inch to  $\frac{1}{4}$ -inch veinlets and thin, irregular pods in the coarse perthite. Some rod-like masses of quartz are oriented in crudely graphic pattern within crystals of the potash feldspar, and such graphic granite is abundantly exposed in the face of the North cut (Pl. XX).

The outer intermediate zone consists chiefly of very coarse-grained blocky perthite, with distinctly less quartz than is present in adjacent parts of the wall zone. This unit also contains veinlets and interstitial aggregates of finely crystalline albite, veinlets and small, almond-shaped masses of very fine-grained, yellow to yellowish green sericite, and numerous scattered coarse prisms of altered schorl. In several places along the northwest side of the ridge, tourmaline forms as much as 7 per cent of the rock.

The inner intermediate zone comprises very coarse crystals of perthite and scattered masses of quartz. Some of the quartz is interstitial to the feldspar crystals, but most of it forms small pods of very coarse-grained anhedral crystals. There are all gradations between the largest of these pods and irregular masses of quartz that seem best interpreted as segments of a discontinuous core. These segments, which are largest and most abundant on the ridge immediately above the rim of the Main cut, range from about 3 feet to nearly 40 feet in maximum dimension. The distinction between the core and the inner intermediate zone is somewhat arbitrary, and the two units are shown together in Plate XX.

Scattered through the feldspar and quartz of the inner pegmatite units are pyrite, biotite, garnet, and iron oxides. Small quantities of allanite, columbite, molybdenite, sphalerite, galena, and such supergene minerals as molybdenite, cerussite, hemimorphite, and wulfenite also are present, chiefly along fractures in quartz. Dark green and black tourmaline forms single prisms  $\frac{1}{8}$  inch to  $1\frac{1}{4}$  inches in diameter, as well as bunches of elongate crystals that diverge slightly from common ends. The crystals show all stages of alteration to mica and clay minerals, and many are jacketed by scaly aggregates of muscovite.

Pyrite, much of it altered pseudomorphically to iron oxide, is locally abundant as well-formed cubes  $\frac{1}{8}$  inch to nearly an inch in diameter. Most of these are scattered in and along the margins of  $\frac{1}{4}$ -inch to 6-inch fracture fillings of quartz, and some others, generally of much smaller size, are strung out along fractures in the altered tourmaline. The concentrations of sulfide minerals are marked by streaks of iron-oxide stain in outcrops and in the faces of the cuts.

Very coarse-grained potash feldspar of excellent commercial grade surrounds the quartz masses of the core and inner intermediate zone, and also is abundant in the inner part of the outer intermediate zone. Typical material is well exposed in the Main cut. Large aggregates of very coarse perthite crystals also are exposed in the North cut, but much of this material contains considerable quantities of intimately intergrown quartz, and hence is of distinctly lower commercial grade.

The general distribution of coarse-grained potash feldspar, as mapped solely in terms of commercial factors, plainly bears a systematic relation to the zoning within the pegmatite mass (see insert, Pl. XX). Material of top quality, for example, is closely associated with the pods of massive quartz, and requires only a rough cobbing for commercial separation. This feldspar of the inner intermediate zone, moreover, represents a relatively high proportion of the rock that must be handled in mining. On the basis of counter-wheel traverses, spaced 5 feet apart and run in two directions at right angles, it is estimated that approximately 68 per cent of the high-grade feldspar-bearing unit shown in Plate XX is coarse-grained perthite. The reserves of such material to a depth of only 30 feet should amount to approximately

10,500 tons, about 80 per cent of which should be recoverable by the usual methods of hand sorting.

Considerably greater reserves of medium-grade feldspar occur farther from the center of the pegmatite body, chiefly in the outer intermediate zone. This material presents a more difficult problem of hand sorting, even though the proportion of quartz in the rock is distinctly lower than that in the high-grade perthite. Despite the occurrence of large masses of nearly pure blocky perthite, much of the feldspar in the rock contains scattered crystals of schorl and irregular masses, veinlets, and interstitial aggregates of anhedral quartz. These impurities would be difficult to remove without serious loss of time or waste of coarse feldspar. Thus, it does not seem likely that more than 10,000 tons of feldspar could be recovered by hand methods as a product of No. 1 grade from the 21,500 tons of medium-grade feldspar-bearing pegmatite estimated to be present to a depth of 30 feet, even though the same mass of rock probably would yield nearly 20,000 tons of No. 2 grade material if it were carefully mined and then shipped without further sorting.

The third commercial unit in the pegmatite, shown as low grade in Plate XX, contains too much intimately mixed quartz and other impurities to yield a No. 1 product by hand cobbing. Although material similar to this is marketed as No. 3 and even as No. 2 grade feldspar in some eastern states, this deposit lies so far from centers of demand that the lower grades of feldspar derived from it probably could not compete successfully under current market conditions. Substantial reserves of higher-quality material seem to be present on the property, however, as the inner units of the pegmatite body probably extend to depths considerably greater than the 30 feet assumed in the foregoing calculations of tonnage.

#### OUTPOST MINE

The Outpost feldspar mine (11, Pl. I) lies near the west end of a prominent ridge in the NW  $\frac{1}{4}$  of the NE  $\frac{1}{4}$  of sec. 3, T. 7 N., R. 3 W. It was worked for bismuth minerals during 1947 and 1948 by the owners, Earl F. Anderson and Sidney B. Anderson of Mesa, and in 1947 the deposit was explored for high-grade feldspar by the Whitehall Corporation of Keene, New Hampshire. Production to date includes approximately 12 tons of bismuth minerals and a 1,500-ton stockpile of feldspar.

The workings comprise the bench-like Main cut, which is 90 feet long, 35 feet wide, and about 20 feet deep at the face; the smaller Bismuth cut and appended 20-foot incline 60 feet to the east; and several irregular trenches, pits, and cuts higher on the slope to the south and east (Pl. XXI). Much of the mine area has been stripped with a bulldozer, and the rocks are unusually well exposed.

The pegmatite body is a large, thick pod, the uppermost parts of which have been laid bare by erosion on the north slope of the ridge. This pod trends north to north-northeast, appears to

dip steeply east, and plunges north-northeast at a moderate angle. It is curved in plan, and its western margin is broadly convex as exposed on the ridge and on the slope to the south (Pls. XXI, XXII). The north, or crestal, part of the pod is largely concealed by dump material, but it appears to split into two sub-parallel prongs that are 15 feet to 70 feet thick immediately north of the mine area.

The country rock is mainly dark-colored hornblende gneiss and quartz-hornblende-biotite gneiss and schist. Chlorite-rich and epidote-rich layers are abundant, and a few thickly tabular masses of greenish, punky-appearing intrusive rock also are present. A thick inclusion of hornblende schist and gneiss is exposed immediately east of the Main cut, and a somewhat larger, more elongate inclusion appears at the southwest end of the cut (Pl. XXI). Schorl is abundant in the schists and gneisses near the pegmatite contacts. Most of the country rock is thinly foliated, and this planar structure trends east and dips steeply north.

The thin border zone of the pegmatite body is fine to medium grained, and consists mainly of quartz with subordinate albite, perthite, schorl, muscovite, and biotite. It encloses a wall zone that is 2 inches to 16 feet thick, and has an average thickness of about 3 feet. This zone is chiefly a medium- to coarse-grained aggregate of quartz, albite, perthite, muscovite, and schorl. Much of the quartz, the principal constituent, is albitized along fractures. Muscovite and biotite are present in small quantities near contacts with the wallrock. As traced inward toward the center of the pegmatite body, the wall zone coarsens gradually and contains increasing amounts of potash feldspar as scattered anhedral to subhedral crystals. The proportions of schorl, quartz, and albite decrease correspondingly, although albite is locally abundant along the eastern margin of the dike.

The outer intermediate zone, mainly a coarse-grained aggregate of perthite with subordinate quartz and minor albite and muscovite, ranges in outcrop breadth from less than an inch to about 55 feet, but its true thickness probably is nowhere greater than 15 feet. Pod-like concentrations of muscovite, in ½-inch to 4-inch books, are scattered through this unit; one of these is well exposed in a bench-like cut that lies a short distance south of the Bismuth cut (Pl. XXI).

The inner part of the pegmatite body comprises an inner intermediate zone that is rich in blocky perthite, and a segmented core of massive quartz. The intermediate zone is arch-like in form, and is thickest on the crest of the core; it thus is most broadly exposed on the northerly slope of the ridge. The perthite is white to pale flesh colored, and occurs in very coarse-grained aggregates that contain little other material.

The quartz core is unusually large with respect to the other zones. It forms irregular masses, the largest of which is about 80 feet wide and extends southward from the ridge crest for a distance of at least 175 feet. A smaller, highly irregular segment

is exposed in and adjacent to the Main cut, and numerous pods 2 inches to 18 feet in maximum dimension are scattered on the hill slope to the south and east (Pl. XXI). Some of these may be projections from one or more larger core segments that lie only a few feet beneath the surface.

The outer parts of the quartz masses contain veinlets of sugary albite and larger, more equidimensional aggregates of cleavelandite in crystals ¼ inch to 1½ inches long. Cleavelandite also forms scattered rosettes and masses that are cauliflower-like in form. These range in diameter from a few inches to 4½ feet, and in places are fringed by, or intergrown with, aggregates of muscovite books. These masses of albite are most abundant along the west side of the main core segment, where albite-rich pegmatite is shown as a separate unit on the map (Pl. XXI). Similar aggregates of cleavelandite also are scattered sparsely through parts of the perthite-rich intermediate zones.

The chief accessory species in the pegmatite are apatite, beryl, fluorite, garnet, microlite, pyrochlore, pyrite and other sulfides, schorl, and a varied assemblage of bismuth, lead, vanadium, and copper minerals. Apatite is present in the outer part of the quartz-rich units as gray to dark bluish gray crystals without clear-cut faces. Beryl occurs as small anhedral crystals in the border and wall zones, and rarely as prismatic euhedral crystals in the inner parts of the inner intermediate zone. A few of these crystals extend into adjacent masses of quartz. Most of the beryl is pale bluish green in color. Pale greenish fluorite and salmon pink to orange-red spessartite are scattered through parts of the outer zones, chiefly as tiny crystals that are associated with schorl. They also form a few much larger crystals in the central part of the dike.

Sulfide minerals, chiefly pyrite and pyrrhotite, are scattered irregularly through the inner units, and are similar in distribution to the sulfides in the Picacho View pegmatite. Local clusters of these crystals have imparted a considerable stain to the adjacent feldspar masses in the zone of weathering. Pyrochlore and microlite are present as tiny, highly lustrous, olive green to dark brown and black crystals, principally in the intermediate zones and adjacent parts of the wall zone. These minerals are widespread, but individual crystals are inconspicuous and nowhere constitute more than 0.1 per cent of the pegmatite in which they occur.

Bismutite and other bismuth minerals are locally abundant in brecciated and sheared quartz-rich pegmatite that is capped by a 2-foot to 9-foot layer of partly albitized wall-zone pegmatite in and near the Bismuth cut. They form veinlets and stockworks in the quartz, and also occur as scattered irregular masses 2 inches to 7 feet in diameter. The bismutite is canary yellow, yellowish green, and greenish gray, and associated with it are small aggregates of finely crystalline, light gray beyerite. Scattered through both minerals are tiny flakes of native bismuth. Dark masses of bismuthinite form the cores of several large



aggregates of bismutite crystals, and probably are hypogene.

Well formed pyramidal crystals of honey yellow to very dark brown cassiterite, some as much as an inch in diameter, are scattered through the earthy masses of bismutite, and are extensively fractured and veined by both bismutite and beyerite. The bismuth minerals are themselves transected by fracture-controlled veinlets that contain wulfenite, vanadinite, pyromorphite, mimetite, anglesite, cerussite, chrysocola, cuprite, and fluorite. Most of these minerals form small, sharply faced crystals. Tiny flakes of native silver and molybdenite are disseminated through some masses of bismutite and beyerite.

The Outpost pegmatite offers greatest commercial promise as a source of potash feldspar. The intermediate zones, which are very rich in coarse perthite, would yield a hand-sorted product of excellent quality. As shown in Plate XXII, the most readily recoverable high-grade feldspar occurs in the inner intermediate zone. This unit is best exposed on the slope southeast of the Main cut, where it surrounds some quartz core segments and presumably forms a blanket over other, more extensive parts of the core.

The minable rock exposed in the stripped area between the Main cut and the east wall of the dike contains about 17 per cent of core quartz, as determined from north-south linear traverses spaced 5 feet apart. This is in essential agreement with a quantitative comparison of the respective outcrop areas of the two units as shown on the map (Pl. XXI). If allowance is made for the masses of quartz and for those parts of the intermediate zone that contain objectionable quantities of muscovite, albite, or interstitial quartz, a reserve of approximately 6,800 tons of high-grade potash feldspar, recoverable by hand sorting, is indicated to a depth of 10 feet. Total reserves in the deposit undoubtedly are much larger, as the coarse feldspar-bearing rock probably extends downward along the flanks of the pegmatite body, as well as northward and downward along its crest.

#### OUTPOST EXTENSION PROSPECT

The Outpost Extension pegmatite (12, Pl. I) is exposed on both sides of San Domingo Wash about 1,200 feet north-northeast of the Outpost mine. It is a cross-cutting mass that trends east-northeast and plunges in the same direction at low to moderate angles. It may be arch-like in section, as suggested by exposures on the southwest side of the wash. Here the dike, which is 25 feet to 35 feet thick, forms a broad hood over a mass of dark gray schist and pink to gray quartzite. This mass of country rock crops out for only a short distance above the level of the wash, and might be an inclusion or the tip of a large, upward projecting septum.

The border zone of the pegmatite body is 2 inches to 14 inches thick, and is a fine- to medium-grained aggregate of quartz, albite, perthite, and schorl. It grades inward into distinctly coarser-

grained perthite—albite pegmatite that contains subordinate quartz. The central part of the dike is mainly coarse, blocky perthite, with scattered pods of massive quartz. Some of the quartz masses are relatively continuous, and are as much as 50 feet in maximum dimension.

Albite is unusually abundant, particularly in the exposure along the edge of the wash and south of the wallrock mass noted above. The mineral occurs in the coarse perthite and quartz as large, platy crystals, and elsewhere as compact, lustrous aggregates of small, tabular, white to pale green crystals. The central parts of the dike are cut by 1-inch to 4-inch fracture-filling stringers of very fine-grained, compact, pale green muscovite.

The part of the pegmatite body exposed on the east side of the wash contains a large core of massive quartz, which is locally sheared and thinly veined with copper, lead, zinc, and bismuth minerals. The mineralogy is somewhat similar to that of the rock mined from the Bismuth cut at the Outpost deposit. The quartz core is flanked by pegmatite rich in large, subhedral crystals of perthite.

#### FRICTION MINE

The Friction feldspar mine (13, Pl. I), on the east side of a prominent ridge in the SE  $\frac{1}{4}$  of the SE  $\frac{1}{4}$  of sec. 34, T. 8 N., R. 3 W., lies near the end of a well defined belt of abundant pegmatites that can be traced for at least  $\frac{1}{2}$  mile to the southwest. The deposit has been worked in a bench-like cut about 100 feet long, 30 feet wide, and 15 feet high at the face, and also is exposed in parts of a stripped area above the cut to the north and northwest.

The pegmatite body appears to be a large, irregular lens, the south margin of which is concealed on the slope below the Main cut (Pl. XXIII). It is elongate in an east-southeasterly direction, and may have a general dip to the southwest. All observed dips are moderate to steep, but few contacts are exposed. Northwest of the cut the pegmatite body splits into two north- to northeast-trending prongs, which are separated by about 25 feet of thinly foliated quartz-mica schist. This country-rock septum appears to taper downward. Similar irregularities in the pegmatite-wallrock contacts are exposed on the lower slope east of the cut.

A thin zone of quartz—albite—schorl—perthite pegmatite forms the border of the lens, and grades inward into a coarse-grained, perthite-rich wall zone. The intermediate zone, by far the largest unit in the pegmatite body, consists of coarse- to very coarse-grained blocky perthite, with subordinate quartz that occurs both interstitially and as scattered irregular masses that are 2 inches to 13 inches in maximum dimension. The core comprises numerous irregular segments of very coarse-grained anhedral quartz, the largest of which has an exposed length of 11 feet. Most of the pegmatite that appears on the face of the open cut represents the inner part of the intermediate zone. Here the coarse

perthite is virtually free from interstitial quartz, but massive quartz is present as core segments, which form 5 per cent to 25 per cent of the rock.

In many places the pegmatite is transected by numerous tiny, irregular veinlets of sugary quartz, and by even thinner veinlets of fine-grained, waxy, yellowish green muscovite. Some prisms and stubby, rounded crystals of schorl are concentrated along fractures, and others are scattered irregularly through the rock. Garnet is a rare constituent of the outer zones, and a few small, tabular crystals of columbite occur within and adjacent to the large quartz masses in the inner part of the pegmatite body.

The deposit has some promise as a source of high-quality potash feldspar. Little interstitial quartz and mica are present in the part of the perthite-rich intermediate zone that is best exposed in and above the Main cut, where an average of approximately 18 per cent of coarse quartz does occur in the form of core segments. This quartz could be removed by hand cobbing, and about 400 tons of commercial feldspar could be recovered from the zone to a depth of 20 feet. The reserves of high-grade material might well be considerably greater than this, however, as the inner part of the intermediate zone almost certainly extends to greater depths. Moreover, abundant medium-grade feldspar is present in the much more extensive outer parts of the intermediate zone, and reserves of such material that could be recoverable by hand sorting probably amount to at least 500 tons per 10 feet of depth in the pegmatite body.

#### MIDNIGHT OWL (LITHIA KING) MINE

The Midnight Owl pegmatites (18, Pl. I) are in the northeastern part of the district, a short distance north of the divide between the Trilby Wash and Buckhorn Wash drainages, and lie in the north half of the NW  $\frac{1}{4}$  of sec. 31, T. 8 N., R. 2 W. They are exposed along the steep north slope of Independence Gulch, and can be reached via San Domingo Wash or Trilby Wash over ungraded truck roads. Since the summer of 1950, two of the deposits have been worked for beryllium, lithium, and columbium-tantalum minerals by the owners, Earl F. Anderson and Sidney B. Anderson of Mesa.

Several pegmatite dikes are exposed in the mine area, where they form a belt that trends nearly due east. Though broadly tabular, they are very irregular in detail, and bulges, thick, stubby projections, and long, thin, branches are common (Pl. XXIV). The principal dike trends east, but its component segments and major branches are elongate in northeasterly, easterly, and southeasterly directions. It terminates westward in a very large bulge that measures 80 by 140 feet in its nearly rectangular outcrop plan, and a slightly smaller bulge marks the junction of major branches in the eastern part of the mine area (Pl. XXIV). In the central part of the area is a third bulge, 90 feet long and about 40 feet in outcrop breadth, and from it major branches extend southward and northwestward. Between bulges

the main dike is 15 feet to 25 feet in outcrop breadth. Most observed contacts between pegmatite and country rock are steeply inclined, but gentle to moderate dips appear along the margins of the major bulges (Pl. XXIV).

Nearly all of the mining has been done in the thick eastern and western bulges of the main pegmatite body. Open-cut methods have been employed thus far. The irregular Upper cut, in the northeast part of the west bulge, is 40 by 50 feet in plan and 25 feet in maximum depth. The Lower cut, about 250 feet to the east, is a slightly smaller opening in the central part of the east bulge (Pls. XV, XXIV).

The country rock in the mine area is mainly a dark gray quartz-hornblende-mica gneiss, in which a well defined foliation trends northeast and dips steeply northwest through most of the mine area. Exposed on the hillside immediately west of the main pegmatite body are numerous thick layers of silvery gray quartz-muscovite schist that contains scattered metacrysts of garnet, chloritoid, and altered staurolite. Schorl is locally abundant in both of these rock types near the pegmatite contacts. The schist and gneiss occur as inclusions and septa in most of the pegmatite dikes, and are particularly abundant near the margins of some bulges. A large septum of schist is exposed in the northwest part of the Upper cut, and several wallrock inclusions have been encountered during the course of mining in the Lower cut (Pl. XXIV). Two tabular masses, 3 feet in average thickness, of greenish gray, punky appearing rock may be post-pegmatite dikes of intermediate to basic composition.

The border zone of the main pegmatite body and its principal offshoots is a fine- to medium-grained aggregate of quartz and albite, with subordinate perthite, schorl, apatite, muscovite, and beryl. It is particularly well exposed in the Upper cut and on the lower hill slope to the southwest of this cut, as well as at the north end of the Lower cut.

The wall zone is similar in mineralogy to the border zone, but contains a higher proportion of potash feldspar and is much coarser grained. It ranges in thickness from a knife edge to at least 20 feet, with an average of about 3 feet. Most of this outer-zone pegmatite is readily recognized, even in areas of few outcrops, by concentrations of schorl, which form dark-colored crystals as much as 8 inches long and locally constitute more than half of the rock. Some of these crystals are grouped in aggregates 5 inches to 12 inches in diameter, but most are scattered irregularly as individuals, or are intergrown with quartz in crudely graphic pattern.

Apatite forms rough, thickly tabular crystals in much of the wall-zone pegmatite. The largest of these are very dark green, and some of them are marked by outer rims of distinctly lighter color. Beryl occurs as scattered anhedral crystals  $\frac{1}{8}$  inch to  $3\frac{1}{2}$  inches in maximum dimension. It is pale green to white, and in places constitutes as much as 40 per cent of the rock. Biotite and muscovite are locally abundant in both wall and border

zones, especially within and adjacent to thin wisps of partly digested country rock.

The outer intermediate zone is a coarse- to very coarse-grained, granitoid aggregate of flesh-colored perthite and gray quartz, with subordinate spodumene, albite, and schorl. Less common constituents, in general distributed irregularly through the rock, include muscovite, lepidolite, beryl, and amblygonite. This zone is fairly continuous in and near the main pegmatite bulges, where it is 5 feet to 30 feet thick. It is the chief unit that has been mined in the Upper cut (Pl. XXIV), where spodumene and a little amblygonite have been recovered. The spodumene is pale bluish, pinkish, and dark pinkish gray, and forms wedge-shaped crystals less than 2 inches long. These commonly are fringed with albite, and in places have been altered to very fine-grained, dense, waxy-appearing aggregates of muscovite that are pale yellow to greenish gray.

As traced in a direction away from the walls in the eastern parts of the main dike, the outer intermediate zone coarsens markedly and grades into another intermediate zone that contains less spodumene and more perthite. This coarse- to very coarse-grained unit varies considerably in composition from place to place, but in general consists of perthite and quartz, with subordinate albite and muscovite, and minor spodumene and schorl. It is well exposed on a small ridge about 25 feet southwest of the Lower cut, and constitutes the major part of the exposed pegmatite in the central bulge (Pl. XXIV). Although it contains some widely scattered plates and laths of spodumene, this zone seems to be analogous in position and relative age to the outer part of the spodumene-free perthite-quartz zone that appears as a very thick, curving lens in the west bulge (Pl. XXIV).

The innermost zones of the two main bulges differ more markedly, as shown in Table 6. In the west bulge the perthite-quartz intermediate zone grades inward into a hood-like unit of massive quartz, and this unit in turn grades into the innermost intermediate zone, which consists of massive quartz with very large, elongate crystals of spodumene (Pl. XXIV). The core, which is exposed on the ridge immediately west of the open cut, is very coarse-grained quartz-amblygonite pegmatite.

The lithium minerals in these innermost zones form some very large crystals. Many of the spodumene logs and laths are at least 3 feet long, and a few are as much as 11 feet long and 10 by 18 inches in section. Most of these crystals are partly altered, and range in color from light gray through pinkish and bluish gray to very dark gray. Under the microscope, however, many of them appear surprisingly fresh, although mica and clay minerals are present along numerous closely spaced fractures and cleavage planes.

Some of the amblygonite in the core forms rough, nearly equidimensional masses 12 inches or less in diameter, and many of these show crude but distinct crystal form. Other masses are much larger, and one unusually large pod, 20 feet in maximum

TABLE 6.—GENERAL CORRELATION OF EXPOSED ZONES IN MAJOR BULGES OF MIDNIGHT OWL PEGMATITE BODY

Zone	General texture	West bulge	Central bulge	East bulge
Core		Quartz - amblygonite pegmatite		Quartz - spodumene - perthite pegmatite
		Quartz - spodumene pegmatite	Quartz - spodumene pegmatite	Perthite - quartz - albite - spodumene pegmatite, with beryl, columbite-tantalite, lepidolite, and phosphate minerals
Intermediate zones	Very coarse grained, non-granitoid	Massive quartz	Perthite - quartz pegmatite, with local pods of massive quartz	
		Perthite - quartz pegmatite		Perthite - quartz - albite - muscovite pegmatite, with minor spodumene and schorl
			Perthite - quartz - spodumene - albite pegmatite, with minor schorl, micas, beryl, and amblygonite	
Wall zone	Medium to coarse grained, granitoid	Perthite - quartz - albite pegmatite, with some schorl, micas, and beryl		
Border zone	Fine to medium grained, granitoid	Quartz - albite - schorl - perthite pegmatite		

exposed dimension, appears to be an aggregate of crystals 3 inches to more than 4 feet in diameter. Associated with the spodumene and amblygonite are individual crystals and coarse aggregates of lepidolite and schorl. Much of the lepidolite occurs with cleavelandite, and the distribution of these two minerals is clearly controlled by fractures in the host quartz, spodumene, and amblygonite.

In the east bulge the second intermediate zone grades inward into a thick, lens-like zone of perthite-quartz-albite-spodumene pegmatite that also contains amblygonite, apatite, beryl, columbite-tantalite, lepidolite, lithiophilite-triphyllite, and spessartite. This unit in turn grades into the innermost exposed zone, which consists of dark-colored massive quartz, coarse lath spodumene, and minor blocky perthite. Some albite is also present as interstitial aggregates, irregular veinlets, and locally as prominent stockworks in the quartz. This zone probably corresponds in position to the inner intermediate zone of the west bulge (Pl. XXIV, Table 6), and hence further exploration of

the east bulge might well reveal a core of quartz—amblygonite pegmatite.

The spodumene in the two inner units of the east bulge occurs typically as a mesh of lath-shaped and log-shaped crystals, most of which are chalky and considerably altered. Some are replaced pseudomorphically by lepidolite, pink muscovite, and albite. Interstitial to the spodumene crystals are very coarse-grained quartz and perthite, as well as cleavelandite, sugary albite, dark bluish gray apatite, white to pale greenish blue amblygonite, white to pale yellowish green beryl in anhedral crystals  $\frac{1}{2}$  inch to 11 inches in maximum dimension, thinly tabular to stubby crystals of columbite-tantalite as much as 5 inches in diameter, and scattered but locally abundant prisms of schorl. Golden brown to wine-colored euhedral crystals of spessartite are scattered irregularly through the rock. Amblygonite and apatite are most closely associated with the spodumene, and some flesh-colored lithiophilite-triphyllite appears as large, irregular groups of crystals that are stained by manganese oxides. Bismutite and other bismuth minerals are present as fracture fillings and small, pod-like masses, especially in the quartz-rich parts of the zones.

Most of the lithiophilite-triphyllite forms crudely faced crystals  $\frac{1}{2}$  inch to 5 inches in diameter, and some clusters of such individuals are as much as 24 inches in maximum dimension. All the crystals thus far exposed are thickly encrusted with manganese oxides, which also stain the adjacent crystals of quartz, feldspar, spodumene, and muscovite. Needle-like crystals of purpurite and strengite form felted masses that line tiny vugs and open fractures in the manganese oxides, and they also occur with stewartite along fractures in the lithiophilite-triphyllite.

The west bulge has been mined for spodumene, and in addition is a potential source of commercial amblygonite and beryl. At least 1,800 tons of pegmatite that contains approximately 8 per cent of coarse-grained spodumene appears to be present to a depth of about 30 feet, and the reserves may prove to be much greater when the vertical dimensions of the intermediate zones this and the central bulge, and in at least three exposures with cent to 40 per cent of the border zone and wall zone in both this and the central bulge, and in at least three exposures with areas of 40 square feet or more this mineral forms approximately 6 per cent of the rock. Nearly all the crystals are too small for recovery by hand sorting.

The east bulge has been worked for spodumene, beryl, and columbite-tantalite. The rock thus far mined has contained an average of approximately 6 per cent of spodumene and 1.1 per cent of beryl recoverable by hand sorting. This intermediate-zone beryl is much coarser than the wall-zone crystals in the other parts of the dike. Although the spodumene-beryl-columbite ore is well exposed in the 12- by 20-foot face of the Lower cut, exposures beyond the cut to the west and southwest are so poor,

and the general structure of the dike is so imperfectly known, that no meaningful estimate of reserves can be made at the present time.

#### INDEPENDENCE PROSPECTS

Additional deposits of spodumene, amblygonite, and beryl occur south of the Midnight Owl workings, chiefly in two pegmatite dikes that are exposed high on the opposite side of the canyon (19, Pl. I). These dikes, which lie on the Independence claim, are very irregular and in general seem to be thinner than those on the Midnight Owl property.

Neither of the dikes is well exposed for its entire length, but both plainly contain discontinuous, beryl-bearing border zones, as well as lens-shaped, lithium-bearing inner zones. The border zones and adjacent parts of the wall zones are medium- to coarse-grained aggregates of perthite, plagioclase, and quartz, with subordinate beryl, apatite, and schorl. The beryl is anhedral, and few of the crystals are more than 2 inches in maximum dimension.

Spodumene and a little amblygonite occur in quartz-rich intermediate zones and segments of the core, where they are associated with scattered coarse crystals of perthite and with irregular aggregates of albite and lepidolite. A few pods of "burr rock," comprising fine-grained to medium-grained book muscovite in massive quartz, are scattered through the inner parts of both dikes. Some of this rock also contains a little spodumene and fine-grained albite.

#### LONG DIKE MINE

A very large, mica-bearing pegmatite dike crops out boldly a short distance north of the Midnight Owl workings, and extends across the line between secs. 30 and 31, T. 8 N., R. 2 W. A thinner, juxtaposed dike has been mined on a small scale for scrap muscovite by Earl F. Anderson of Mesa, mainly in an open cut near the bottom of a canyon that drains eastward into Independence Gulch (20, Pl. I). This cut is 30 feet long, 15 to 18 feet wide, and its 20-foot face is being advanced along the base of a high, nearly vertical cliff. Some of the mined material has been trucked about 5 miles to a small mill in San Domingo Wash, and some has been hauled about 50 miles to Aguila for processing.

The large dike is 15 feet to 50 feet thick, with an average thickness of about 25 feet, and is traceable for a distance of at least 1,800 feet along the strike. It is somewhat sinuous in plan, but in general trends N. 65° E. and dips 55° to 70° NNW. It is enclosed by greenstone and by amphibole schist and quartz-biotite schist in which a well marked foliation trends north-northeast and dips moderately to steeply west-northwest. Some layers of the country rock are impregnated with large amounts of muscovite, especially along and near contacts with the pegmatite.

Most of the large dike is a medium- to coarse-grained aggregate of perthite, quartz, plagioclase, and muscovite. Irregular intermediate-zone masses of graphic granite are common in the central parts of the dike, as are several pods of massive quartz. The pods are 6 inches to 10 feet in maximum dimension, and probably are segments of a discontinuous core. Some of them are studded with small but thick books of muscovite, and such masses of "burr rock" have been prospected for mica in several places. Accessory minerals in the pegmatite include garnet, schorl, apatite, and rare beryl. Beryl and columbite-tantalite also are present in tabular masses of quartz, 6 inches to 3 feet thick, that transect the outer zones of the dike at several places.

The smaller, mica-rich dike is about 10 feet thick, and diverges in an east-southeasterly direction from the main dike at the canyon bottom. It adjoins the main dike as traced southwestward from the point of junction, but tapers out approximately 25 feet beyond the open cut. The contact between the two dikes is smooth in detail, but some broad fluting is visible in the walls of the cut. A small fault, also exposed in the cut, displaces the main dike about 2 feet, but evidently antedates the other, mica-rich dike.

The smaller dike is mainly a fine- to medium-grained aggregate of albite, perthite, quartz, and very abundant muscovite, with a discontinuous border zone of quartz—muscovite "burr rock." All the mica occurs as crinkled, ruled, sheared, and torn books of green to yellowish green color, and most of these books are tightly intergrown. The mica content for the entire thickness of the dike ranges along the strike from 30 per cent to 80 per cent, and the average is nearly 40 per cent. The total tonnage of such pegmatite available for mining probably is not very large, however, as the pegmatite appears to pinch out not far beyond the cut.

#### NEW LOOKOUT PROSPECTS

Several muscovite-bearing pegmatite dikes have been extensively prospected on the slopes and ridges west of the Midnight Owl mine. These dikes (21, Pl. I) consist mainly of medium- to coarse-grained perthite and quartz, with widely scattered sugary albite. Small books of muscovite are abundant in the border zones, and larger books fringe pods of massive quartz in the central parts of the dikes. Some muscovite also occurs within the quartz pods to form "burr rock." None of these deposits contains as high a proportion of muscovite as the small dike that has been worked at the Long Dike mine.

#### LONE GIANT PROSPECT

The lithium-bearing Lone Giant dike (22, Pl. I) is exposed on the walls of Independence Gulch, about 2,800 feet east of the Midnight Owl mine, and lies in the SE  $\frac{1}{4}$  of sec. 30, T. 8 N., R. 2 E. This dike dips steeply, trends north, and is traceable

for a distance of several hundred feet along its strike. It appears to be 4 feet to 25 feet thick.

The dike comprises a fine- to medium-grained quartz—albite—perthite—schorl border zone, a coarser-grained wall zone of similar composition but with a higher proportion of perthite, an outer intermediate zone rich in coarse, blocky perthite, an inner intermediate zone of perthite, quartz, and lath spodumene, and a discontinuous core of quartz—amblygonite pegmatite. In general these zones are lithologically similar to those in the thickest parts of the Midnight Owl dikes.

Beryl occurs both as small, anhedral masses in the outer zones and as much larger, anhedral to subhedral crystals in the spodumene-bearing intermediate zone. The coarser beryl commonly is associated with tabular crystals of columbite. Lepidolite, albite, and some muscovite form scattered fine-grained aggregates in the inner part of the dike.

## SERVICES OFFERED BY THE ARIZONA BUREAU OF MINES

(Continued from inside front cover)

3. Geologic investigations of mining districts and counties and the making of topographic and geologic maps and reports. In cooperation with the United States Geological Survey a large-scale base map, a reconnaissance geologic map, and a topographic map (100-meter contours) of the entire State have been published. Geologic reports on various mineral resources of the State are prepared.

4. The Bureau provides an ore-testing service for ores originating within the State of Arizona. Full details will be furnished on request.

5. Semitechnical meetings with miners and prospectors are held throughout the State.

6. The collection and dissemination of statistics relating to the mineral industries of the State.

7. The collecting and filing of items regarding Arizona mines and minerals from Arizona newspapers and technical periodicals.

### MAPS OF ARIZONA

The Arizona Bureau of Mines now has prepared for distribution the following maps of the State:

A. Base Map of Arizona on a scale of about 17 miles to the inch. This map is strictly geographic, indicating towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, revised to 1939. It is printed in black on one sheet 22x26 inches and sells for 30c.

B. Topographic Map of Arizona in one sheet 42x54 inches, on a scale of about 8 miles to the inch. It conveys all of the information given by the Base Map and, in addition, shows topography and highways. The topography is indicated by contour lines of 100-meter interval. A table for converting meters to feet is printed on the map. This map was issued in 1933 and revised as to highways in 1946. It is sold for \$3.00.

C. Geologic Map of Arizona in one sheet of many colors. It was issued in 1924 on the same scale as the Topographic Map, but is now out of print, and its lithographic plates are worn beyond repair. The Geologic Map is available for inspection at the office of the Arizona Bureau of Mines on the University campus and at the office of the Arizona Department of Mineral Resources in Phoenix.

The Bureau is prepared to supply sets of 44 Kodachrome slides, 2x2 inches in size, covering the entire map. The slides may be used with either a low-cost pocket viewer or a projector. The price of the set is \$9.00 which includes mailing charges.

D. Metallic Mineral Map of Arizona, 25x27 inches. This map consists of a red overprint made on Map A, and shows the principal known localities of metallic minerals by means of representative symbols. It also gives the value of metal production for the major districts and for the State. Roads are indicated. This map was revised in May, 1946, and sells for 35c.

E. Nonmetallic Mineral Map of Arizona, 25x27 inches, similar to Map D but devoted to nonmetallic minerals. This map sells for 35c.

F. Map of Arizona Mining Districts, 25x27 inches. This map consists of a red overprint made on Map A and shows the principal mining districts or mining localities by means of numerals and index. Roads are also indicated. This map is sold for 35c.

G. Base Map of Arizona, 42x54 inches, similar to Map A but on a scale of about 8 miles per inch. This map sells for 50c.

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All communications should be addressed and remittances made payable to the Arizona Bureau of Mines, University Station, Tucson, Arizona.