PART I

GEOLOGY OF THE PIKES PEAK GRANITE AND ASSOCIATED ORE DEPOSITS, LAKE GEORGE BERYLLIUM AREA, PARK COUNTY, COLORADO

UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

GEOLOGY OF THE PIKES PEAK GRANITE AND ASSOCIATED ORE DEPOSITS, LAKE GEORGE BERYLLIUM AREA, PARK COUNTY, COLORADO

by

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2. Geology of the Pikes Peak granite and associated ore deposits, Lake George beryllium area, Park County, Colorado, by C. C. Hawley. 283 p., 17 pl., 28 figs., 14 tables. On file in Bldg. 25, Federal Center, Denver, Colo.

3. The Bannock thrust zone, southeastern Idaho, by F. C. Armstrong. 95 p.

4. Fluid impact craters and hypervelocity--high velocity impact experiments in metals and rocks, by H. J. Moore, R. W. MacCormack, and D. E. Gault. 29 p., 5 figs., 1 table. On file in Bldg. 25, Federal Center, Denver, Colo.; 345 Middlefield Rd., Menlo Park, Calif.

5. Large uraniferous springs and associated uranium minerals, Shirley Mountains, Carbon County, Wyoming--a preliminary report, by J. D. Love. 23 p., 11 figs., 1 table. On file at Bldg. 25, Federal Center, Denver, Colo.; 345 Middlefield Rd., Menlo Park, Calif.; Wyoming Geol. Survey, University of Wyoming, Laramie, Wyo.; USGS, Francos Bldg., 2121 Carey Ave., Cheyenne, Wyo.; 437 Federal Bldg., Salt Lake City, Utah.

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GEOLOGY OF THE PIKES PEAK GRANITE AND ASSOCIATED ORE DEPOSITS, LAKE GEORGE BERYLLIUM AREA, PARK COUNTY, COLORADO

by Charles C. Hawley

Abstract

Beryllium deposits are inferred to be related to late facies of the Pikes Peak Granite in the Lake George area because of association, composition, and similar age (about 1 b. y.) of granites and deposits. The late facies of the granite form simple and zoned plutons emplaced in coarser Pikes Peak Granite and in still older Precambrian rocks. The oldest rocks, gneisses and schists of the Idaho Springs(?) Formation, were invaded successively by synkinematic sheets of granitic and mafic rocks, now gneisses, by biotite-muscovite granite and a funnel-shaped pluton of gabbro and quartz monzonite, and, finally, by Pikes Peak Granite.

The late facies of the Pikes Peak Granite of the area can be divided into three main groups, a medium-grained equigranular granite, a somewhat finer seriate porphyritic granite, and fine-grained equigranular granite. All are mainly composed of quartz, albite-oligoclase, potassic feldspar, commonly perthitic, and biotite or muscovite. Fluorite is the most common accessory. All three facies are found in the Tarryall lobe, a crudely oval pluton about four miles across, and in the smaller China Wall pluton. The small Boomer stock, host of important beryllium deposits, is composed of fine-grained granite.

Granite facies comprising most of the Tarryall lobe fall into the field of maximum concentration of chemically analyzed plutonic granites which probably represents a thermal trough in natural granite systems. The variation in composition, muscovite-biotite ratio, and texture found in the lobe appears to correlate with volatile contents, with the biotitic granular border zone of the pluton forming from a melt with relatively low volatile content. A general accumulation of volatiles in the inner part of the pluton was made possible by the early crystallization of the outer zone. Small beryllium deposits found as pipes in an intermediate zone probably formed from local concentrations of residual solutions.

The most important beryllium deposits occur as veins, pipes, and irregular bodies with fine-grained granite in local border zones on the Tarryall lobe or in the upper or outer parts of the two smaller plutons. These granites are more siliceous than most other granites; they contain late quartz, albite, and muscovite and were modified autometasomatically by abundant residual solutions. These granites formed from melts highly enriched in volatiles which locally had accumulated in the upper and outer parts of larger granite masses.

The beryllium deposits are localized by small fissures, contacts and favorable wall rocks. Most deposits consist mainly of beryl or bertrandite and typical greisen minerals, quartz, muscovite, topaz, and fluorite. The deposits are enveloped by barren greisen. Barren greisen is locally enriched in SiO_2, iron oxides, CaO, and F with respect to unaltered granite and ore greisen. The beryllium deposits are mainly composed of only five components, BeO, Al_2O_3, K_2O, H_2O or F, and SiO_2.

They probably formed under constant volume conditions, and can be examined by a phase rule governed by T, V, chemical potentials of mobile components, and concentrations of inert components. Assuming constancy of intensive terms, the maximum number of equilibrium phases is one more than the number of inert components. Number of phases found in ore bodies range from one to four, and it is inferred that from zero to three of the components BeO, Al_2O_3, and K_2O were inert. Fluorine is believed to have controlled the inert or mobile status of beryllium and aluminum.

CHAPTER I

INTRODUCTION

Most of the beryllium ores mined in the United States have consisted of scattered beryl crystals in granite pegmatites. Deposits of this type have yielded beryllium economically, but the beryl-bearing pegmatites form only a small proportion of all granite pegmatites, and the beryl within favorable pegmatites is sporadically distributed, thus offering problems in both exploration and mining. Starting at about the time of World War II and extending to the present, an intensive effort has been made to find other types of beryllium deposits which might have more favorable features; the earlier efforts by the U. S. Geological Survey to evaluate beryllium deposits of the so-called nonpegmatite type were documented by Warner and others (1959). Recently, important deposits of the nonpegmatite type have been discovered, and in several areas the beryllium deposits being explored belong to this broad class of ores (Stager, 1960; Staatz and Griffitts, 1961; Sainsbury, 1962; Evans and Dujardin, 1962; Levinson, 1962). No rigorous subdivision of the nonpegmatite beryllium ores has been proposed, but the most significant recent beryllium discoveries belong to well-recognized types of deposits, namely, contact metamorphic deposits in carbonate hosts; bedded replacement deposits in carbonate rocks, rhyolite tuffs or flows, and gneisses; low-temperature fluorite vein deposits; and high-temperature replacement deposits associated with greisened wall rocks.

Beryllium-bearing ores were discovered in the Lake George area in late 1955 by John Sager at the Boomer mine, an old prospect previously worked for silver, and prospected in various "boom" times for molybdenum, uranium, and other metals. The deposit at the Boomer mine and most of those in the surrounding area belong to the broad class of nonpegmatite deposits and specifically are beryllium-rich greisens which contain small to moderate amounts of typical greisen elements such as tin and tungsten. Beryllium-bearing greisens are common, but the deposit at the Boomer was exceptionally rich, and was the first beryllium deposit of this type to be exploited in this country. Since 1955 the deposit has yielded ore valued at more than $500,000.

Like many other greisens the deposits of the Lake George area are closely associated with intrusive acidic rocks. All known deposits are found in or very near to late facies of the Pikes Peak Granite of Precambrian age. The spatial relation of the deposits to certain members of the granite series suggested that detailed studies of both the Pikes Peak Granite and the ore deposits might furnish evidence on the manner of transition existing between an acidic magma and an ore-forming solution, and the organization and scope of this report reflects this emphasis.

Certain parts of the report are theoretical or speculative, but other parts including those on the distribution of beryllium deposits in relation to certain types of granite (p. 137-140), the mineralogy and general character of the ores (p. 142-177), discussions of mines and mine areas (p. 223-252) and the analytical data in Appendix C and throughout the report have a more practical bent, and I hope will be of interest to the prospector and mining man, as well as to the geologist.

Geography

The area known to contain beryllium deposits is centered about 8 miles northwest of Lake George, Park County, Colorado, and is mostly in T. 11S., R. 72 W. It is easily accessible from graded gravel roads leading northward from U. S. Highway 24 and southward from U. S. 285 (fig. 1). The area mapped thus far contains almost all the beryllium deposits, and is a large part of the northeast one-third of the Tarryall $7\frac{1}{2}$-minute quadrangle.

The rugged Tarryall Mountains form the northeast part of the Lake George beryllium area; a broad intermontane valley, called the Badger Flats, forms most of the rest of the area, lying between the southern part of the Tarryall range and the Puma Hills. The Puma Hills separate the area from the South Park.

The Tarryall Mountains are largely made up of Pikes Peak Granite, and in most places in the mountains outcrop is good. The Badger Flats are mainly underlain by metamorphic rocks, and outcrop ranges from poor to good depending largely on the particular type of rock underlying the area. The larger areas of surficial deposits which mask the bedrock have been mapped (plate 1), but in general thin residual cover on the Flats has not been shown. An idea of typical amounts of exposure on the Badger Flats can be gained from the outcrop map of the Boomer mine area (plate 11).

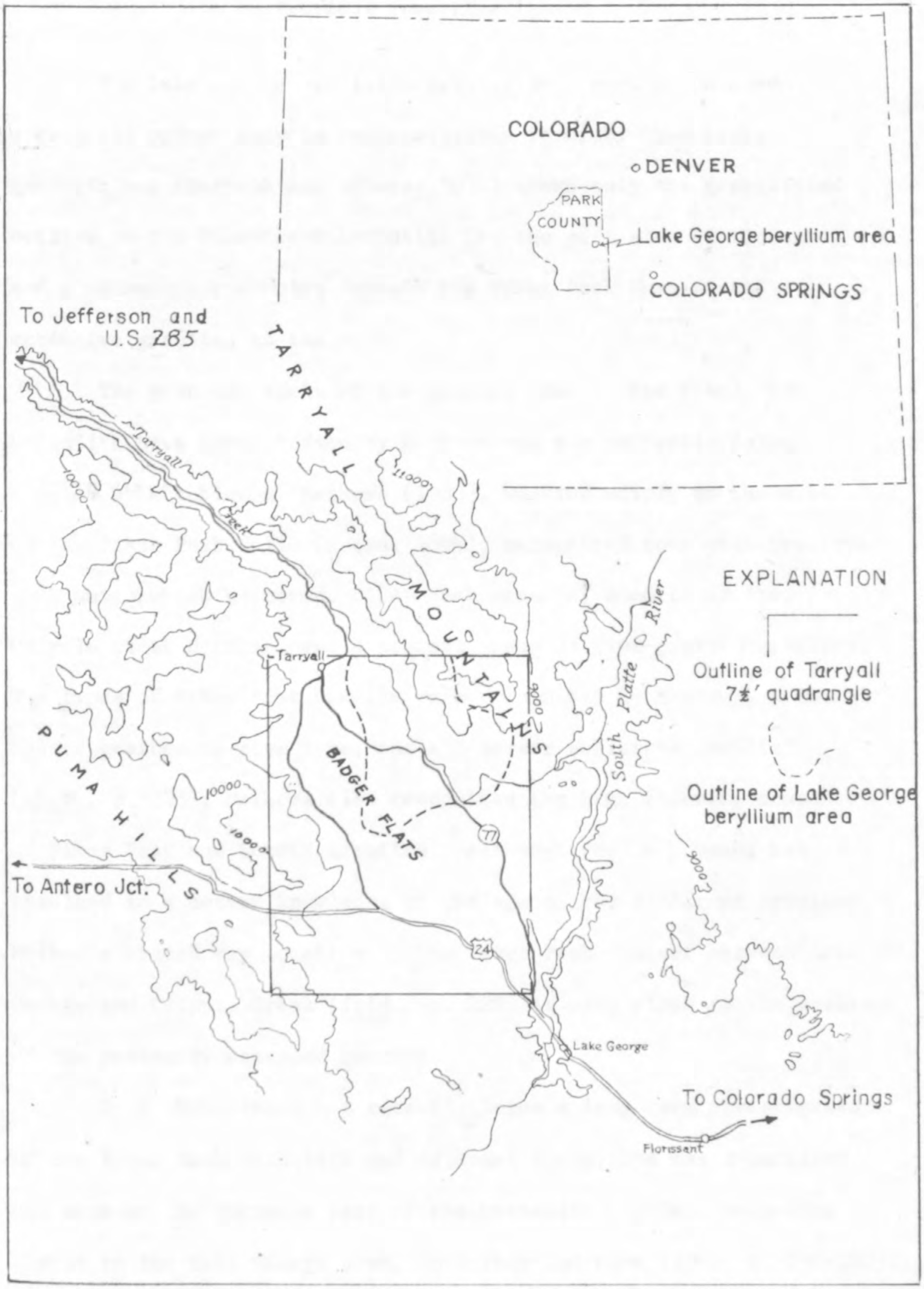

FIGURE 1. --INDEX MAP OF THE LAKE GEORGE BERYLLIUM AREA

5 0 5 Miles

Previous investigations

The Lake George beryllium area is in a part of Colorado previously mapped only in reconnaissance fashion. The state geologic map (Burbank and others, 1935) shows only the generalized outline of the Pikes Peak batholith (on the east side of the area) and a metamorphic complex between the Pikes Peak Granite and extensive granites to the west.

The granitic rocks of the general area of the Pikes Peak batholith have been studied by Mathews and are currently being studied by Hutchinson. Mathews (1900), working mainly in the area of the Pikes Peak folio (Cross, 1894), recognized four main granitic rock units which he termed Pikes Peak Granite, Summit Granite, Cripple Creek Granite, and a general group of fine-grained granites. Two types of Pikes Peak Granite were recognized by Mathews, a normal coarse-grained massive type, and a "coarser schistose granite" (ibid., p. 223); Mathews also recognized the high fluorine contents of Pikes Peak and Summit granites. Although recent mapping has resulted in a better knowledge of the age of the different granites, Mathew's sketch map location of the Pikes Peak contact between Lake George and Cripple Creek (ibid., p. 222) is very close to the position of the presently accepted contact.

R. M. Hutchinson has recently begun a long term investigation of the Pikes Peak batholith and adjacent rocks, and has summarized his work on the northern part of the batholith (1960a), extending almost to the Lake George area, in Weimer and Haun (1960, p. 170-180). Hutchinson (1960b, p. 95) has also compared certain features of the Pikes Peak Granite with those of late Precambrian granites of the Llano region, Texas, and presented pertinent data (1960c) on the age relations of certain of the rocks along the southwest edge of the batholith. Specifically he shows that Mathew's schistose "Pikes Peak Granite" is actually an older granite, and that Mathew's Cripple Creek Granite is younger rather than older than the Pikes Peak. Qureshy (1958) reports a large positive gravity anomaly about coextensive with the Pikes Peak batholith.

Very little has been published on the early prospecting activity in the area. Worcester (1919, p. 73-74) described operations at the Redskin mine, then being prospected for molybdenum, and also noted a report of molybdenite with copper minerals at the Boomer mine. Butler and Riley (1940) briefly described ore-bearing pipes of the Redskin mine area, noting a similarity with tin-bearing pipes in South Africa. Tungsten (scheelite) deposits in calc-silicate gneisses scattered through the metamorphic complex have been described by Tweto (1960, p. 1412-20).

Some of the earlier studies on the beryllium deposits were reported in an Annual Report of the Geological Survey. Hawley, Sharp, and Griffitts (1960, p. B71-73) noted major pre-mineralization faulting in the area, and Sharp and Hawley (1960, p. B73-74) described the bertrandite-bearing greisen found in some of the deposits. The occurrence of the rare beryllium mineral, euclase, at the Boomer mine and in the Redskin Gulch area was described by Sharp (1961).
W. R. Griffitts of the U. S. Geological Survey made a brief reconnaissance study of part of the area, and I have been able to use his sampling data, maps, and a manuscript report.

Very little has been written specifically about beryllium deposits of the type found in the Lake George area. Adams (1953, p. 114-117) and Holser (1953, p. 604-606) have written short summaries on vein-type beryllium deposits, and Warner and others (1959) have summarized geology, geochemistry, and extensive sampling of nonpegmatite deposits of beryllium, including a short section similar in scope to those of Adams and Holser on the vein-type beryllium deposits (ibid., p. 35). Much other pertinent data is scattered through the extensive literature on the high temperature vein deposits of tin, tungsten, and molybdenum. Since about 1957 important reports on greisens, including some beryllium-bearing types, have begun to appear in English translations of Soviet journals. A short summary on Soviet beryllium-bearing greisen deposits prepared by Beus and Sitkin, Ginzberg, and others (1958, p. 2-73) is available from the U. S. Dept. of Commerce.

Acknowledgments

The field work and early laboratory studies on the Lake George beryllium area were made as part of a study for the U.S. Geological Survey. Most of the laboratory work and the writing of this report were done at the University of Colorado under a National Science Foundation graduate fellowship.

Mr. William N. Sharp, U.S. Geological Survey, worked with me in the Lake George area in 1959 and 1960; he had primary responsibility for the geology of beryllium deposits within the main body of the Pikes Peak granite. Many people in the Lake George area aided in the field work. Data on the beryllium deposits were furnished by D. H. Peaker and Harlan Foresyth of the U. S. Beryllium Company, and John Wood and others of the Minerva Oil Company. Bob Beal, Jim Donnell, and the Late William Van Couten, miners and excellent observers, pointed out many interesting and significant features of the deposits. Mr. H. H. Moses and sons and Jack Smith furnished a camp site, and described the geography and early history of the area.

I particularly thank Professors R. M. Honea and W. A. Braddock, University of Colorado Geology Department, who introduced me to many of the aspects of granites, geochemistry, and ore deposits discussed here. I also wish to acknowledge aid received from R. B. Taylor, U.S. Geological Survey, in preparation of photomicrographs.

Analyses--methods and analysts

All thin sections, polished sections, and rock analyses were made in the laboratories of the U. S. Geological Survey at Denver, Colorado. Twenty-seven rocks, mainly granites and greisens, were analyzed (Standard Rock Analyses) in the Rock Analysis Laboratory by Margaret C. Lemon and Paula M. Buschmann under the supervision of Lee C. Peck. Many samples were analyzed for beryllium by the morin-fluorescent method by L. F. Rader or by an activation method by Wayne Mountjoy. Semiquantitative spectrographic analyses on many samples were made by J. C. Hamilton and P. R. Barnett. The spectrographic data are reported according to the system outlined by Myers, Havens, and Dunton (1961). In this system each power of 10 (in weight percent of a particular element) is subdivided into three equal geometric ranges, and the number or concentration reported is the geometric midpoint of the range, as for example:

Order to be subdivided (%)	Ranges of the division (%)	Midpoints reported (%)
	.046-.1	.07
.01-.1	.022-.046	.03
	.01 -.022	.015

Recently the system has been modified to a six-step breakdown, and the midpoints reported are, for example, 0.01, 0.015, 0.02, 0.03, 0.05, and 0.07. Most of the spectrographic data are reported in Appendices B and C. Averages of the spectrographic data given at several places in the text are geometric means.

Porosity and grain- and bulk-density were measured on all samples submitted for the quantitative rock analysis; about half of the samples were run by the author, the rest by David Cuningham and John Moreland of the Geological Survey.

CHAPTER II

GRANITES, GREISENS, AND THE GEOCHEMICAL CYCLE OF BERYLLIUM

A REVIEW

The association of certain types of ore deposits with greisens and acidic igneous rocks is known from several of the classic mining regions of the world, and has generally been accepted as a genetic association. Deposits with greisened wall rocks have been mined chiefly for tin or tungsten, but many of the deposits contain a variety of metals; some greisen districts are zoned and different constituents are recovered in different areas. Beryllium minerals have been noted in many greisen districts, and in the past beryllium has often been considered as a characteristic but sporadic component of the greisen type deposits.

Greisens, their description, form, and origin

Most greisens are products of high temperature rock alteration caused by fluids which must have contained fluorine or boron. A few greisens have been postulated to be igneous intrusive rocks; for example, Scrivenor (1914) proposed that a quartz-topaz greisen at Gunong Bakau in the Malay states intruded porphyritic granite, and was in turn intruded by a topaz-bearing aplite. Williams (1934a, p. 413-418; 1934b, p.323) also considered a topaz-bearing greisen as intrusive. Harker (1895, p. 144) tentatively interpreted the Grainsgill quartz-muscovite greisen as intrusive but Hitchen (1934,p. 181-182) later showed that this greisen was more likely formed by alteration. The rocks described by both Scrivenor and Williams can also be interpreted as metasomatic products, and, in general, greisens have been accepted as products of alteration by metasomatic processes.

Several rock types comprise the greisen suite. In many locales the dominant rock unit is a white to gray, granular rock composed essentially of quartz and a light-colored mica, commonly lithia-bearing; such greisens apparently may grade into nearly monomineralic muscovite greisens (White, 1940, p. 970) or quartz griesens (Lisitsina and Omel'yanenko, 1961, p. 37-38). Quartz-mica greisens characteristically contain small amounts of fluorite, topaz, and cassiterite, and in some areas these and rarely other minerals are abundant enough to characterize greisen rocks which are, however, generally associated with a dominant quartz-muscovite type. Tourmaline occurs in many but not all greisens; tourmaline-rich rocks have also been referred to as schorl-rocks or luxullianites, both names assigned from the Cornwall region of England.

Clay minerals are locally found in greisens or in extensively altered zones near greisens, but they have not generally been interpreted as primary components of the greisen mineral association; Sainsbury (1960, p. 1485-1499) has described late hypogene clay zones apparently superposed on the greisen in the Lost River district, Alaska and he notes (<u>ibid</u>., p. 1485) a general similarity in the relations of greisens and argillized zones to that found on a larger scale in Cornwall. He (<u>ibid</u>., p. 1483) further proposes that the minerals comprising the unaltered greisens form at temperatures above the temperature-stability range of the clay minerals. Using the recent data of Hemley (1959) and Carr and Fyfe (1960) this may indicate that greisens generally form above about $400^{\circ}C$. Little (1960) has estimated from fluid inclusion studies that cassiterite and related minerals in greisens have generally formed in the range of 300 to $500^{\circ}C$.

Although the greisen assemblage may lack early hypogene clay minerals, the manner of occurrence of the greisens is similar to the clay-bearing altered zones surrounding typical mesothermal ore bodies. Like these argillic rocks the greisens form envelopes around ore bodies, and are much more widely distributed than the ore. Also, as with the argillic bodies, their form is generally determined by structure. Vein and stockwork greisen deposits structurally similar to mesothermal deposits are well known (Ferguson and Bateman, 1912, p. 221-223; Beyschlag, Vogt, and Krusch, 1914, p. 425-27; and Garretty, 1953a, p. 960-961). Certain forms of deposits, such as pipe-like, seem to be especially characteristic of greisens; pipes are found at Zinnwald in the Erzgebirge (Štemprok, 1960, p. 44), some deposits in the U.S.S.R. (Govorov, 1958, p. 47, 52), and in the Transvaal, South Africa (Hall, 1932, p. 487-489). According to Hall the pipes in the Potgietersruet area are commonly about 5 by 8 feet across and have been followed downdip for as much as 2500 feet. Probably the best known pipes are those of the Australian-Tasmanian tin province. Blanchard (1947, p. 267) states that the Australian pipes range from 2 to 60 feet across and characteristically occur in granite close to its intrusive contact with overlying sedimentary rocks; other pipes are found in the adjacent sediments. The pipes in the Kingsgate district, N.S.W., described by Garretty (1953b, p. 962-65) are as much as 60 feet across and some have been followed for more than 500 feet. Many of the Australian pipes have very irregular courses.

Some of the greisen pipes are structurally controlled; in others a structural control is not obvious is present at all. Blanchard (1947, p. 270) noted that cassiterite- and wolframite-bearing pipes of the Australian province had marked fracture control, but that bismuth-bearing pipes showed no obvious control. This observation is apparently substantiated by Garretty (1953a and b, p. 956 and 965): Cassiterite-bearing pipes in the Ardlethan tinfield were structurally controlled; the bismuth-molybdenite pipes of New England (N.S.W.) were, apparently, not. Pipes in the Transvaal region, South Africa which show no marked structural control were attributed by Knyaston and Mellor (cited in Ferguson and Bateman, 1912, p. 222-23) to the rise of metal-bearing gases through practically unbroken, partly crystalline magma.

Deposits of unusual form have been described by Thomas from the Blue Tier tinfield, Tasmania (1953) as "floor deposits". The floor deposits generally occur at the contact of granite and an overlying barren granodiorite, and, in detail, below a thin pegmatite zone developed at this contact. Acording to Thomas (ibid., p. 1217):

> . . . all the pegmatite floors so far discovered are gently arched or domed with outward dips of 5^{o} to 10^{o} from the center of the arch. The tin-bearing emanations rose up vertical contraction joints, now marked by greisen veins, and being obstructed by the arch of pegmatite, or the granodiorite roof, spread into the adjacent tin granite, to form an unusual type of "blanket deposit".

The floor deposits are reminiscent of tabular deposits described by Hall from the Transvaal (1932, p. 487-488): The tabular deposits occur with greisen pipes and other forms of greisen deposits in a psuedostratified granite sheet related to the Bushveld complex. From bottom to top the granite consists of coarse porphyritic granite, miarolitic granite, markedly stratified aplite, coarse pegmatite, and granophyre. The tabular deposits occur at the base of the pegmatite. In as much as the deposits of this type characterize a vertical zone in the granite, they are also similar to vertically zoned beryllium greisen deposits described by Beus and Sitkin (1958, p. 14-15) which lie near the crests of granite cupolas and overlie albitized and weakly greisened granite.

Other areas where greisens appear to have a limited depth range are the Kiangsi region, China where Hsu (1943, p. 442, 458) reported a noticeable decrease in the intensity of greisening and mineralization with depth, and Altenberg where Dalmer (1894, p. 315) noted that workable ore occurs only in about the upper 230 meters of t he Altenberg stock. Lisitsina and Omel'yanenko (1961, p. 35) report decrease in greisening with depth at an unknown locality. The occurrence of the greisen pipes of the Australian province near low-dipping granite contacts also suggests a limited depth range for these deposits. In contrast are certain of the Cornish veins such as the Dolcoath which were followed to great depth. Even in the Cornish deposits, Dines (1933) shows that the zoning is probably largely lateral rather than vertical, and thus that the depth range of the deposits is probably not as great as previously supposed.

Although some greisens are controlled by large, through-going structures, it seems apparent that some controls are minor structures of the granites themselves and are not directly linked to external structural activity. The greisens localized by minor structures are one line of evidence which suggests a direct genetic relation between greisens and associated igneous rocks. It is also possible that in some deposits, as for example in the vertically zoned greisen domes described by Beus and Sitkin (1958), that the controls are more physical-chemical than structural; these authors (ibid, p. 37-41) emphasize that the type of structural control shown by the deposit depends on a coincidence in time of some structural activity with the metasomatic processes involved in forming the greisen.

Data on the chemical changes involved in greisening have been reported or summarized by Lindgren (1901, p. 620-625), Ferguson and Bateman (1912, p. 236-251), Takimoto (1944, p. 232-233), Sainsbury (1960, p. 1491-95), and several others. There seems to be a general tendency towards decrease in Na_2O and CaO and increase in FeO, F, and perhaps Fe_2O_3 in the greisened rocks. K_2O, Al_2O_3, and SiO_2 show variable tendencies, which apparently depend on the relative abundance of quartz, topaz, and muscovite in the greisen. The pattern, from the few districts where careful studies have been made, seems to be a slight increase in SiO_2 in initial greisenization (high SiO_2 in greisens far from a central fissure) and a general increase in Al_2O_3 and decrease in SiO_2 with increased intensity of greisenization (high Al_2O_3 and low SiO_2 in greisens close to a central fissure). The tendency towards alumina enrichment is reflected both in chemical data and in the mineralogy of zoned greisens reported by White (1940, p. 970-978), Hsu (1943, p. 456-460), and Sainsbury (1960, p. 1493). At least locally there may be a thin zone of silica enrichment between the aluminous greisens and the vein-filling (Lisitsina and Omel'yanenko, 1961, p. 37).

Govorov (1958, p. 47-55) regards silica-deficient beryllium greisens containing large amounts of topaz and diaspore as due to desilication of granites by nearby limestones, but low silica greisens also form in granites without associated carbonate rocks so the carbonates do not appear to be essential to the formation of all aluminous greisens.

Lisitsina and Omel'yanenko (1961, p. 35-41) describe zoned greisens, where a central vein zone is surrounded nearly symmetrically by quartz greisens, quartz-topaz greisens, and quartz-muscovite greisens which, in turn, grade into unaltered granite. Using a system of paragenetic analysis, and a phase rule applicable to metasomatic systems under constant external conditions (Korzhinskii, 1959, p. 63), they postulate that the zoning reflects a decreasing number of inert components towards the central zone of the greisens; in order of decreasing mobility the components of the greisen are H_2O, CO_2, F, SiO_2, MgO, CaO, Fe, Na_2O, K_2O, and Al_2O_3. The quartz greisen next to the vein-filling is essentially a one-phase system, and since Korzhinskii's modification of the phase rule gives:

$$p_{max} = c_i + 1$$

p = the number of stable minerals in an assemblage

c_i = the number of inert components

they believe that all components including Al_2O_3 are mobile in the central (quartz) greisen zone. The ore components and some of the elements leached from the greisened wall rocks are deposited in fractures in the greisen with decreased acidity of the ore solution.

In some districts skarns or tactites are apparently formed in carbonate rocks at about the same time that greisens are being formed in aluminosilicate rocks: examples include the Lost River area, Alaska (Sainsbury, 1960) and the Mt. Zeehan field, Tasmania (Edwards and others, 1953). Singewald (1912, p. 265-271) gave examples of several regions where greisens occurred near contact-metamorphic type deposits to illustrate his thesis that the tin-bearing greisens had to be considered as related genetically, at least in places, to more common types of ore deposits.

In places garnet is found as a minor component of greisens, and garnet is a major component in the bismuth-molybdenum pipes in granite described by Jack (1953, p. 968-969), so tendencies towards a tactite-like product can also exist in the aluminosilicate rocks.

Greisens have traditionally been regarded as forming pneumatolytically from gaseous fluids, however, this concept has been challenged and is probably at best only partly true. Little (1960, p. 500) determined that the fluids filling microscopic inclusions in cassiterite and related transparent minerals commonly showed liquid-like filling characteristics. That is, the common two-phase fluid inclusion (liquid-gas at ordinary temperatures) fills with rising temperature by an expansion of the liquid rather than the gas phase. Little, however, recorded many temperatures above the critical temperature of water, so the filling material should probably be considered as a dense "gas" rather than a liquid.

Some Soviet scientists (Ginzberg, 1958, p. 8-9; Beus and Sitkin, 1958, p. 37-40) believe that two interrelated stages are involved in the formation of the greisen deposits. One stage, that of albitization (or sodium metasomatism) is believed due to a gaseous fluid; the related greisenization (potassium metasomatism) is considered to be due to the condensed liquid phase. Following this view greisens are often referred to in the Soviet literature as pneumatolytic-hydrothermal deposits.

Beryllium in greisens

A survey of the literature suggests that beryllium is essentially absent in some greisen districts or provinces, is present in trace amounts in others but forms no or few discrete minerals, occurs as discrete, scattered minerals in still other regions, and, in a very few areas, is the chief ore component. Consequently there is a divergence of opinion on the significance of beryllium in the greisen cycle. From widespread mineral occurrence Beyschlag, Vogt, and Krusch (1914, p. 421) considered beryllium to be a characteristic greisen component along with Sn, Si, F, B, P, Li, U, Nb, Ta, Mo, and W. Ferguson and Bateman (1912, p. 231) listed both beryl[1] and phenakite as members of a group of minor associated minerals contrasting with the universal associates, topaz and flourite, and general associates molybdenite, wolframite, and tourmaline.

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[1]Beryllium minerals found in greisens and other ore deposits belong chiefly to silicate, aluminate, and alumino-silicate groups; compositions of relatively common beryllium minerals, beryllium minerals found in the Lake George area, and typical greisen minerals are given below:

Beryllium minerals		Typical greisen minerals	
Beryl (ideal)	$Be_3Al_2Si_6O_{18}$	Cassiterite	SnO_2
Bertrandite	$Be_4(OH)_2Si_2O_7$	Fluorite	CaF_2
Chrysoberyl	$BeAl_2O_4$	Molybdenite	MoS_2
Euclase	$BeSiAlO_4(OH)$	Muscovite (ideal)	$K_2Al_4(OH)_4Si_6Al_2O_{20}$
Helvite	$Mn_4SSi_3Be_3O_{12}$	Quartz	SiO_2
Phenakite	Be_2SiO_4	Topaz	$Al_2(F,OH)_2SiO_4$
		Tourmaline	$(Na,Ca)_5(Al,Fe,Mg,Mn,Ti)_{27}(Si,B)_{27}O_{86}(OH)_4$ (?)
		Wolframite	$(Fe, Mn)WO_4$

On the other hand in the earliest extensive geochemical investigation of beryllium, Goldschmidt and Peters (1952, p. 372) found an appreciable concentration of beryllium in only one greisen and concluded that, geochemically, beryllium was not markedly enriched in "pneumatolytic tin ores". Schröcke(1955, p. 452) on the basis of much wider sampling found no great enrichment, but did consider beryllium as a member of a sporadic trace elements group (with Ga, In, V, and Zr) contrasted with the characteristic elements (Nb, Sc, Ta, Ti, W, and, of course, Sn) of the greisens. In contrast to these views is the statement of Ginzberg (1958, p. 2) in a summary report on some greisen deposits of the U.S.S.R.: "...beryllium is sharply concentrated in the course of the development of the pneumatolytic-hydrothermal processes and is for them just as characteristic an element as are tin, tungsten, or molybdenum"; Grigoryev (1957, p. 16-30) states that the most characteristic associated minerals in the tin deposits of the Transbaykal region are albite, columbite-tantalite, topaz, beryl, tourmaline, and muscovite.

The Erzgebirge region of Czechoslovakia is perhaps an example of a province with widely dispersed beryllium. Goldschmidt and Peters (1932, p. 366-67) found appreciable beryllium only in a zinnwaldite-bearing greisen. Schröcke (1955, tables 1-8 and p. 441, 452) detected beryllium spectrographically in somewhat less than half of the Erzgebirge samples, and found evidence of a possible general enrichment only in the Geyer district where several samples contain on the order of 10 ppm beryllium. Apparently, discrete beryllium minerals must be extremely rare if present at all. The rare beryllium mineral euclase has been observed in druses in the Waldstein granite in the neighboring Fichtelgebirge tin district (Beyschlag, Vogt, and Krusch, 1914, p. 418).

Small amounts of beryllium in scattered samples from greisens in the Cornwall region, England (Goldschmidt and Peters, 1932, p. 366; Schröcke, 1955, table 9) probably also signify generally dispersed beryllium, but beryllium minerals are reported from several Cornish localities suggesting a slight tendency for enrichment in beryllium. Beryl, bertrandite, and locally phenakite have been reported from lode deposits by Hallimond (1939), Phemister (1940) and Hosking (1952, table 6) as well as from veinlets in joints and in unusual metal-bearing pegmatites. Trace amounts of beryl as an accessory mineral in the Bodmin Moor granite pluton were reported by Ghosh (1927, p. 307), and beryl occurs with topaz, smoky quartz, feldspar, mica, and tourmaline in vugs in granite from Lundy Island (McLintock and Hall, 1912, p. 296). Phenakite is reported from the geologically related tin deposits of Brittany at Villeder (Beyschlag, Vogt, and Krusch, 1914, p. 430).

A similar, scattered distribution of beryllium minerals seems also to characterize the Australian-Tasmanian tin province and the Japanese province. Beryl is reported only from the veins of the Moina district, Tasmania (Reid, 1919, p. 52, 69-70, 102-104; Elliston, 1953, p. 1196), from deposits in New South Wales (Hess and Graton, 1905, p. 169-173; Runner and Hartman, 1918, p. 32), and from unusual wolframite-bearing dikes in the Mt. Carbine wolframite district (Staff, Queensland Dept. Mines, 1953, p. 836-839). Takimoto (1944, table 8, p. 238) notes beryl as a component of only

5 out of 30 or so Japanese tin-districts. Possibly beryl is somewhat more widely distributed in the great Kiangsi tungsten-tin-molybdenum mining region of south China (Hsu, 1943, p. 451-453).

Although greisen-type deposits are not particularly abundant or productive in the United States and Canada, beryllium seems to be a rather characteristic and abundant component of many of the known greisens. Examples include the tin-bearing greisens at Winslow, Maine (Hess and Graton, 1905, p. 162-166), Irish Creek, Virginia (Ferguson, 1918, p. 8: Koschmann, Glass, and Vhay, 1942, p. 271, 281), the Seward Peninsula, Alaska (Sainsbury, 1960, p. 1482; 1962), and the greisens associated with aplitic pegmatites of the Carolina tin-spodumene belt (Kesler, 1942, p. 253-258; Griffitts, 1954). Beryl and phenakite are associated with molybdenum-bearing greisens in the Mt. Antero region, Colorado (Landes, 1934; Adams, 1953), and beryl occurs with tungsten deposits showing affinities to greisens at Bagdad, Arizona (Anderson, Scholz, and Strobell, 1955, p. 19, 79, 97), and at other localities in Arizona and New Mexico (Holser, 1953, p. 599-607; Warner and others, 1959, p. 35). Beryl is moderately abundant in the quartz-topaz-worframite veins in the Burnt Hill deposit, New Brunswick (Victor, 1957, p. 153).

A few greisens show beryllium as the major ore component and tin, tungsten, and molybdenum as minor components. Examples include some of the greisens in the Lake George district, and several deposits recently described from the U.S.S.R.: According to Ginzberg (1958, p. 5-8) so-called pneumatolytic-hydrothermal deposits of beryllium occur in granitic domes affected by "albitization, greisenization, or quartzification". On an average these deposits are reportedly larger and higher grade than Soviet pegmatite deposits; they range from 0.08 to 0.15 percent BeO compared with 0.04-0.06 percent BeO for pegmatite deposits. The Russian nonpegmatite ores have been subdivided into three main groups according to the composition of the rocks invaded by the granites. Greisens characterize the deposits formed in aluminosilicate rocks, mica-rich rocks characterize the deposits in ultrabasic hosts, and skarns and related metasomatic rock types are typical of the deposits in carbonate hosts. The Soviet deposits have also been discussed recently by Beus and Sitkin (1958, p. 13-41), and Govorov (1958, p. 47-55). Adams (1953, p. 115-116) cites some of the older data on other nonpegmatite beryllium-bearing deposits of the Soviet Union.

According to samples analyzed by Shröcke (1955, table 10), the tin-tungsten-silver ores of the Bolivian tin belt at Fabulosa, Uncia-Llallagua, Potosi, or Huanuni have no detectable beryllium. Perhaps it is significant that these deposits and their tourmalinized and sericitized hosts are mainly associated with quartz diorite to quartz monzonites rather than granites (Ahfeld, 1954, p. 18-21; Turneaure and Welker, 1947, p. 600-601).

Granite associated with greisens

Greisens are generally associated with acidic igneous rocks, and many occur with granite which is here considered to be the highly silicic calcium-poor rock which approaches the ternary system albite-orthoclase-silica in composition. The association of tin-bearing greisens with granites was the first well documented ore and igneous rock association and was pointed out specifically in 1841 by Daubrée (Singewald, 1912, p. 264). The association has been reevaluated several times; for example, by Ferguson and Bateman (1912), Westerveld (1936), and Rattigan (1960). Analyses of igneous rocks collected from various tin-greisen regions by Westerveld (1936, table 1) showed that only a Bolivian quartz porphyry departed noticeably from a granite composition; "granites" from Japanese tin-deposits (Takimoto, 1944, p. 202-210) are more calcic than any of the granites reported by Westerveld except those from Bolivia, but they are siliceous (average 72.16 percent SiO_2) and fall into the granite group as defined by Tuttle and Bowen (1958, p. 126-130) on the basis of >80 percent normative quartz, albite, and orthoclase.

Rattigan (1960, p. 1277) pointed out that it ". . . would be unreasonable to suppose that differentiation in acid magmas does not have a similar influence in controlling ore type as in basic rocks where it is more obviously displayed". An apparent example of such a control is Blanchard's observation (1947, p. 267-269) that greisen pipes containing native bismuth-molybdenite occur in coarser and less siliceous granites than do wolframite-bearing pipes which in turn occur in less siliceous granites than the tin-bearing pipes of the same region.

Differentiation may, however, be indicated by other components than SiO_2, and Rattigan (1960, p. 1278-79) has suggested that differentiation expressed by the relative concentrations of alkali and cafemic components might be more significant to the type of ore than that indicated by the silica content. The experimental studies of Tuttle and Bowen (1958) on the position of the minimum in the artificial granite system suggest that differentiation at a very late stage in the magmatic cycle with high water pressures could actually trend in the direction of decreased silica content, and with a distinct shift in relative amounts of K_2O and Na_2O.

In at least some places where greisens are associated with intermediate rocks, the intermediate rocks have been transformed metasomatically to a near granite composition. Beryl-bearing greisens described by Žabolotnaya and Novikova (1958, p. 42-59) are closely associated with albite-quartz-mica rocks developed in granodiorites consisting originally of 30-60 percent plagioclase (An_{28-32}), 10-30 percent K-feldspar, as much as 20 percent quartz and 25 percent biotite and hornblende.

In most regions our knowledge of the granites associated with greisens is based on only a few chemical analyses or modes, but extensive mineralogical and chemical studies have been made in a few greisen areas. Detailed investigations of granites associated with deposits of the Cornwall area, England have been reported by Richardson (1923), Ghosh (1927; 1934), and Brammell and Harwood (1932). The St. Austell granite investigated by Richardson and the Bodmin Moor and Carnmenelles plutons studied by Ghosh have closely associated ore deposits; the Dartmoor granites studied by Brammell and Harwood are also in the Hercynian granite belt, but are perhaps slightly older and are less mineralized. In general it has been found in the Cornish granites that the older, coarser, and more potassic rocks occur toward the edges of the irregular stock-like plutons, and younger, finer-grained sodic rocks occur towards the centers of the plutons. The older types are dominantly biotite granites; these are succeeded, in order, by two-mica granites, muscovite granites, and dike rocks (elvans) closely associated with the ores, and then the greisens.

In the St. Austell pluton, Richardson (1923, p. 554) found that the oldest type was a two-mica granite, which was intruded by gradational lithionite-muscovite granites; partial modes of these rocks are shown below:

	Biotite-muscovite granite	Lithionite granite	Muscovite granite
Quartz	31.7	33.8	29.9
Perthite	37.3	34.1	33.7
Plagioclase	16.5	18.5	22.0
Biotite	7.6	----	----
Lithionite	----	8.8	----
Muscovite	3.4	----	9.7

The main sequence determined on the Carnmenelles massif (Ghosh, 1934) shows three granites; the oldest (Type I) is coarsest and contains orthoclase in excess of plagioclase (oligoclase) and biotite greater than muscovite. It forms the outer parts of the pluton which is about 8 miles across. Type II (next younger) granite is somewhat finer, contains about equal amounts of orthoclase and plagioclase (albite), and abundant muscovite. Type III granite which forms the core of the pluton is still finer-grained and contains relatively more plagioclase and muscovite. The chemical changes as reflected in the norms (ibid, 1934, opposite page 276) show:

	Type I	Type II	Type III
Q	34.92	31.14	30.00
or	32.35	30.58	27.80
ab	17.29	26.72	31.44
an	5.56	3.34	4.45
cor	3.26	2.75	1.43
femic	5.83	5.02	3.29
An content of normative plagioclase	24	11	12

It seems very likely that the changes in types and proportions of mica-minerals and in the proportions of plagioclase to alkali feldspar correlate with an increase in the water vapor pressure of the magma with time. Yoder and Eugster (1955, p. 266-269) have shown that very high water pressures must exist before muscovite will form at magmatic temperatures, and Tuttle and Bowen (1958, p. 74-75, fig. 38) found that the position of the minimum in the system albite-orthoclase-albite-H_2O shifts markedly towards the sodic field with increasing water-vapor pressures.

Some of the granites most closely associated with greisens have been modified by albitization as well as greisening, so granites actually found with greisens may have quite different compositions than those "granites" formed in simple artificial systems. Albitization of granite has been noted in several recent studies of Soviet greisens; it has also been noted by Štemprok (1960, p. 43) at Zinnwald, and Tronquoy (1912, p. 899-900) has described the formation of secondary water-clear albite along tin-bearing veins in granite at Villeder, Brittany.

Many of the granites associated with greisens are miarolitic, and essentially all are sharply crosscutting, massive rocks. Many, perhaps most of them would be classed as epizonal plutons in the sense defined by Buddington (1959, p. 677-680). The probable importance of reaction with wall rocks as a factor in the diversification in the Dartmoor granites has been pointed out in the classic paper by Brammell and Harwood (1932, p. 228) but extensive granitization is not generally indicated or implied by the literature.

Geochemistry of beryllium in granites and greisens

The concentration of beryllium in some granite pegmatites and greisens is apparently the culmination of a tendency towards beryllium enrichment observed in the magmatic cycle. Goldschmidt and Peters (1932, p. 360) pointed out that, as a lithophile element, beryllium should be enriched in the late differentiates and residual magma, and their sampling indicated in fact that beryllium was much more abundant in the late members of the magmatic series such as granites and feldspathoidal rocks than it was in the more mafic rocks or nonfeldspathoidal rocks. Recent estimates of beryllium abundance collected by Turekian and Wedepohl (1961, table 2) indicate the general direction of the trend:

Ultrabasic rocks	Basaltic rocks	High calcium granitic rocks	Low calcium granitic rocks	Syenites
		(Beryllium, ppm)		
0.x	1	2	3	1

The syenites considered in this estimate are weighted toward the common nonfeldspathoidal types; syenites weighted toward the feldspathoidal types would probably give a value close to that of the low calcium granitic rocks. Warner and others (1959, p. 23) estimated that feldspathoidal syenites contained about 9 ppm Be.

The trend of enrichment in the granites can apparently continue under favorable conditions beyond the granite stage into the granite pegmatites or hydrothermal or pneumatolytic fluids. Griffitts (1954, p. 8) reports that certain aplitic pegmatites in the tin-spodumene belt, North Carolina uniformly average about 0.05 percent BeO or essentially the same as the 0.04-0.06 BeO given by Ginzberg (1958, p. 2) for Soviet pegmatite type beryllium deposits. Enrichment does not apparently continue in the feldspathoidal rocks into the pegmatite stage.

The differences in behavior of beryllium in acidic and feldspathoidal magmas were attributed by Goldschmidt and Peters (1932, p. 375-376) partly to the ratio of alkalies to alumina, and partly to relatively extensive substitution of beryllium in minerals characteristic of the feldspathoidal rocks. Most granites contain more alumina than total alkalies, and Goldschmidt proposed that aluminum occurred in granite magmas in both simple cations and in complex anions with silicon and oxygen. In contrast, in the feldspathoidal and similar magmas where alkalies exceed alumina, he postulated that all the alumina was in complex anionic form and none was available to form normal or basic aluminum salts. In the late stages of the granitic (or plumasitic) trend alumina-rich minerals such as muscovite, topaz, and beryl form; in the alumina-deficient (or agpaitic) trend, there is a tendency for aluminum-free minerals to form and beryllium, for example, may go into leucophanite or meliphanite.

Regardless of whether Goldschmidt's ideas on the state of aluminum in a melt are true or not, the hypothesis is a useful one on an empirical basis. Holser (1953, p. 607-609) has generalized the concept strictly on the basis of the relative amounts of alumina to the total of alkalies and lime, suggesting that beryl will tend to form in any environment where alumina is greater than total lime and alkalies, and helvite in environments where alumina is deficient.

The beryllium minerals reported from greisens are beryl, bertrandite, phenakite, and euclase. Chrysoberyl should probably not be found in appreciable quantities, at least in deposits containing both beryl and phenakite (or bertrandite) with quartz (Goldschmidt and Peters, 1932, p. 374). Helvite and other non-aluminous beryllium minerals should probably not occur in typical greisens, but they do occur in environments where some of the wall rocks are calcareous (Holser, 1953).

Limited data suggest that some granites or granite provinces may contain slightly to appreciably higher concentrations of beryllium than average granites, and thus there may be beryllium-granites in the same sense that the German granites studied by Goldschmidt and his associates are probably tin- and lithium-granites. Sandell (1952, p. 212) considered that the granites of the Llano region, Texas were relatively rich in beryllium containing about 5.5 ppm Be in comparison with his estimate of 3 ppm Be in average granites. Beus and Sitkin (1958, p. 22) imply that average Soviet granites contain about 5 ppm Be in contrast to a typical high beryllium granite which contains about 8 ppm Be.

Although Goldschmidt and Peters (1932, p. 361) found anomalous amounts of beryllium in only one greisen, they did find evidence of enrichment of beryllium in some other types of mineral deposits, and inferred that beryllium may enter into the hydrothermal-pneumatolytic regimen.

The geochemical bases for the enrichment of beryllium in the residual magmas and related solutions appear to be basically related to the small size of the beryllium ion, its divalent charge, and a noble-gas type electron structure. The combination of small size and low charge tend to make isomorphic substitution difficult and, thus, loss by camouflage in early magmatic crystals is not important. The noble-gas electron configuration of the ion and its small charge indicate that the beryllium ion should not be either strongly polarized or have high polarizing power, and finally its very small size suggests that it must be tetrahedrally coordinated with a large anion such as fluorine or oxygen in both melt and crystal.

Size, charge, and to some extent coordination are considered in the field strength concept used by Osborne (1950) to explain the mechanism of concentration of the beryllium in a magma. The field strength (FS) of an element is defined as:

$$FS = \frac{z}{\left(\underset{\text{radius}}{O^{2-}} + \underset{\text{radius}}{\text{Cation}}\right)^2} \qquad z = \text{ionic charge}$$

According to Osborne (ibid., p. 222):

> . . . Be^{2+} has to fit into a structure determined by major constituents. But because it has a fourfold coordination, it is excluded from entering the positions . . . occupied by other Group II elements, even though it has the highest field strength of members of this group. Because of its size, then, Be^{2+} must compete with Si^{4+} for position, while a simultaneous substitution is made in another position . . . to maintain electrical neutrality. But the field strength of Si^{4+} is about twice that of Be^{2+}. Beryllium therefore does not enter the early crystal structures to any appreciable extent and is concentrated relative to silicon in the residual liquids.

A similar view is stated by Ringwood (1955, p. 247) who relates lack of early crystallization of beryllium minerals to the low positive charge of the beryllium ion, and the consequent instability of the BeO_4 complex at high temperature relative to SiO_4; Ringwood (ibid., p. 248) also mentions the possibility of complexing of Be with F and OH as a factor leading to the late crystallization of beryllium minerals.

Fluorine complexing of beryllium may be important, also, after beryllium leaves the magmatic cycle. The association of beryllium minerals with fluorine-bearing minerals has been widely noted in nonpegmatite deposits (Warner and others, 1959, p. 40); Beus (1958, p. 392) has proposed that beryllium is transported in solution as an alkali fluoberyllate stable only in a certain pH range.

Discussion

The greisens, beryllium deposits, and associated granites of the Lake George area hold many features in common with greisen-like deposits and associated granites of other regions. Some of these features have been stressed in the preceding pages. The Lake George deposits also have their own characteristic properties, but in general the similarity seems to be one more link serving to relate greisen and granite as a world-wide genetic association.

One problem that has not been completely resolved is the precise definition of the granites associated with greisens. In certain regions, such as Cornwall, it seems clear that the associated granites are low-calcium rocks and are granites in the limited sense used by Tuttle and Bowen (1958); in many other regions the data are not sufficiently abundant to determine the average character of the rocks, and in some regions such as the Bolivian tin-belt, greisen-like deposits occur with calcic granitic rocks.

Perhaps it may be found that gross chemical composition is outweighed by other factors. Rattigan (1961, p. 1278-79) suggested that the significant stage of differentiation might be indicated by alkali:cafemic ratio rather than by the SiO_2 content.

It seems certain that differentiation with respect to volatile content must also be important. Besides H_2O the volatiles that consistently show up in greisens are fluorine or boron; phosphorous is less important (except in certain of the Bolivian deposits). The state of differentiation of a magma with respect to volatile components is, however, more difficult to evaluate from chemical or mineralogic data than the differentiation as related to non-volatile components. The presence of volatile components in igneous rocks is indicated directly by certain minerals such as fluorite, topaz, tourmaline, and apatite, more or less indirectly by ratios of certain minerals such as pyroxene-hornblende, hornblende-mica, and biotite-muscovite, and indirectly by rock compositions which can be compared with similar compositions studied in the laboratory under different volatile component pressures. Perhaps the indirect data are more significant, because with very high volatile pressures many components might be lost to a fugitive phase. Using both direct and indirect data it can be inferred that at least some greisens, including those of the Lake George beryllium area, form in a late stage of a magmatic sequence characterized by serially increasing volatile pressures.

CHAPTER III

GEOLOGIC SETTING

The Lake George beryllium area is underlain by rocks of Precambrian age. The southwest part of the area is a metamorphic complex consisting of schists and gneisses, complexly interlayered on a large and small scale, cut by small bodies of igneous rock (plate 1). The northeast part of the area is underlain by granite related to the major Pikes Peak batholith of the Colorado Front Range. Near O'Brien Gulch small remnants of a Tertiary ash flow locally cover the Precambrian rocks, and alluvium, somewhat older terrace gravels, and colluvium of Quaternary age cover the older rocks in and near the principal drainages.

The oldest rocks are fine-grained gneisses and schists tentatively correlated with the Idaho Springs Formation. In approximate order of abundance they consist of biotite gneisses and schists, amphibolite, quartz gneiss, and calc-silicate gneiss. They are interlayered on a small scale, and probably formed by the metamorphism of interlayered shales, sandstones, and carbonate rocks. Interlayered with rocks of the Idaho Springs(?) Formation on a large scale are granitic gneiss, and quartz diorite gneiss. These rocks are of uncertain origin, but are apparently somewhat younger than rocks of the Idaho Springs(?) Formation. Still younger Precambrian rocks show intrusive relations, and were probably emplaced after most of the metamorphism of old rocks was completed. In probable order of decreasing age, these rocks are biotite-muscovite granite, gabbro and associated quartz monzonites, and the Pikes Peak Granite. Small masses of the biotite-muscovite granite are widely distributed in the metamorphic complex. The Pikes Peak Granite and the gabbro and related quartz monzonites have more limited distributions.

The rocks are broken by major faults which strike northwesterly and by smaller faults of other trends. The oldest faults of the area formed in Precambrian time and predate the biotite-muscovite granite; the youngest faults formed in Tertiary time, and some are younger than the Tertiary ash flow.

Precambrian rocks

Idaho Springs(?) Formation

The name Idaho Springs(?) Formation is used to describe a varied assemblage of metasedimentary rocks lithologically similar to the Idaho Springs Formation described by Ball (1906) in the Idaho Springs-Georgetown area of Clear Creek County, Colorado. Direct stratigraphic correlation is not implied because the lithologic similarity may be due simply to high-grade regional metamorphism of similar sedimentary rocks in both the Idaho Springs and Lake George areas.

The dominant rocks of the Idaho Springs(?) Formation are interlayered fine-grained biotite and biotite-muscovite schists and gneisses. In most places these rocks are interlayered on too fine a scale or are not well enough exposed to separate in mapping, but rock types such as quartz-sillimanite gneiss, amphibolite, and calc-silicate gneiss locally form mappable bodies. The formation includes many bodies of the biotite-muscovite granite and homogenous granite pegmatite which were also too small to separate during mapping.

One common variety of biotitic gneiss is a light-gray rock which contains small biotite flakes scattered through a fine-grained matrix dominantly composed of plagioclase and quartz. A second common type is a darker more schistose rock containing relatively more biotite and quartz. Sillimanite is a common constituent of the biotite gneisses; it varies in coarseness from microscopic aggregates or single crystals to prismatic crystals as much as 1-inch long. Locally the more schistose varieties of biotite gneiss contain thin granitic layers.

Quartz-sillimanite gneiss forms a large part of the southeast corner of the map area. The gneiss is a gray to bluish-gray rock which is harder and finer-grained than most other varieties of the biotite gneisses. Quartz is the most abundant constituent of the gneiss; the sillimanite occurs in very fine-grained aggregates which are visible megascopically as thin white films and streaks on freshly broken surfaces of the gneiss. Plagioclase, small grains of magnetite, and probably small amounts of potash feldspar are typically present. Cordierite is locally abundant and imparts the bluish cast to the rocks. The cordierite and possibly some of the other minerals may well be products of contact metamorphism caused either by the intrusion of Pikes Peak Granite or gabbro into the gneiss. Small bodies of quartz-rich gneiss are found as layers in the biotite gneisses and also in calc-silicate gneiss.

Amphibolites occur in layers and lenticular bodies which seem to be particularly abundant in the area east of the Boomer mine.

One amphibolite layer, exposed about 250 feet south of the Boomer, can be traced for about 1500 feet along strike, but most bodies are more lenticular and can be traced for only a few hundred feet. Typical amphibolite is a dark, massive to moderately foliated rock composed essentially of hornblende, plagioclase, and quartz. It is likely to be confused only with the hornblende-pyroxene calc-silicate gneiss which is, however, better foliated and finer-grained.

Calc-silicate gneiss of two main varieties occurs in the Idaho Springs(?) Formation. One type is a fine-grained, black to bluish-gray, finely-laminated rock probably composed in most places of hornblende, pyroxene, quartz, and feldspar. It resembles the amphibolites, and is shown on the map as amphibolitic calc-silicate gneiss. The second type is a fine- to coarse-grained rock composed of varying amounts of garnet, epidote, idocrase, pyroxene, calcite, hornblende, and locally small amounts of scheelite and sulfide minerals.

The texture, composition, and complex interlayering of the major components of the Idaho Springs(?) Formation indicate that they are metasedimentary rocks which probably formed from an interlayered sequence of shales, sandstones, and carbonate rocks. Possibly the amphibolites are metavolcanics but a metasedimentary origin for these rocks is not improbable.

Quartz diorite gneiss

Quartz diorite gneiss forms a crudely lenticular body ($gnqd_I$) about one mile long exposed west and southwest of the Boomer mine in Sections 21 and 28[1], and a large sheet-like body ($gnqd_{II}$), interrupted by younger intrusive rocks, in the south part of the map area (plate 1).

The gneiss appears to be conformable in structure to the gneisses and schists comprising the Idaho Springs(?) Formation, but inclusions of these latter rocks, and similarity in composition and form to probable metaigneous rocks in the Front Range, suggest that they are metaigneous rocks, hence they are called quartz diorite gneiss.

The gneiss exposed in the western part of Sections 21 and 28 ($gnqd_I$, plate 1) is a light- to dark-gray, medium-grained equigranular gneiss which ranges in composition from a quartz diorite to a quartz monzonite (fig. 2 and table 1; sample locations are shown in fig. 3). In thin section the texture is granoblastic; the gneissic aspect is mainly due to alined biotite flakes. Cataclastic structure is present in the gneiss along a northeasterly trending belt of minor folds exposed in the SW 1/4, Section 21.

The plagioclase is twinned polysynthetically, and shows myrmekitic intergrowths with quartz where it is in contact with the sparse alkali feldspar. Biotite is the dominant mafic mineral; magnetite is locally present, but, like muscovite, seems to be an alteration product of the biotite. Apatite is the main accessory mineral.

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[1]Unless otherwise noted, all Sections are in T.11S., R.72W.

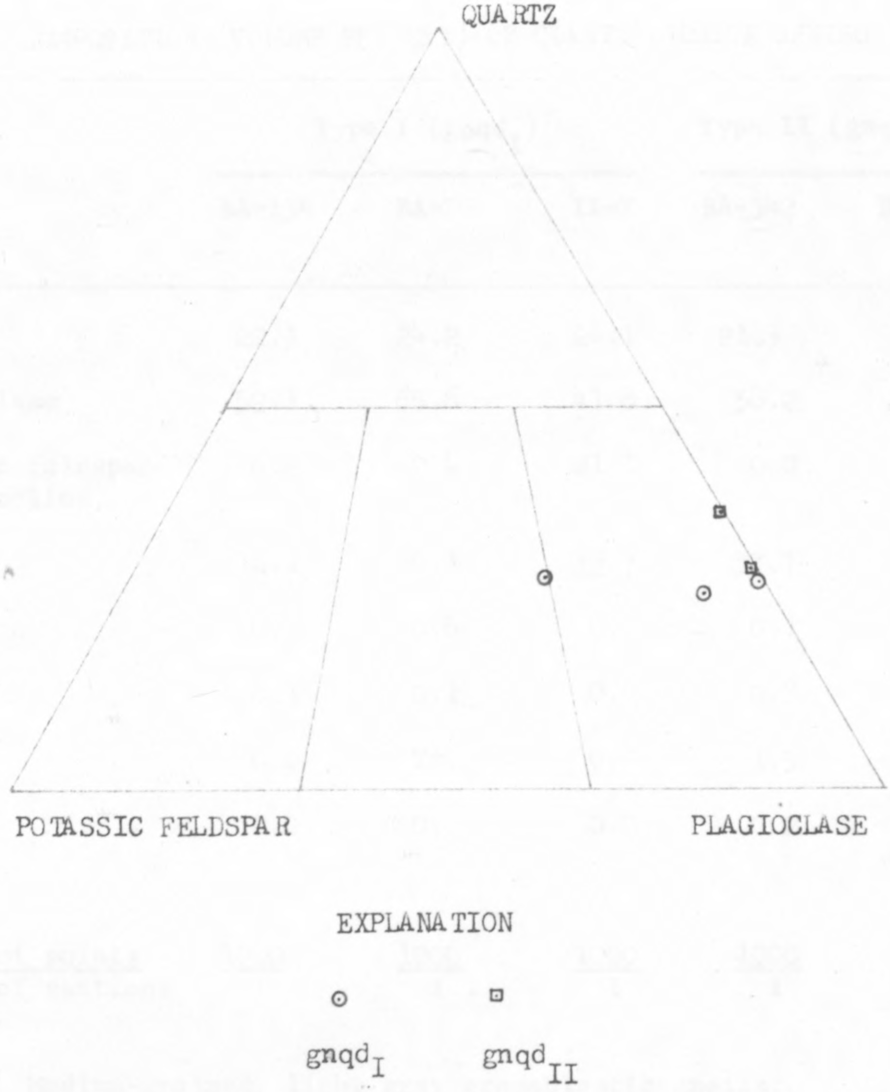

FIGURE 2. MODAL COMPOSITION OF QUARTZ DIORITE GNEISS

TABLE 1

MODAL COMPOSITION (VOLUME PERCENT) OF QUARTZ DIORITE GNEISS

Sample number	Type I ($gnqd_I$)			Type II ($gnqd_{II}$)	
	BA-134	BA-79	II-7	BA-342	BA-400
Quartz	22.1	24.2	24.1	21.5	23.8
Plagioclase	59.1	65.6	41.8	38.2	59.2
Potassic feldspar (microcline)	6.2	0.4	21.1	0.0	0.0
Biotite	12.1	9.1	12.7	37.7	14.9
Muscovite	0.4	0.6	0.6	0.1	0.1
Apatite	0.1	0.1	0.0	0.8	0.6
Opaques	0.0	Tr.	0.7	1.5	1.3
Zircon	0.0	0.0	0.0	0.2	0.1
Number of points / Number of sections	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1

BA-134: Medium-grained, light gray granoblastic gneiss.

BA-79: Medium-grained, light gray gneiss, local cataclasis.

II-7: Medium-grained, light gray granoblastic gneiss.

BA-342: Dark gray and white, porphyroblastic augen gneiss.

BA-400: Dark gray and white, porphyroblastic massive gneiss; on an average is medium-grained.

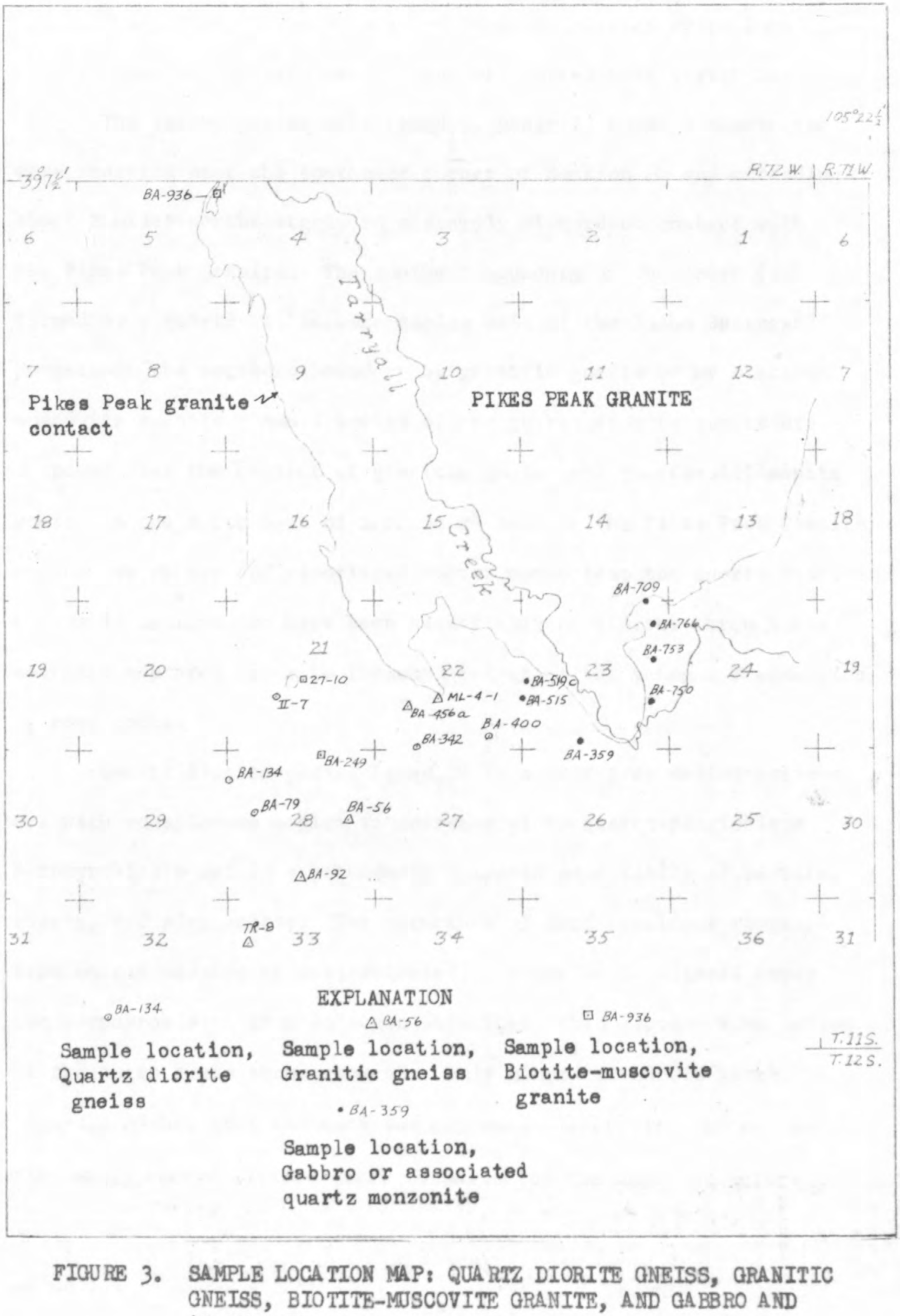

FIGURE 3. SAMPLE LOCATION MAP: QUARTZ DIORITE GNEISS, GRANITIC GNEISS, BIOTITE-MUSCOVITE GRANITE, AND GABBRO AND ASSOCIATED QUARTZ MONZONITES

The gneiss is cut by light-colored pegmatites which locally show a crude zoning with development of central quartz-rich masses.

The second gneiss unit ($gnqd_{II}$, plate 1) forms a sheet-like mass starting near the southeast corner of Section 28 and extending about 2 miles northeasterly to a sharply discordant contact with the Pikes Peak Granite. The southern boundary of the sheet is formed by a quartz-sillimanite gneiss unit of the Idaho Springs(?) Formation; the northern boundary by granitic gneiss or by biotite-muscovite granite. Small bodies of the quartz diorite gneiss are exposed near the contact of granitic gneiss and quartz-sillimanite gneiss in the north part of Section 24 east of the Pikes Peak Granite and of the gabbro and associated quartz monzonite; the quartz diorite gneiss is believed to have been essentially continuous through the southern map area prior to the emplacement of the younger Precambrian igneous rocks.

Quartz diorite gneiss ($gnqd_{II}$) is a dark-gray medium-grained rock with conspicuous medium to coarse-grained quartz-plagioclase porphyroblasts set in a groundmass composed essentially of biotite, quartz, and plagioclase. The structure of hand specimens ranges from nearly massive to well foliated. In the well foliated types, the porphyroblasts show an augen structure; thin section examination of the augen types shows, however, only minor cataclasis which suggests either that the rock was deformed plastically, or was nearly completely recrystallized after formation of the augen structure.

The type II gneiss ($gnqd_{II}$) is appreciably more mafic than $gnqd_I$ (table 1). It also differs in including many small (1-2-inch) inclusions of gneiss and schist of the Idaho Springs(?) Formation. Both types resemble rocks found as phacoliths in the Idaho Springs-Central City area, as for example, the phacolithic "granodiorite" shown by Moench, Harrison, and Sims (1962, pl. 1) near Bald Mountain; tentatively the rocks in Idaho Springs-Central City area are regarded as related to the Boulder Creek Granite of Lovering and Goddard (1950).

Granitic gneiss

Granitic gneiss occurs extensively in the metamorphic complex in Sections 13, 22, 24, and 28. Like the more mafic quartz diorite gneiss ($gnqd_{II}$) it forms a sheet-like body which trends northeasterly, and is believed to have been essentially continuous across the area prior to the emplacement of biotite-muscovite granite, gabbro and associated quartz-monzonites, and Pikes Peak Granite.

The gneiss is variable in texture and composition (fig. 4, table 2), but forms a distinctive map unit. It apparently varies in composition from a granodiorite to a granite, and "granitic" is used in its larger sense in defining the unit. Two types of rock are dominant; one is a noticeably gneissic biotite-bearing rock, commonly with an augen structure; the second is a fine-grained almost massive rock with sparse mica. Where both types are present in the same outcrop, the contact between them is sharp, but not obviously of intrusive origin. Very locally the fine-grained type forms dike-like masses in the coarser type, and is inferred to be younger. Gneissic structure seems to cross the dike-like zones of fine-grained granite, and so it is tentatively inferred that the metamorphism followed formation of the granitic gneiss unit.

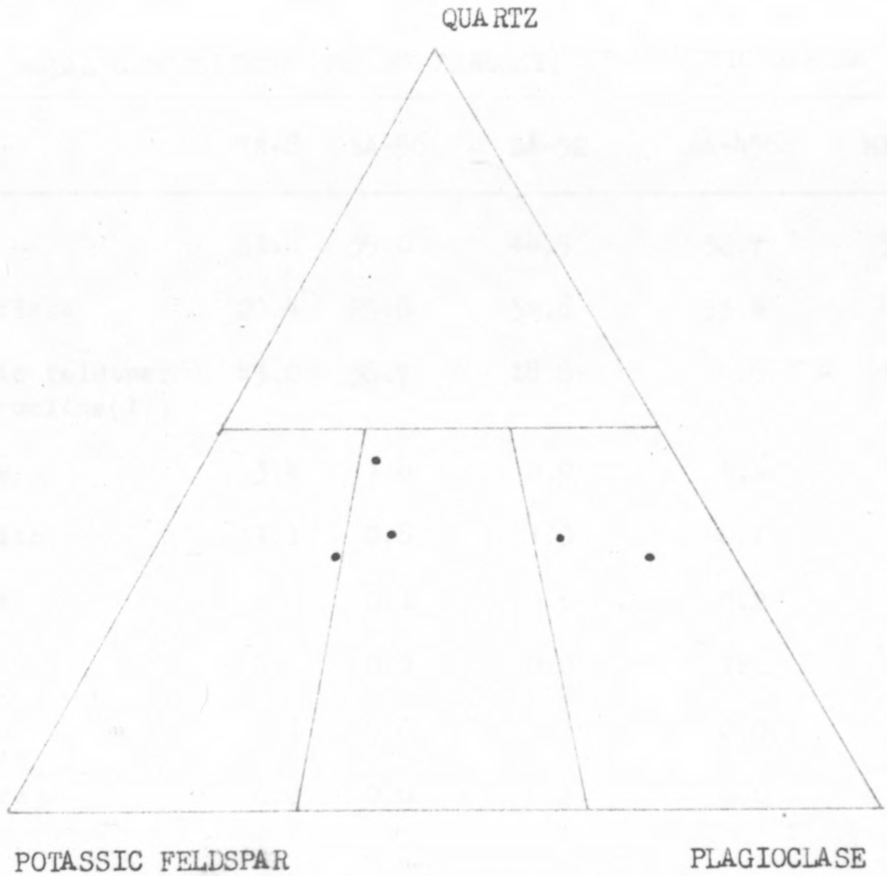

FIGURE 4. MODAL COMPOSITION OF GRANITIC GNEISS

TABLE 2

MODAL COMPOSITION (VOLUME PERCENT) OF GRANITIC GNEISS

Sample number	TR-8	BA-56	BA-92	BA-456a	ML-4-1
Quartz	31.8	35.0	44.5	32.7	31.6
Plagioclase	20.4	25.6	32.8	53.4	40.5
Potassic feldspar (Microcline(?))	43.2	36.7	18.6	9.6	16.6
Biotite	3.4	1.8	2.9	3.4	11.2
Muscovite	1.1	0.8	1.0	0.7	0.1
Opaques	0.0	0.1	0.0	0.2	Tr.
Zircon	0.0	0.0	0.0	Tr.	Tr.
Apatite	0.1	0.0	0.1	0.0	0.0
Fluorite	0.0	0.0	0.1	0.0	0.0
Number of points	1000	1000	1000	1000	1000
Number of sections	1	1	1	1	1

TR-8: Fine-grained granoblastic gneiss, intergrown biotite-muscovite, microcline has well developed grid twinning.

BA-56: Fine-grained granoblastic gneiss; faint twinning in microcline.

BA-92: Medium- to coarse-grained granoblastic gneiss; microcline has well developed grid twinning. Plagioclase is myrmekitic in contact with microcline.

BA-456a: Medium-grained granoblastic gneiss, secondary muscovite; faint twinning in microcline.

ML-4-1: Fine-grained granoblastic gneiss, with scattered potassic feldspar augen 3-4 mm across. Potassic-feldspar is apparently not twinned.

In thin section, the texture is granoblastic; locally there is a tendency towards segregation of quartz-rich and feldspar-rich layers, but most of the foliation is due to the alinement of biotite and, locally, muscovite. The plagioclase is polysynthetically twinned; the potassic feldspar, which is sparsely perthitic, is strongly grid twinned in the samples near the western edge of the map area (TR-8 and BA-92) but only faintly twinned or apparently not twinned at all in the samples close to the Pikes Peak Granite. The plagioclase is myrmekitic where it is in contact with the potassic feldspar.

The granitic gneiss locally contains inclusions of biotite gneiss of the Idaho Springs(?) Formation, and of the quartz diorite gneiss ($gnqd_{II}$). In turn it is included in or cut by dikes of biotite-muscovite granite, granitic pegmatite, and Pikes Peak Granite.

Biotite-muscovite granite (Silver Plume(?) Granite)

Numerous bodies of biotite-muscovite granite occur in dikes, small stocks, and irregular masses throughout the metamorphic complex. Many of the bodies are too small to map. The largest body is a crudely circular stock about 3500 feet across exposed about 1/2 mile south of the Boomer mine; other extensive bodies crop out in the northwest part of the area in Section 5, and in the east part of the area, mainly in Section 13.

The stock-like body south of the Boomer mine appears to have been intruded partly along the contact between granitic gneiss and the quartz diorite gneiss ($gnqd_{II}$) and partly along the Badger Flats fault. Smaller bodies of the biotite-muscovite granite are found within the Boomer mine area (plate 11): One body is nearly concordant, and appears to have been intruded along the contact between rocks of the Idaho Springs(?) Formation and quartz diorite gneiss ($gnqd_I$). A second body exposed on the southwest flank of the Boomer stock is sharply discordant, and occupies a northeast trending fracture zone.

The other large areas of biotite-muscovite granite are incompletely mapped. In both the northwest and east parts of the map-area (plate 1) the biotite-muscovite granite is cut by Pikes Peak Granite. A large, almost flat biotite-muscovite granite dike can be traced for about a mile in Sections 4 and 9.

The biotite-muscovite granite is similar in composition (fig. 5, table 3) and megascopic appearance to rocks in the Front Range which have generally been mapped as Silver Plume Granite. Characteristic features of the granite at many places are alined tabular crystals of potassic feldspar, seriate porphyritic texture, and the presence of two micas. The composition of the granite in areas where it has been carefully studied (see for example, Harrison and Wells, 1959, p. 18-19) seems to be relatively uniform with about equal amounts of quartz, plagioclase, and potassic feldspar which is generally microcline. Under some classifications the rock would be called a quartz monzonite, however, the plagioclase is sodic, and a few chemical analyses (Lovering and Goddard, 1950, p. 27, analyses 6-10) suggest that the rock would generally contain more than 80 percent normative q, or, and ab, so here it is called a granite.

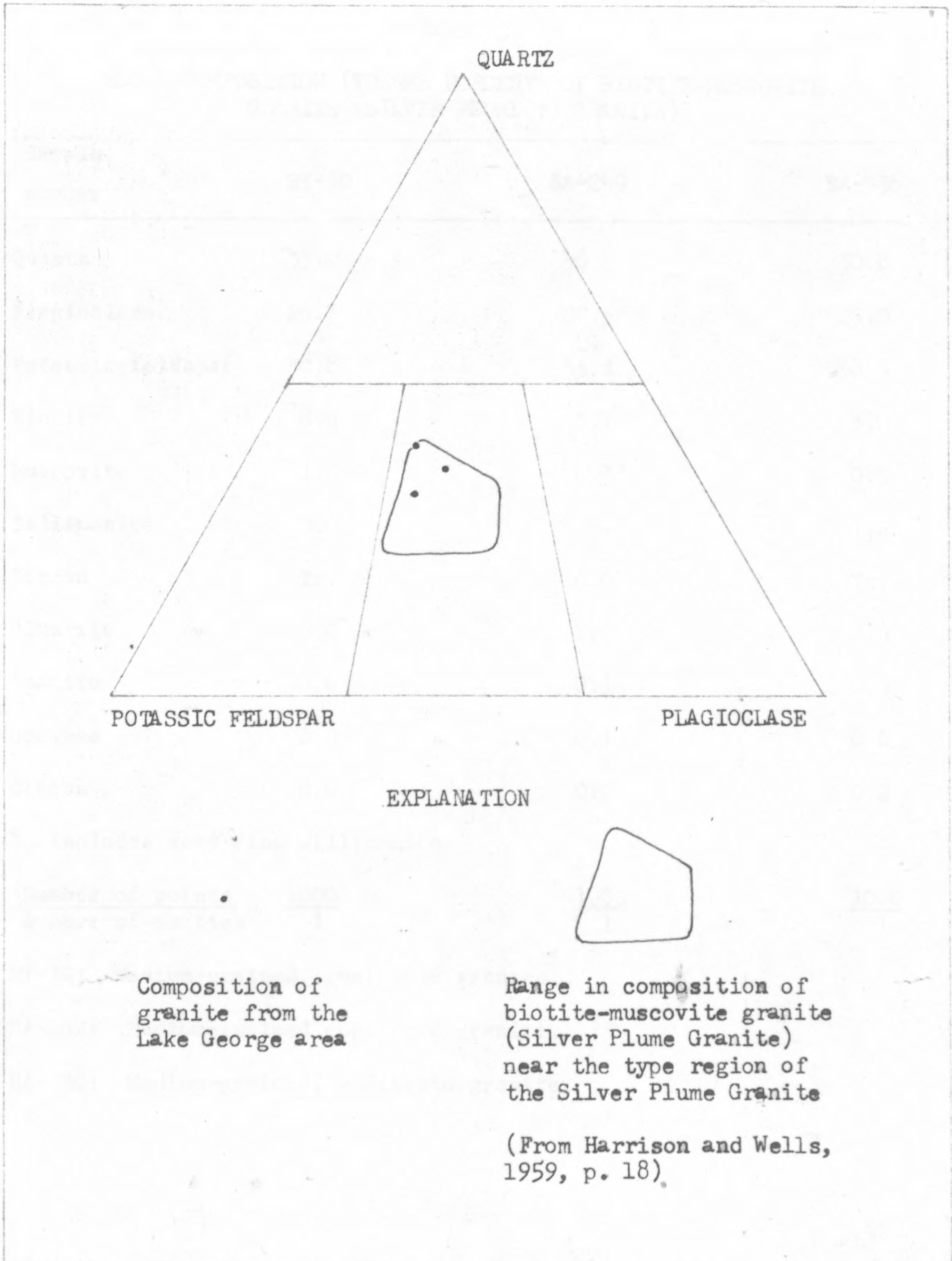

FIGURE 5. MODAL COMPOSITION OF BIOTITE-MUSCOVITE GRANITE

TABLE 3

MODAL COMPOSITION (VOLUME PERCENT) OF BIOTITE-MUSCOVITE GRANITE (SILVER PLUME(?) GRANITE)

Sample number	27-10	BA-249	BA-936
Quartz	33.0	36.2	30.8
Plagioclase	26.3	20.5	25.0
Potassic feldspar	30.8	33.1	38.4
Biotite	8.9	3.7	3.9
Muscovite	1.0	6.3*	0.5
Sillimanite	0.0	-	1.2
Zircon	Tr.	0.0	Tr.
Fluorite	0.0	Tr.	0.0
Apatite	0.0	0.1	0.0
Opaques	0.0	0.1	0.0
Others	0.0	0.0	0.2

* includes very fine sillimanite

Number of points / Number of sections	1000 / 1	1000 / 1	1000 / 1

27-10: Medium-grained, gneissoid granite.

BA-249: Medium-grained gneissoid granite.

BA-936: Medium-grained, gneissoid granite.

Relations in the Lake George area show conclusively that the biotite-muscovite granite is older than both gabbro and its associated rocks and the Pikes Peak Granite. Hutchinson found that the lithologically similar Cripple Creek Granite (1960c) also is older than the Pikes Peak Granite.

The granite in the Lake George area is a light tan to light gray, medium-grained rock with potassic feldspar tabs in part greater than 5 mm long; two micas can be seen in most hand specimens, and in all megascopic respects it is a typical Silver Plume Granite. Microscopic examination shows, however, that the texture and composition have been modified by metamorphism. The contacts between the quartz and feldspars are granoblastic, and the whole texture might be referred to as seriate granoblastic. Although some of the biotite and muscovite occur in interstitial intergrowths typical of Silver Plume type Granite, other mica cuts across feldspar grains; muscovite in particular seems to form at the expense of plagioclase. Sillimanite occurs with the secondary muscovite or in monomineralic aggregates cutting across the feldspars. A further evidence of metamorphism is the very sparsely developed grid twinning of the potassic feldspar. As in the granitic gneiss unit, plagioclase in contact with potassic feldspar is myrmekitic; this relation, however, is also reported from non-metamorphosed Silver Plume Granite in the type area (Harrison and Wells, 1959, p. 19).

Granitic pegmatites

Light-colored rocks of pegmatitic aspect are found at many places in the metamorphic complex. The pegmatitic rocks locally appear to intergrade with alaskitic granitic rocks, and for the purposes of this report all such rocks are lumped under the term granitic pegmatite. The pegmatites form both concordant and discordant bodies.

Most of the pegmatites are of the simple or homogeneous type; a few have quartz cores. Besides quartz, feldspar, and muscovite, many pegmatites contain garnet, and a few, particularly the cored pegmatites, contain small amounts of tourmaline and beryl.

The age relations of these rocks are not certain, and it is likely that, as mapped, not all are of the same age or the same origin. In general, they are younger than most gneissic rocks, but apparently show little relation to the younger igneous rocks. Tentatively they are considered to be related to the period of metamorphism which produced the gneisses.

Gabbro and associated quartz monzonites

Gabbro and associated quartz monzonites underlie part of the area near Tarryall Creek in Sections 23 and 24, and form a crudely semicircular area which is inferred to be a remnant of a composite funnel-shaped pluton. Small dikes of quartz monzonite and quartz monzonite porphyry cut the complex, and a quartz monzonite dike about 2000 feet long cuts both granitic gneiss and the biotite-muscovite granite east of the complex in Sections 13 and 24. The pluton is composed mainly of three rock types, gabbro, quartz monzonite, and quartz monzonite porphyry.

All three rock units are cut by the Pikes Peak Granite, and it seems almost certain that prior to the intrusion of the granite the body, at the map elevation, was an oval complex about 8,000 feet long and 5,000 or 6,000 feet wide consisting of an outer gabbro rim, an intermediate quartz monzonite, and a quartz monzonite porphyry mass set in the northeast part of the quartz monzonite area. The inferred extent of the area is compared with the equivalent present map area in figure 6.

The gabbro is a coarse-grained, dark bluish-gray to greenish rock that appears in hand specimen to consist of plagioclase, interstitial dark silicate minerals, and a considerable amount of a gray metallic mineral. In most places the plagioclase has a subparallel alinement, which parallels the outline of the body. Except in the south part (NW 1/4, Sec. 26), the planar structure dips inward toward the center of the body.

In thin section, the texture is intersertal. In most rocks the original mafics have largely been altered to an aggregate of very fine biotite which corrodes the plagioclase (labradorite). In one rock (BA-515, table 4) the mafics are nearly unaltered, and consist mostly of olivine, pyroxene, and an opaque mineral, with locally abundant apatite. The olivine has a 2V of about 79°, suggesting that it is about Fa_{34}. The pyroxene has a 2V of about 83°; it is biaxial negative and is probably hypersthene.

Halos of biotite resembling reaction rims surround the opaque mineral, and in turn are surrounded by scattered, minute crystals of a high relife, glassy accessory, possibly corundum. The corundum(?) also is found in the same type of occurrence next to hypersthene(?).

The quartz monzonite is a bluish-gray, medium- to coarse-grained granitoid rock which locally shows a planar structure due to alinement of feldspar crystals; like the planar structure of the gabbro, it is subparallel to the outline of the body. In thin section, the

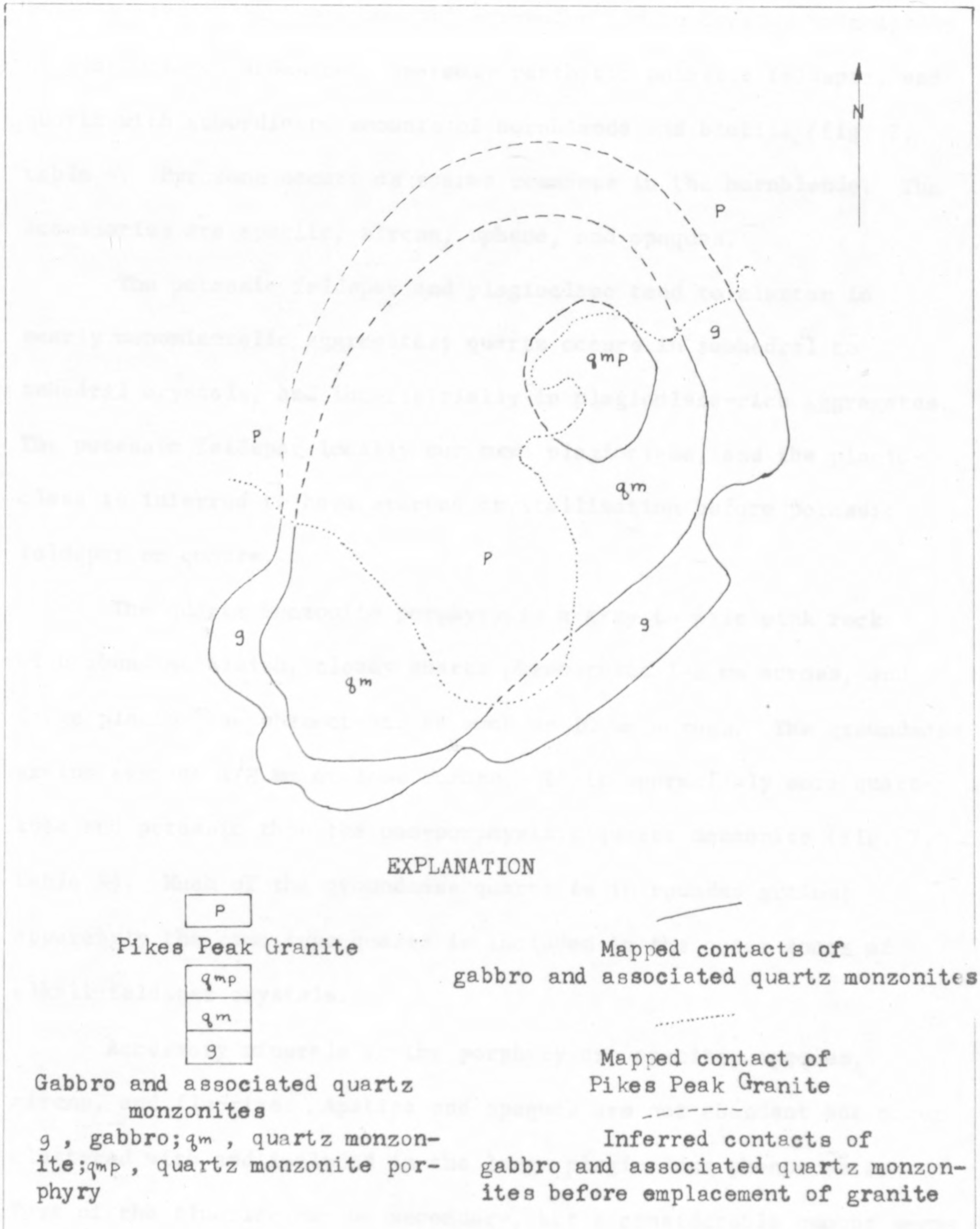

FIGURE 6 .--INFERRED DISTRIBUTION OF GABBRO AND ASSOCIATED QUARTZ MONZONITES, IN TERMS OF THE PRESENT LAND SURFACE, BEFORE THE EMPLACEMENT OF PIKES PEAK GRANITE

0) 1 Mile

rock is seen to be hypidiomorphic-granular and to consist principally of plagioclase (andesine), sparcely perthitic potassic feldspar, and quartz with subordinate amounts of hornblende and biotite (fig. 7, table 4). Pyroxene occurs as sparce remnants in the hornblende. The accessories are apatite, zircon, sphene, and opaques.

The potassic feldspar and plagioclase tend to cluster in nearly monomineralic aggregates; quartz occurs in subhedral to anhedral crystals, and interstitially in plagioclase-rich aggregates. The potassic feldspar locally surrounds plagioclase, and the plagioclase is inferred to have started crystallization before potassic feldspar or quartz.

The quartz monzonite porphyry is a gray to pale pink rock with abundant bluish, cloudy quartz phenocrysts 1-2 mm across, and large plagioclase phenocrysts as much as 10 mm across. The groundmass grains average 1/2 mm or less across. It is appreciably more quartzose and potassic than the non-porphyritic quartz monzonite (fig. 7, table 4). Much of the groundmass quartz is in rounded grains; apparently the same type quartz is included in the outer zones of alkali feldspar crystals.

Accessory minerals in the porphyry are apatite, opaques, zircon, and fluorite. Apatite and opaques are not abundant but occur clustered with and included in the large plagioclase phenocrysts. Part of the fluorite may be secondary, but a considerable amount seems to occur interstitially with biotite. The occurrence of the large plagioclase phenocrysts with included opaques and apatite, and the sharply discordant contact with Pikes Peak Granite appear definitely to relate the quartz monzonite porphyry to the gabbro-quartz

TABLE 4

MODAL COMPOSITION (VOLUME PERCENT) OF GABBRO, QUARTZ MONZONITE, AND QUARTZ MONZONITE PORPHYRY

Sample number	BA-515	BA-359	BA-750	BA-753	BA-709	BA-766	BA-519c
Quartz	1.0	18.0	14.1	20.9	32.9	36.4	28.3
Plagioclase	67.2	38.7	37.4	38.6	20.9	24.9	47.8
Potassic feldspar	0.0	31.6	41.1	27.4	41.5	33.4	23.6
Olivine	12.7	0.0	0.0	0.0	0.0	0.0	0.0
Hypersthene(?)	3.4	0.3	0.0	0.0	0.0	0.0	0.0
Hornblende	0.0	7.8	4.0	3.2	0.0	0.0	0.0
Biotite	5.5	2.3	1.9	8.7	3.2	4.4	0.0
Opaques	7.5	0.8	0.4	0.7	0.2	0.1	0.0
Muscovite	0.0	0.0	0.0	0.0	0.8	0.4	0.0
Apatite	2.4	0.4	0.6	0.2	0.0	Tr.	0.0
Corundum(?)	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Fluorite	0.0	0.0	0.0	0.0	0.5	0.4	0.3
Zircon	0.0	Tr.	0.4	Tr.	Tr.	Tr.	0.0
Sphene	0.0	0.1	0.1	0.3	0.0	0.0	0.0

Number of points / Number of sections — All are 1000 / 1

BA-515: Olivine-pyroxene gabbro
BA-359: Hornblende-biotite quartz monzonite.
BA-750: Hornblende-biotite quartz monzonite.
BA-753: Biotite-hornblende quartz monzonite.
BA-709: Biotite quartz monzonite porphyry.
BA-766: Biotite quartz monzonite porphyry
BA-519c: Leuco-quartz monzonite dike rock cutting gabbro and quartz monzonite.

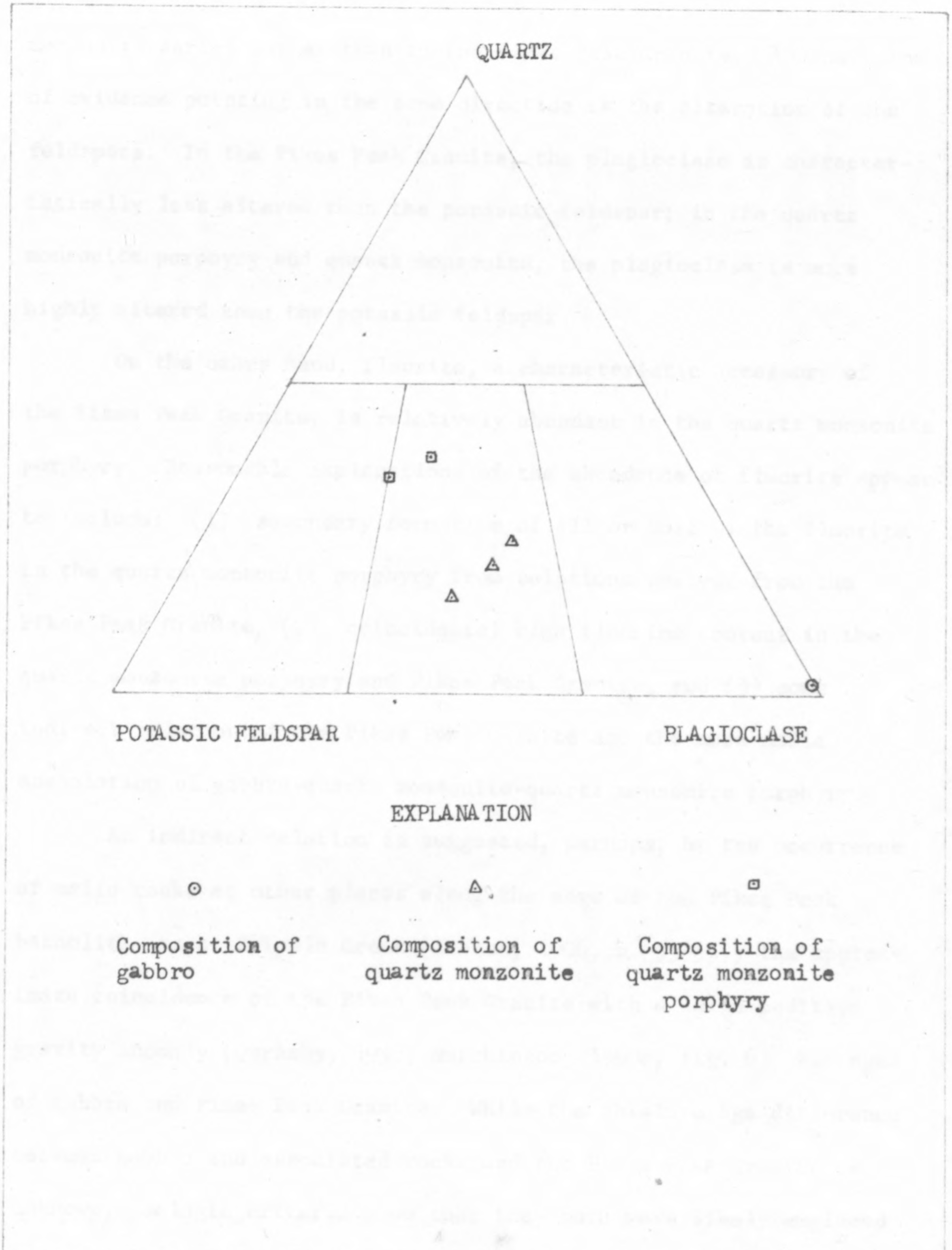

FIGURE 7. MODAL COMPOSITION OF GABBRO AND ASSOCIATED QUARTZ MONZONITES

monzonite series rather than to the Pikes Peak Granite. Another line of evidence pointing in the same direction is the alteration of the feldspars. In the Pikes Peak Granite, the plagioclase is characteristically less altered than the potassic feldspar; in the quartz monzonite porphyry and quartz monzonite, the plagioclase is more highly altered than the potassic feldspar.

On the other hand, fluorite, a characteristic accessory of the Pikes Peak Granite, is relatively abundant in the quartz monzonite porphyry. Reasonable explanations of the abundance of fluorite appear to include: (1) secondary formation of all or most of the fluorite in the quartz monzonite porphyry from solutions derived from the Pikes Peak Granite, (2) coincidental high fluorine content in the quartz monzonite porphyry and Pikes Peak Granite, and (3) some indirect relation of the Pikes Peak Granite and the more mafic association of gabbro-quartz monzonite-quartz monzonite porphyry.

An indirect relation is suggested, perhaps, by the occurrence of mafic rocks at other places along the edge of the Pikes Peak batholith, as at Cripple Creek (Graton, 1906, p. 53-55), the approximate coincidence of the Pikes Peak Granite with a large positive gravity anomaly (Qureshy, 1958; Hutchinson, 1960a, fig. 6), and ages of gabbro and Pikes Peak Granite. While the absolute age difference between gabbro and associated rocks and the Pikes Peak Granite is unknown, geologic criteria show that they both were likely emplaced as shallow magmas, and hence are possibly closely related in time. In terms of relative ages the rocks belonging to the gabbro association are younger than all the Precambrian rocks with the exception of the Pikes Peak Granite. The main gabbro body cuts across the interlayered quartz-sillimanite gneiss, quartz diorite gneiss, and granitic gneiss and the biotite-muscovite granite. Furthermore, the rocks of the gabbro association have not been metamorphosed, and finally their mode of occurrence in a ringlike complex suggests emplacement at a rather shallow depth.

Structure

The metamorphic complex consists of schists and gneisses apparently formed by the regional metamorphism of sedimentary (Idaho Springs(?) Formation) and probably igneous rocks (quartz diorite gneiss and granitic gneiss). The granoblastic texture of the biotite-muscovite granite suggests that it too was recrystallized, but under less intense metamorphic conditions. The foliation in the Idaho Springs(?) Formation is generally parallel to the compositional banding, and it is inferred to be a bedding foliation; locally a younger shear foliation transects the bedding foliation. Both types of foliation are found in a banded biotite gneiss included in quartz diorite gneiss ($gnqd_{II}$) in the NE$\frac{1}{4}$SE$\frac{1}{4}$ Section 28. The older foliation parallels a fine-banding which has a varve-like appearance. The younger foliation is shown by minute fractures and orientation of muscovite flakes; it forms an angle of about 20^{o} with the old foliation.

The gross structure of the metamorphic rocks is shown by the distribution of different types of gneisses and by changes in the bedding foliation. In the southeast part of the metamorphic complex the rock layers and foliation generally strike northeast and dip steeply to the northwest; in the north and west parts of the complex the rock layers generally strike northwest and dip to the east. One interpretation of this gross structure is that a large open syncline trends about north-northeast through the metamorphic complex. Other interpretations, however, are also possible; it seems likely that the gross structure will be resolved by mapping to the south and west.

Some small-scale folds and other lineations have a north-northeast trend, and thus tend to support the idea of a major north-northeast structure, but other small folds and lineations trend east-northeast, east, and north-northwest. The east-northeast trend is well marked in part of the quartz diorite gneiss body exposed 1000 feet south of the Boomer mine by small folds, some of which show cataclastic effects, and possibly by the arcuate nature of the body.

Faults of north-northwest, northeast, and rarely other strike directions traverse the rocks of the area. In general the faults are not exposed but are inferred from alinements visible on maps or aerial photographs, displacement of rock layers, and discordant dikes or veins. The major fault thus far mapped is the Badger Flats fault (plate 1) which trends about north-northwest through the metamorphic complex. It appears to be a complex zone, and at various places is marked by greisens, breccias, and discordant pegmatite dikes. The fault shows an apparent left lateral movement which is believed to reflect a real component because both north and south dipping rocks show the same sense of displacement. Faults which are subparallel to the Badger Flats fault are inferred in other parts of the metamorphic complex west of the mapped area and in the Pikes Peak batholith.

The Badger Flats fault displaces metamorphic rocks and metamorphic structures, and so is inferred to have formed after intense regional metamorphism and folding. It is believed, however, to be older than the body of biotite-muscovite granite exposed in the southwest part of the area in Sections 21, 22, 27, and 28. Part of the granite extends northwestward in what appears to be a dike along the fault zone, and the granite is not cataclastically deformed along the fault as would probably be the case if the major movement had taken place after intrusion of the body. A third point of evidence is that gneissoid foliation in the granite near the fault locally is about parallel to the strike of the fault but diverges from this trend away from the fault zone. Further evidence of Precambrian faulting is found in discordant dikes of biotite-muscovite granite and Pikes Peak Granite which cut the metamorphic complex, and possibly, in the nearly straight northwesterly or northeasterly trends of certain segments of the contact of the Pikes Peak Granite.

Evidence of younger faulting is found in the Pikes Peak Granite itself and in the Tertiary welded tuffs. Faults which can be traced for distances of hundreds of feet in the Pikes Peak batholith are shown by fluorite-filled veins; shear zones which have small displacements but may be traced for long distances are mainly inferred from alinements clearly visible on the maps or photographs of the area. Except for the fact that they are post-Pikes Peak their age is uncertain. It can perhaps be inferred from the fluorite-rich nature of the Pikes Peak Granite and the occurrence of fluorite veins only in and adjacent to the Pikes Peak that some of the faults are essentially of Pikes Peak age. A small occurrence of welded tuff in the northwestern part of Section 22 appears to be cut and possibly downdropped by faults; this is the only direct evidence of post-Precambrian movement on faults of the area, but Laramide movement on at least some faults can logically be inferred on the basis of the geologic history of the Front Range.

Precambrian history prior to the emplacement of the Pikes Peak Granite

The Precambrian history of the area, prior to the emplacement of the Pikes Peak Granite, can be partly deciphered from the composition, structure, and sequence of the older rocks. In general, a change in conditions from those of the catazone to the mesozone, and possibly to the epizone is indicated, along with a parallel change in metamorphic conditions from plastic to cataclastic, and finally to essentially an ametamorphic environment.

The oldest rocks of the district are the complexly interlayered gneisses and schists comprising the Idaho Springs(?) Formation, which, with the possible exception of the amphibolites, are almost certainly sedimentary rocks transformed by intense regional metamorphism. The quartz diorite gneiss and granite gneisses are inferred to be, respectively, syntectonic mafic and granitic igneous rocks which were intruded as sheet-like bodies, and metamorphosed during the same period. The deformation was largely plastic, and the rocks recrystallized mimetically. The metamorphic grade is that of the amphibolite facies; the concordant contacts and lack of cataclastic effects suggests a high intensity metamorphic environment typical of the catazone.

Somewhat later the rocks were affected by a cataclastic deformation which, in the area thus far mapped, is shown mainly in a belt of northeasterly trending broken folds in the SW$\frac{1}{4}$ of Section 21, and possibly in a secondary shear foliation locally developed in the Idaho Springs(?) Formation over a wider area.

The emplacement of the biotite-muscovite granite followed the first recognized period of faulting, in which large north-northwest trending faults were formed. The granoblastic texture of the granite suggests, however, that this faulting may have occurred in the late stages of regional metamorphism.

Gabbro, the associated quartz monzonites, and the Pikes Peak Granite apparently were emplaced under ametamorphic conditions. They are sharply discordant to the older rocks and have not been metamorphosed. Age determinations on typical Silver Plume Granite, which is believed to be approximately correlative with the biotite-muscovite granite of the Lake George area, and on the Pikes Peak Granite suggest that the emplacement of the two granites was separated by at least 250 m.y., or almost half the total of post-Precambrian time. The lack of metamorphism of gabbro and associated quartz monzonites and other criteria previously cited are believed to indicate that these rocks are closer to Pikes Peak than to Silver Plume age.

CHAPTER IV

PIKES PEAK GRANITE

General

Pikes Peak granite underlies all the northeast part of the Lake George beryllium area (plate 1). The main body of granite appears to be a lobe extending about due south from the southwest edge of the Pikes Peak batholith (fig. 8); for convenience in discussion this body is called the Tarryall lobe. West of the Tarryall lobe in Sections 4 and 5, and separated from it by remnants of metamorphic and older igneous rocks, is a satellitic body about 1/2 mile across, termed the China Wall pluton from the local name of a canyon cut in granite about 1/2 mile to the east. A second, smaller body is exposed near the Boomer mine in Section 21. The Boomer pluton (stock) is the host for the major beryllium deposits of the area. Thin dikes of Pikes Peak Granite cut the older Precambrian rocks at several places. The major concentrations of dikes are in the area near the Boomer mine (plate 11), and in an area just west of the Tarryall lobe in Section 16. Dikes of Pikes Peak Granite also follow the hanging wall and footwall of the large biotite-muscovite granite dike exposed in the northwest part of the map area in Sections 4 and 9.

At first glance the Pikes Peak Granite of the area is massive. Close inspection shows, however, that certain facies of the granite locally are weakly foliated due to alinement of feldspar crystals, or, rarely, the alinement of inclusions. In most places the foliation dips steeply. Particularly in the outer part of the Tarryall pluton the foliation appears to parallel the atitude of the granite contacts; at many places, however, the foliation shows no obvious relation to any structure.

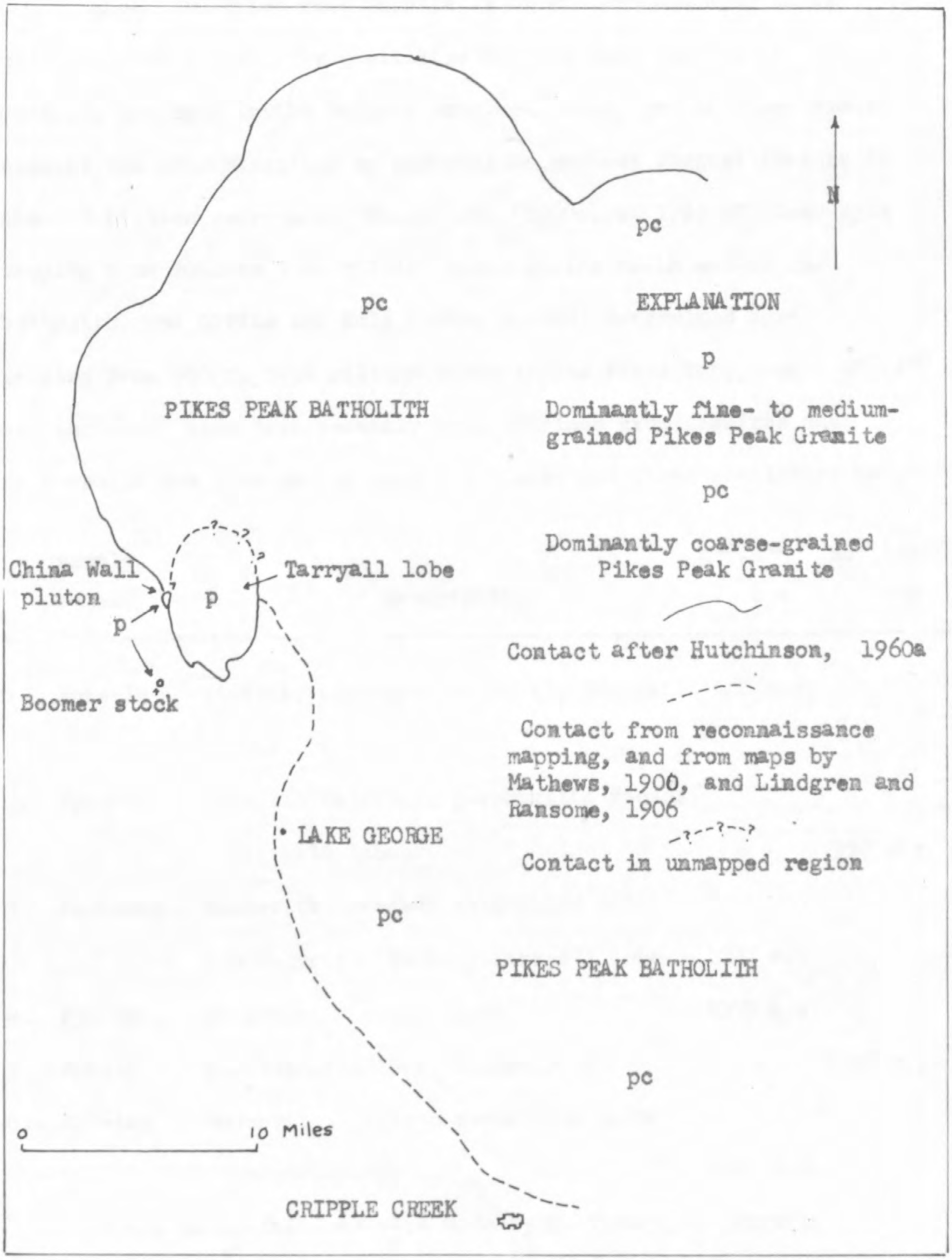

FIGURE 8. RELATION OF PIKES PEAK GRANITES, LAKE GEORGE BERYLLIUM AREA, TO THE PIKES PEAK BATHOLITH

Age. The Pikes Peak Granite is of Precambrian age; it is overlain unconformably by quartzites of late Cambrian age at Colorado Springs; in the Deckers embayment area, and in other places; several age determinations by radioactive methods suggest that it is about 1 billion years old. Hutchinson (1960a, p. 171) obtained ages ranging from 1050 to 1080 million years in the north end of the batholith, and Giffin and Kulp (1960, p. 220) determined ages ranging from 980 to 1030 million years in the Pikes Peak area. K^{40}/A^{40} and Rb^{87}/Sr^{87} ages have recently been obtained from granites and greisens of the Lake George beryllium area, and these are listed below:

Sample number	Description	K^{40}/A^{40} age	Rb^{87}/Sr^{87} age
1. Pprs-1b	Biotite; porphyritic facies, Tarryall lobe.	980 m.y.	
2. Pprs-1k	Potassic feldspar; porphyritic facies, Tarryall lobe.		950 m.y.
3. Pprs-1mg	Muscovite; greisen associated with porphyritic facies, Tarryall lobe.	1020 m.y.	
4. Ppb-1m	Muscovite; Boomer stock	1000 m.y.	
5. Ppb-1k	Potassic feldspar; Boomer stock		1020 m.y.
6. Ppb-1mg	Muscovite; greisen associated with Boomer stock.	1000 m.y.	

These determinations were made by H. Thomas, R. Marvin, F. Walthall, C. Hedge, and W. Long, Isotope Geology Branch, U. S. Geological Survey, Report of May 4, 1962.

Cross-cutting relations and the lack of metamorphic effects in the Pikes Peak Granite show that it is the youngest of the major intrusives of this part of the Colorado Front Range. It intrudes biotite-muscovite granite in the Lake George area as well as gabbro and related quartz monzonite and the rocks comprising the metamorphic complex. Hutchinson (1960c) has found that the granite is younger than a coarse microcline augen gneiss and the Cripple Creek Granite southeast of the Lake George area. Previously, the augen gneiss had been regarded as sheared Pikes Peak Granite, and the Cripple Creek Granite was tentatively considered younger than the Pikes Peak (Mathews, 1900, p. 223, 240). The Cripple Creek Granite, like the biotite-muscovite granite of the Lake George area, probably belongs to the general group of two mica rocks characterized by potassic feldspar tabs and a flow foliation generally referred to in the Front Range as Silver Plume Granite.

Facies and classification. The Pikes Peak Granite of the Lake George area was divided during mapping into three main facies, termed granular, porphyritic, and fine-grained, primarily on the basis of texture, grain-size, and other megascopic characteristics (table 5). Further study of the granites has shown that, in general, the textural and grain-size breakdown is reflected in composition. The granite facies comprising the three main zones (plate 1) of the Tarryall lobe are termed the main granites; granites found in the China Wall pluton, the Boomer stock, and dike rocks are termed the satellitic granites.

TABLE 5

MEGASCOPIC CHARACTERISTICS OF THE MAIN FACIES OF THE PIKES PEAK GRANITE, LAKE GEORGE BERYLLIUM AREA

	Granular facies	Porphyritic facies	Fine-grained facies
Texture:	Granitoid	Seriate porphyritic	Granitoid to aplitic; locally sparsely porphyritic
Grain-size:	Medium grained		
	Rarely to 7-8 mm	Average grain-size appreciably less than granular facies. Potassic feldspar phenocrysts locally as much as 10 mm long.	Generally less than 1 mm; locally grades into porphyritic facies, and average grain size is about 1 mm.
Associated dike rocks:	Common fine-grained granite dikes: sparse porphyritic dikes. Very sparse pegmatites, locally miarolitic.	Dikes of fine-grained granite are found in a zone along Tarryall Creek; cut by one fine-grained dike in China Wall pluton. No other dikes.	Local pegmatitic segregations, in part miarolitic.
Inclusions:	Inclusions are very rare; faint inclusions are seen in places near contacts with metamorphic rocks.	Inclusions are common in porphyritic granite of the Tarryall lobe. Many sharp-walled fine-grained light-colored biotite gneiss(?) inclusions; sparse sharp-walled amphibolite inclusions.	Inclusions are abundant only in the fine-grained dike zone in the porphyritic granite along Tarryall Creek.

Both the porphyritic and granular facies are mainly composed of medium-grained (1-5 mm) granite. Facies of the Pikes Peak Granite very locally developed in the Lake George beryllium area are coarse-grained (cm-sized) equigranular and porphyritic granite and pegmatite. The coarse-grained equigranular and porphyritic granite crops out only at the northern edge of the map, but it forms most of the Pikes Peak batholith north and east of the beryllium area.

All three main facies of the granite are developed in the Tarryall lobe and the China Wall pluton. The granular facies forms an outer zone of the Tarryall lobe and the inner zone of the China Wall pluton; porphyritic granite forms an intermediate zone in both bodies, and fine-grained granite forms the outer part of the China Wall pluton and the inner zone of the Tarryall lobe. The Boomer stock and many of the dike rocks are composed of fine-grained granite; a few dikes are composed of granular or porphyritic types of granite.

Pegmatites of mappable size are very rare, but many fine-grained, aplitic rocks contain thin pegmatitic zones. Locally the granular granite contains pegmatitic segregations associated with aplitic dikes, and in these locales granite, and the associated pegmatite and aplite may be miarolitic. The miarolitic cavities range from less than an inch to at least six inches across. Most are lined mainly with coarse crystals of microcline and clear or smoky quartz, but topaz occurs sparcely in many cavities. No pegmatites have been found in the porphyritic granite facies.

The main facies of granite characteristic of the Lake George beryllium area are somewhat younger than the typical coarse-grained Pikes Peak Granite. Medium-grained granite typical of the granular facies of the beryllium area cuts coarse-grained granite typical of the main batholith just north of the mapped area in Section 6, T. 11 S., R. 71 W., and fine-grained granite of the China Wall pluton cuts coarse-grained granite within the mapped area north of Tarryall Creek in Section 4 (T. 11 S., R. 72 W.).

In regards to the three main textural facies characteristic of the area, it is believed that, in general, granite of the granular facies is somewhat older than granite forming the porphyritic facies which, in turn, is somewhat older than the fine-grained granite. It is recognized from lack of chilled contacts, however, that the age differences between different facies are slight, and that any difference may actually be in the time of crystallization rather than the time of emplacement. It is also recognized that all bodies of one textural facies may not be exactly of the same age.

In the main granites comprising the Tarryall lobe the relative age of crystallization of granular and porphyritic facies seems definitely established. Dikes of porphyritic granite which are oriented about parallel to the main facies contact cut the granular type in Section 1 and just north of the map area in Section 4. The ages of porphyritic and fine-grained main granites of the lobe are less certain. It is assumed from the central location of the main mass of fine-grained granite that it was fluid after the porphyritic facies was largely crystalline.

Both granular and porphyritic rocks of the Tarryall lobe are cut by fine-grained dike rocks.

The contacts of the Pikes Peak Granite with older igneous and metamorphic rocks are generally well exposed, in several places in mine openings. The contacts are invariably sharp and in most places show no apparent contamination of the granite by wall-rock or alteration of the wall rocks by the granite. In a few areas segments of the contact are extensively greisened. Inclusions are abundant in only two rock bodies; namely, the porphyritic facies of the Tarryall lobe, particularly near its contact with the granular facies, and in the fine-grained dike rocks which parallel this contact along Tarryall Creek. Most of the inclusions are composed of a fine-grained pink to light gray biotitic rock with sparse feldspar crystals; a few inclusions are composed of amphibolite. Sharp walled inclusions have also been noted very locally in the fine-grained granite forming the Boomer stock.

The Pikes Peak Granite of the Lake George area is characterized chemically by a low calcium content and mineralogically by high fluorite or topaz content, and by the presence of zircon as the next most abundant accessory mineral after fluorite or topaz. All except micrographic varieties of fine-grained granite have two feldspars, a sodic plagioclase which forms subhedral to euhedral tabs and a subhedral potassic alkali feldspar. The potassic feldspar is coarsely perthitic in the granular facies and in the phenocrysts of the porphyritic facies; the size and amount of the perthitic intergrowths seem to decrease with grain size of the rock, and only occasional plagioclase intergrowths are seen in the alkali feldspar of the fine-grained types or in the matrix of porphyritic granite.

The rocks are all considered to be granites, although under some other classifications some of the rocks could be considered quartz monzonites, granodiorites, or quartz diorites. One reason that a Johannsen-like classification is not adopted is that the oldest main granite (granular facies of the Tarryall lobe) would fall right on the dividing line in most modal classifications between granite and quartz monzonite (fig. 8), but the younger rocks range in composition from leuco-alkali quartz monzonite to leuco-alkali granodiorite and rarely to leuco-alkali quartz diorite. At least part of this variation can be apparently explained by changes in the "artificial granite" system, SiO_2-albite-orthoclase-water, and it seems more logical to consider all the rocks as granites than to consider the youngest facies to be quartz monzonites, granodiorites, or quartz diorites.

Petrography and composition

Main granites of the Tarryall lobe. The Tarryall lobe shows a general concentric distribution of three different kinds of granite, modified at its southern end by the appearance of local and zonally anomalous border facies. The lobe is mainly composed of an outer zone of medium-grained equigranular granite, an intermediate zone of medium-grained seriate porphyritic granite, and an inner zone of fine-grained granite. The rocks comprising these zones are collectively termed the main granites and, respectively, belong to the granular, porphyritic, and fine-grained facies of the Pikes Peak Granite.

Modal or chemical analyses of representative and average rocks of the three facies are given in table 6. The results of all modal analyses of the Pikes Peak Granite and a brief discussion of the method of analysis is given in Appendix A to this report. Locations of samples of the main granites are shown in figure 1-A, Appendix A.

The granular facies is composed of a light tan to pink, medium-grained equigranular granite which consists chiefly of quartz, perthitic potassic alkali feldspar, and sodic plagioclase in hypidiomorphic-granular relation. Biotite and sparse opaques are the only mafic minerals; muscovite is present in much of the granite, but in general in greatly subordinate amounts to biotite; fluorite and zircon are the characteristic accessories.

On an average the granular granite of the Tarryall lobe is composed of more than 95 percent perthitic potassic feldspar, sodic plagioclase, and quartz, generally in that order of abundance; most of the specimens cluster near the 2/3ds alkali feldspar line in a quartz-potassic feldspar-plagioclase diagram (fig. 9).

The potassic alkali feldspar is a coarse microcline microperthite of vein or patch type (plate 2) in subhedral grains xenomorphic against plagioclase. The potassic phase of the perthite is pale pink and dusty in microscopic appearance probably because of very fine disseminated hematite and slight dueteric alteration. The plagioclase lamellae are apparently unaltered. The potassic

TABLE 6

MODAL (VOLUME PERCENT), CHEMICAL AND NORMATIVE (WEIGHT PERCENT) COMPOSITION OF REPRESENTATIVE AND AVERAGE ROCK TYPES IN THE TARRYALL LOBE, LAKE GEORGE BERYLLIUM AREA, PARK COUNTY, COLORADO

	Representative rocks, granular facies			Average[1] granular facies		Representative rocks, porphyritic facies				Average[2] porphyritic facies	Representative rocks, fine-grained facies		Average[3] fine-grained facies
	BA-657	BA-822	BA-944		TR-83	BA-872	BA-687	BA-719	BA-889		TI-20	TI-36	
Modal composition													
Quartz	27.8	39.8	31.6	31.2	32.8	38.2	32.9	27.8	25.5	30.25	28.8	27.0	29.7
Plagioclase	20.2	22.2	24.9	21.75	35.2	32.9	31.6	34.2	36.6	33.65	36.6	37.4	35.3
Alkali feldspar	46.0	32.0	40.0	42.7	27.3	25.6	30.3	33.4	32.0	31.25	27.3	29.2	28.4
Potassic feldspar fraction	37.2	24.8	32.5	---	23.5	23.9	28.6	29.2	30.0	---	26.8	---	----
Albitic fraction	8.8	7.2	7.5	---	7.8	1.7	1.7	4.2	2.0	---	0.5	---	---
Biotite	5.3	5.1	2.8	3.3	3.3	0.6	3.2	3.1	4.2	2.2	4.8	4.0	2.9
Muscovite	0.1	0.2	0.1	0.35	0.6	2.5	0.7	0.8	0.8	1.85	1.8	2.2	3.2
Fluorite	0.6	0.6	0.5	0.6	0.8	0.2	0.9	0.7	0.9	0.5	0.4	0.2	0.4
Topaz	0	Tr.	Tr.	Tr.	0	0	0.1	0	0	0.01	0.1	0	0.01
Iron oxides	Tr.	0	0.1	0.07	Tr.	0	0.2	0	0	0.04	0.2	Tr.	Tr.
Zircon	0	0.1	Tr.	0.04	Tr.	0	0.1	Tr.	Tr.	0.03	Tr.	Tr.	0.08
Others	0	Apatite, tourmaline	Tr.	Apatite, kaolinite						Tr. kaolinite, apatite			
Chemical composition													
SiO_2	74.47	75.83	74.51		74.42	74.24	74.03	74.28	73.58				
Al_2O_3	12.93	12.65	13.09		13.20	13.72	13.44	13.43	13.56				
Fe_2O_3	0.60	0.36	0.47		0.85	1.08	0.48	0.52	0.50				
FeO	1.26	0.90	1.48		0.63	0.41	1.17	1.03	1.17				
MgO	0.05	0.02	0.03		0.05	0.05	0.06	0.06	0.05				
CaO	0.76	0.57	0.75		0.69	0.80	0.80	0.70	0.89				
Na_2O	3.72	3.79	3.81		4.16	4.29	4.18	4.24	4.17				
K_2O	5.22	4.89	5.21		4.81	4.36	4.82	4.81	4.98				
H_2O (+)	0.20	0.20	0.18		0.20	0.33	0.17	0.17	0.25				
H_2O (-)	0.04	0.07	0.04		0.13	0.14	0.06	0.08	0.05				
TiO_2	0.13	0.09	0.11		0.09	0.09	0.11	0.09	0.12				
P_2O_5	0.00	0.01	0.01		0.01	0.01	0.02	0.01	0.01				
MnO	0.04	0.03	0.03		0.02	0.01	0.05	0.05	0.03				
CO_2	0.01	0.02	0.01		0.00	0.01	0.01	0.02	0.02				
Cl	0.02	0.01	0.01		0.01	0.01	0.02	0.02	0.01				
F	0.45	0.39	0.48		0.43	0.44	0.52	0.47	0.51				
Subtotal	99.90	99.83	99.82		99.70	99.99	99.94	99.98	99.90				
Less O	.19	.16	.20		0.18	.19	.22	.20	0.21				
Total	99.71	99.67	99.62		99.52	99.80	99.72	99.78	99.69				
Normative composition													
Q	31.7	34.5	32.0		31.7	32.6	30.4	30.6	29.4				
or	31.1	28.9	30.6		28.5	25.6	28.4	28.4	29.5				
ab	31.4	32.0	32.0		35.1	36.2	35.6	35.6	35.1				
an	0.6	0	0		0	0.6	0	0	0.6				
cor	0.9	1.1	1.2		1.2	1.8	1.6	1.3	1.1				
femic	2.7	2.2	2.3		1.8	1.6	2.5	2.5	2.6				
fluorite	0.9	0.8	1.0		0.9	0.9	1.1	0.9	1.1				
An (weight percent) of normative plagioclase	1.9	0	0		0	1.6	0	0	1.7				

1 Average of 29, table 1-A, Appendix A

2 Average of 27, table 1-A, Appendix A

3 Average of 6, table 1-A, Appendix A

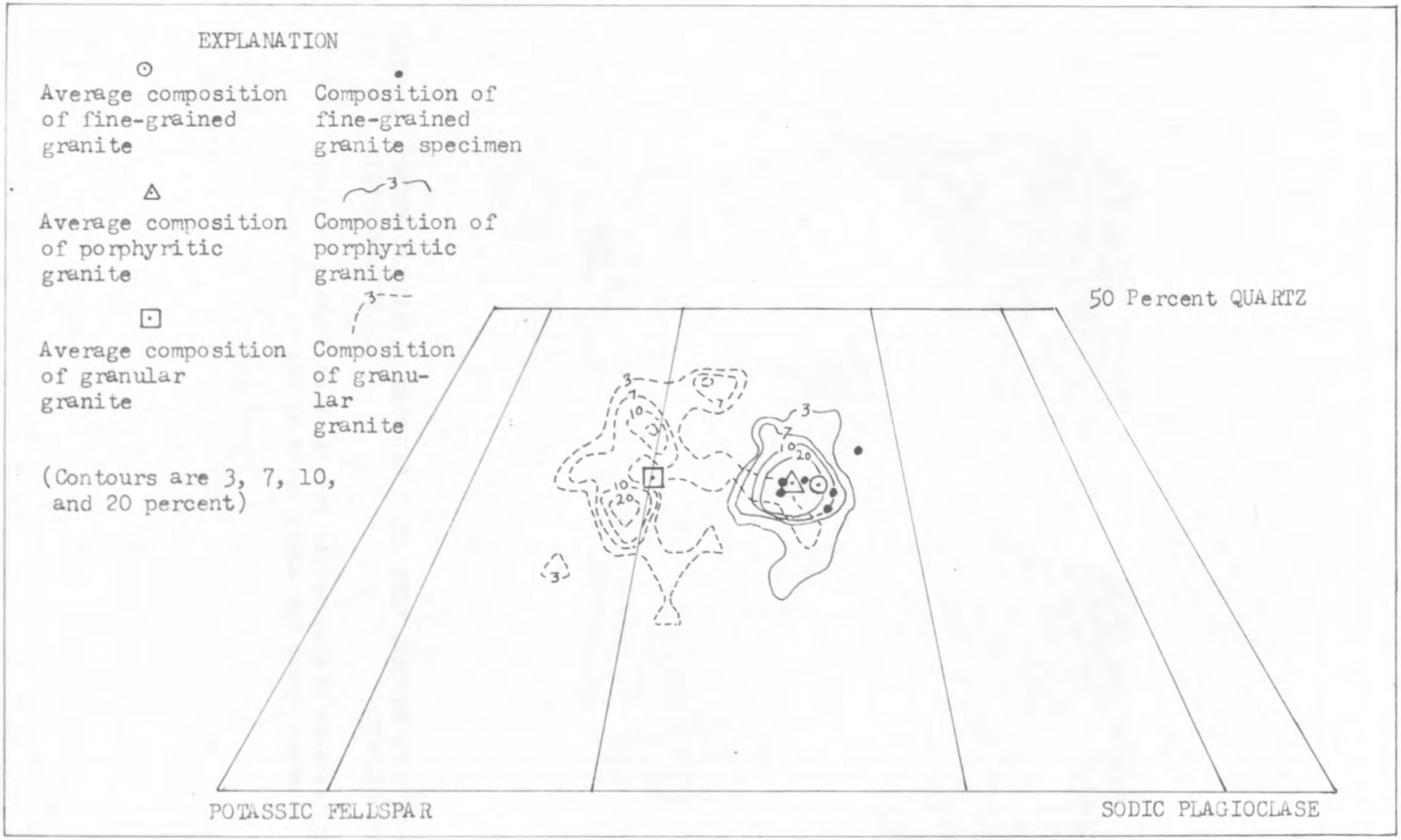

FIGURE 9.-- MODAL COMPOSITION OF MAIN GRANITES, TARRYALL LOBE

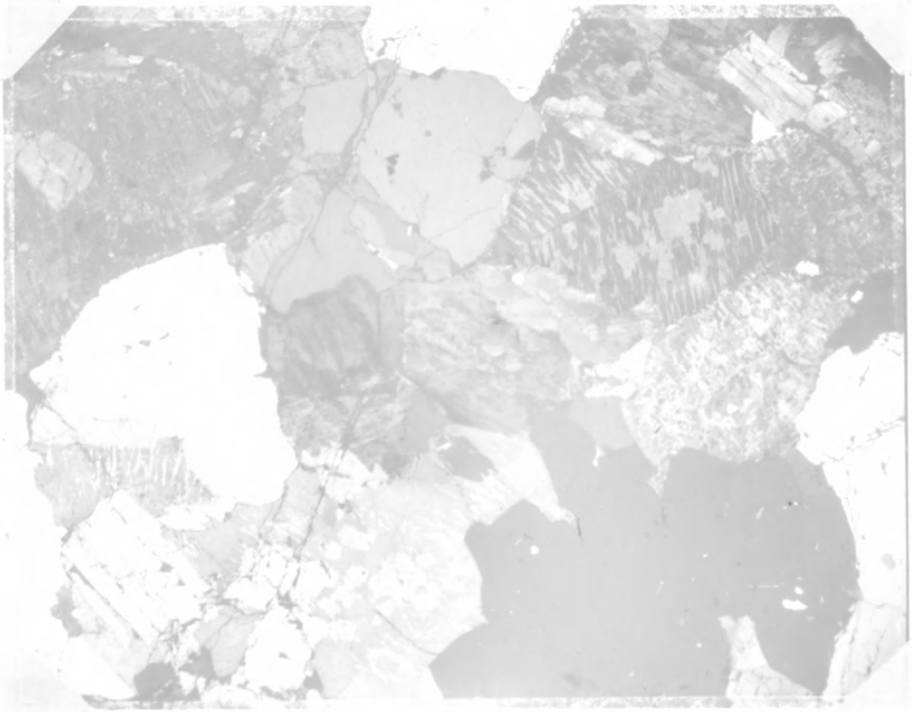

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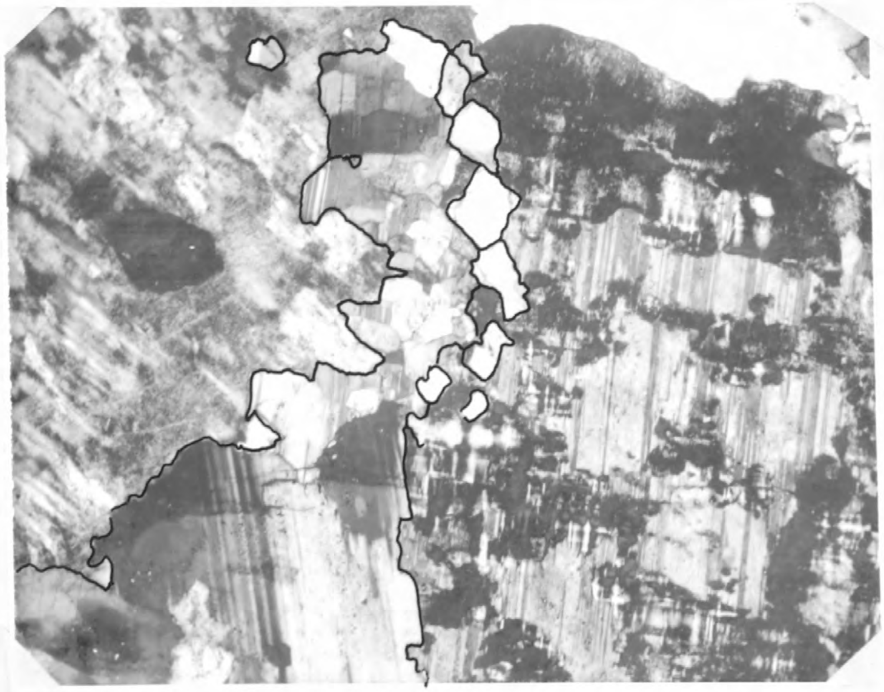
PLATE 2. PHOTOMICROGRAPH: GRANULAR PIKES PEAK GRANITE SHOWING COARSE MICROPERTHITE. CROSSED NICOLS.

(Quartz is light to dark gray structureless mineral; twinned plagioclase grains in upper right and lower corners) feldspar includes small tabs of plagioclase some of which are cut by the albitic lamellae of the perthite. Locally either the potassic or albitic phases of the perthite apparently replace sodic plagioclase.

Potassic and albitic phases of the potassic feldspar were counted separately in the modal analyses; the average ratio is about 78:22 (potassic feldspar:albite). The range in the ratio was only from 70-90:30-10. The small range in proportions of the perthitic components, and scarcity of secondary plagioclase in the granular facies, suggests strongly that the plagioclase fraction of the perthite is of exsolution rather than replacement origin.

Plagioclase, exclusive of that found in perthitic intergrowths, forms subhedral to euhedral crystals which are polysynthically twinned. The plagioclase is probably slightly finer-grained on an average than the potassic alkali feldspar and also has a wider range in grain size. Many of the finer-grained plagioclase crystals are included in potassic feldspar, or form aggregates between two potassic feldspar grains (plate 3). The coarser crystals in many places form interlocking aggregates; locally they are also partly mantled by the potassic alkali feldspar.

Composition of the plagioclase as determined by extinction angles measured on the universal-stage ranges from An_0 to An_{14} (table 1-A; Appendix A), and on the average is medium albite. The plagioclase is not obviously zoned, but an increase in extinction angles from the center to the edge in some grains, and concentration of alteration products in the centers of some grains indicate that



50X

PLATE 3. PHOTOMICROGRAPH: AGGREGATE OF SMALL PLAGIOCLASE CRYSTALS BETWEEN LARGE PERTHITIC FELDSPAR CRYSTALS. CROSSED NICOLS.

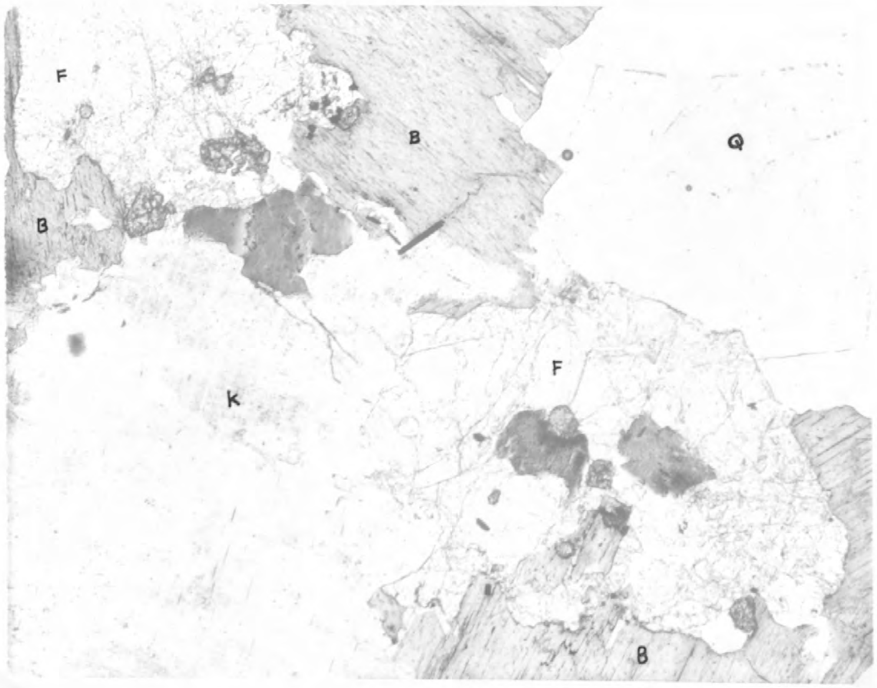
the plagioclase is not uniform in composition and is more calcic in the centers.

Quartz generally occurs in subhedral to anhedral grains or aggregates; locally it is idiomorphic against potassic alkali feldspar. Quartz also forms symplectic border zones around a relatively small proportion of the biotite, and locally appears to replace plagioclase, potassic feldspar, and biotite.

Biotite typically forms euhedral to subhedral books which occur interstitially in the granite. It is accompanied by interstitial fluorite (plate 4A), zircon (included in the mica or fluorite), and, locally, by muscovite. On the average muscovite is greatly subordinate to biotite, rarely is it dominant (table 1-A; Appendix A). It may occur as a thin rim on the biotite, in zones cutting across biotite crystals, or in crystals intergrown with biotite. The first two modes of occurrence, which are considered to be secondary or deuteric, are dominant. Two (TR-99 and T1-8) of the four high-muscovite rocks found in the facies (table 1-A, Appendix A) contain appreciably more plagioclase than the average for the granular facies; the other two, (BA-967 and TR-42) are nearer the average composition but TR-42 is slightly altered.

Very small crystals of fluorite, white mica, and topaz, also occur in plagioclase, and in this mode of occurrence are considered to be secondary or deuteric in origin. Probably not more than 1/10th of the fluorite occurs in this fashion.

Of the main components of the granular facies (plagioclase, potassic feldspar, and quartz) plagioclase seems definitely to



A. 50X

B. 50X

PLATE 4. PHOTOMICROGRAPHS: A. FLUORITE ASSOCIATED WITH BIOTITE. B. INTERGROWTH OF POTASSIC FELDSPAR AND QUARTZ. BOTH PLAIN LIGHT.

(F-fluorite; B-biotite; K-potassic feldspar; q-quartz, the quartz in B. forms blebs in large feldspar crystal) have begun to crystallize before quartz or potassic feldspar. Plagioclase occurs in randomly oriented small and moderate-sized tabs included in or partly mantled by the alkali feldspar, and in small embayed remnants in quartz, but, in contrast, it never appears to include either potassic feldspar or quartz. Locally the plagioclase is replaced by potassic or albitic components of the alkali feldspar, and albitic perthite lamelae rarely vein the plagioclase tabs included in potassic feldspar. The relations between quartz and potassic feldspar are less certain; quartz is locally idiomorphic against potassic feldspar, but it also locally appears to include or replace the feldspar. Tentatively the quartz and potassic feldspar are regarded as crystallizing at about the same time with the slightly higher degree of crystallinity of quartz due to a greater inherent tendency towards idiomorphism. Biotite and its associates zircon and fluorite probably began to form about the same time as plagioclase.

The lack of porphyritic texture suggests, perhaps, that crystallization was relatively rapid with a small interval separating the beginning of crystallization of plagioclase from that of quartz and potassic feldspar. In contrast to some of the fine-grained rocks, most of the textures of the granular facies can be explained by crystallization from a melt, modified only slightly by deuteric recrystallization. The deuteric effects apparent are the formation of some muscovite, fluorite, and topaz, and, possibly, the minor replacement relations involving quartz and potassic feldspar.

Chemically the granular rock-type of the Tarryall lobe is peraluminous and highly silicic (table 6). It is characterized by a very high fluorine content: the average (arithmetic mean) fluorine content of 3 granite samples is 0.44 percent which compares with Turekian and Wedepohl's (1961, table 2) estimate of .085 percent fluorine for comparable low calcium granitic rocks and exceeds any value given by Correns (1956, p. 184-85) for plutonic rocks. CaO and MgO are present in very small amounts, and only one of the three analyzed samples shows any normative anorthite. In part, however, the sparcity of normative anorthite is misleading: the norm assigns all the fluorine to fluorite, some of it, however, enters into biotite, muscovite, and topaz. If the modal amount of fluorite is used as a control on the amount of CaO to assign to normative fluorite, then the average calculated An content of the plagioclase is 6.5 mole percent. The relative abundance of iron oxides with respect to MgO suggests that the biotite is an iron-rich type.

All granular rocks analyzed spectrographically contained trace amounts of Be, Ba, Ce, Cu, Ga, La, Li, Nb, Pb, Sn, Sr, Y, Yb, and Zr (table 1-B, Appendix B). With the exception of Ba, Sr, Cu, Zr, and possibly Ce, these elements are somewhat more abundant in the granular Pikes Peak Granite than in average low-calcium granitic rocks of Turekian and Wedepohl.

The porphyritic granite of the Tarryall lobe is generally light tan to pale pink in color; slightly altered granite is pink to brownish red. The porphyritic granite is appreciably finer-grained than the granite of the granular facies. Scattered potassic feldspar phenocrysts, as much as 10 mm long, and finer-grained, more dispersed mica is also characteristic of the porphyritic facies. In thin section the texture is seriate porphyritic and crystal relations hypidiomorphic. Plagioclase, in particular, shows a seriate grain-size relation forming tabs ranging, commonly, from about 1/2 mm to about 4 mm long and, rarely, to as much as 7 mm long. Most of the conspicuous phenocrysts of the rock are feldspar, but locally quartz forms phenocrysts and the rock has a "quartz porphyry" aspect.

The rock is composed on an average of nearly equal proportions of quartz, sodic plagioclase, and perthitic potassic feldspar which together make up about 95 percent of the rock; the rest is mainly biotite or muscovite (table 6, fig. 8; table 1-A, Appendix A). Fluorite, zircon, opaques, topaz, kaolinite(?), and apatite, in approximate decreasing order of abundance, comprise the accessory minerals.

The potassic alkali feldspar is mainly microcline microperthite, which forms subhedral phenocrysts or occupies an interstitial or hyalo-ophitic position in finer-grained parts of the rock. The potassic feldspar phenocrysts are coarsely perthitic in the same fashion as potassic feldspar in the granular facies, but the finer-grained potassic feldspars are noticeably less perthitic. This is reflected in the larger average potassic fraction (92 percent vs. 78 percent) in the alkali feldspar of the porphyritic facies relative to that of the granular facies.

Most of the plagioclase occurs in fine- to medium-grained sub- to euhedral tabs, on an average composed of medium albite. Small tabs are included in irregular fashion in coarser potassic feldspars, and medium-grained crystals are partly mantled by potassic feldspar. As in the granular facies, some tabs are broken and have been veined by the potassic feldspar. A clear, non-twinned sodic plagioclase is present in small amounts as a late mineral in the porphyritic facies.

Quartz is present, in various rocks of the facies, in euhedral crystals, "rounded" phenocrysts, and irregular aggregates of anhedral crystals. In some thin sections, the quartz phenocrysts are lobate against the adjacent minerals suggesting replacement. Most of the quartz is, however, regarded as magmatic (primary). The quartz showing replacement relations is inferred to be late magmatic or deuteric showing replacement relations where it was added to the boundaries of earlier quartz.

On an average biotite and muscovite are almost equally abundant, although the relative amounts vary widely. In all except one thin section muscovite is more abundant than the average amount contained in the granular rocks of the Tarryall lobe. The muscovite occurs in several ways. It forms interstitial, probably primary, crystals with or without associated biotite, and forms as a secondary mineral after biotite and locally potassic feldspar. Sparse sericite also occurs with topaz in plagioclase. Biotite is generally interstitial, but some appears to be secondary after plagioclase.

The accessories, chiefly fluorite and zircon are, as in the granular facies, generally associated with mica. Smaller amounts of fluorite and topaz occur as replacements of plagioclase. Fine-grained aggregates of a low-birefringent mineral with moderate relief, tentatively identified as kaolinite, also occurs in the mica-fluorite aggregates, and as a replacement product, in part associated with fluorite, of feldspar.

The presence of a small amount of late sodic plagioclase and the relatively common lobate contacts shown by quartz suggest somewhat more extensive secondary effects than inferred in the granular facies. In general, however, most of the texture of the porphyritic facies can also be interpreted as due to crystallization from a melt. The sequence of beginning of crystallization, namely, plagioclase, then quartz and potassic feldspar, inferred for the granular facies is also believed to apply to the porphyritic facies.

The porphyritic granite possibly contains slightly more Be than either the granular or the fine-grained granites of the Tarryall lobe. Excluding one high Be sample (BA-872, table 1-B, Appendix B), the porphyritic granite averages about 7 ppm Be in contrast to 6 ppm and 5 ppm, respectively, in granular and fine-grained rocks. Although the average for the fine-grained main granites of the Tarryall lobe rocks is based on only two samples, in general it has been found that all fine-grained granites of the area average about 5 ppm so the two samples may be representative.

The average estimated abundance of some other trace elements compared with their abundance in the granular granite in the Tarryall lobe and the low-calcium granitic rocks of Turekian and Wedepohl (1961) are:

	Ba	Ce	Cu	La	Li	Nb	Pb	Sn	Y	Yb
					(percent)					
1.	.02	not calc	.0007	.007	.0098	.007	.002	.003	.01	.0015
2.	.015	<.02	.0007	.01	.0080	.01	.003	.002	.01	.0015
3.	.0840	.0092	.0010	.0055	.0040	.0021	.0019	.0003	.0040	.0004

1. Main porphyritic granite.
2. Main granular granite.
3. Low-calcium granitic rocks

All averages of the granites are geometric means reported to the nearest value used in the semiquantitative spectrographic system (p. 9). Lithium was determined quantitatively by a spectrographic method.

The fine-grained granite classed in the main granite group (p. 75) forms the inner zone of the Tarryall lobe, and grades outward into the porphyritic facies; it also forms a small outlying body in Section 11 about 2000 feet south of the main body. The fine-grained rocks forming dikes and border zones on the Tarryall lobe are discussed in the succeeding section (p. 90-93). Typical fine-grained granite is pale pink to brownish red in color and nearly equigranular; its contact with the porphyritic facies is drawn on the basis of a slight increase in average grain-size, and the presence of feldspar phenocrysts in the porphyritic facies. Only 6 modal analyses were made so the compositional data are not nearly as complete as on the porphyritic and granular facies. The average composition, in terms of quartz-plagioclase-potassic feldspar, is shifted slightly from that of the porphyritic type, but only one of the six samples studied lies outside the field of composition of the porphyritic granite shown on figure 9.

Microscopically the relations of plagioclase and potassic feldspar are the same as those observed in granular and porphyritic rocks, that is, the plagioclase occurs mainly as sub- to euhedral tabs with interstitial or mantling potassic alkali feldspar. The relative amounts of perthitic plagioclase are very low (table 1-A, Appendix A). Lobate borders on quartz suggesting replacement reactions are common.

On an average muscovite is more abundant than biotite, but the relative abundances are highly variable. In the muscovite-rich samples, a high proportion of the muscovite occurs as irregular replacements of the potassic phase of the alkali feldspar.

<u>Dike-rocks and border facies of the Tarryall lobe</u>. The general concentric pattern of the main granites of the Tarryall lobe is interrupted by numerous thin granite dikes in the granular facies, by the dike zone near Tarryall Creek, and is significantly modified at the south end of the lobe by fine-grained and porphyritic granite which forms border zones on the granular granite. In detail, the border zones are developed on lobes of secondary scale which extend southeasterly from the Tarryall lobe.

In several places fine-grained and porphyritic granites are associated near the borders of the lobe, and appear to intergrade. For example, porphyritic granite and fine-grained granite occur along the almost flat contact of the Pikes Peak Granite with quartz monzonite porphyry (plate 1, section B-B'). The succession going toward the contact from the granite is normal granular facies, porphyritic granite, and fine-grained granite. The fine-grained granite has a psuedostratified appearance and contains sparse pegmatite and greisen zones, at least one of which is beryl-bearing.

A fine-grained border facies which has associated beryllium deposits is found in the Mary Lee mine area, Section 22, extending as a lobe trending southeasterly from the main body of granite.

Dikes and border facies of the Tarryall lobe are represented by 15 samples (fig. 10, table 2-A, Appendix A). Several different rocks are represented, so this number of samples is inadequate to characterize all the granites, but they appear to show some common characteristics which distinguish them from the main granites, namely:

(1) The border facies rocks are probably more quartzose on an average than are the main granites of the Tarryall lobe.

(2) Topaz is locally more abundant than fluorite; it occurs almost to the exclusion of fluorite in a few rocks.

(3) Mineral intergrowths of various kinds are more common than in the main granites. One type of intergrowth involves potassic alkali feldspar and quartz, with the quartz forming many round blebs through the outer parts of the potassic feldspar crystals (as in plate 4B). This type of intergrowth is characteristic of porphyritic

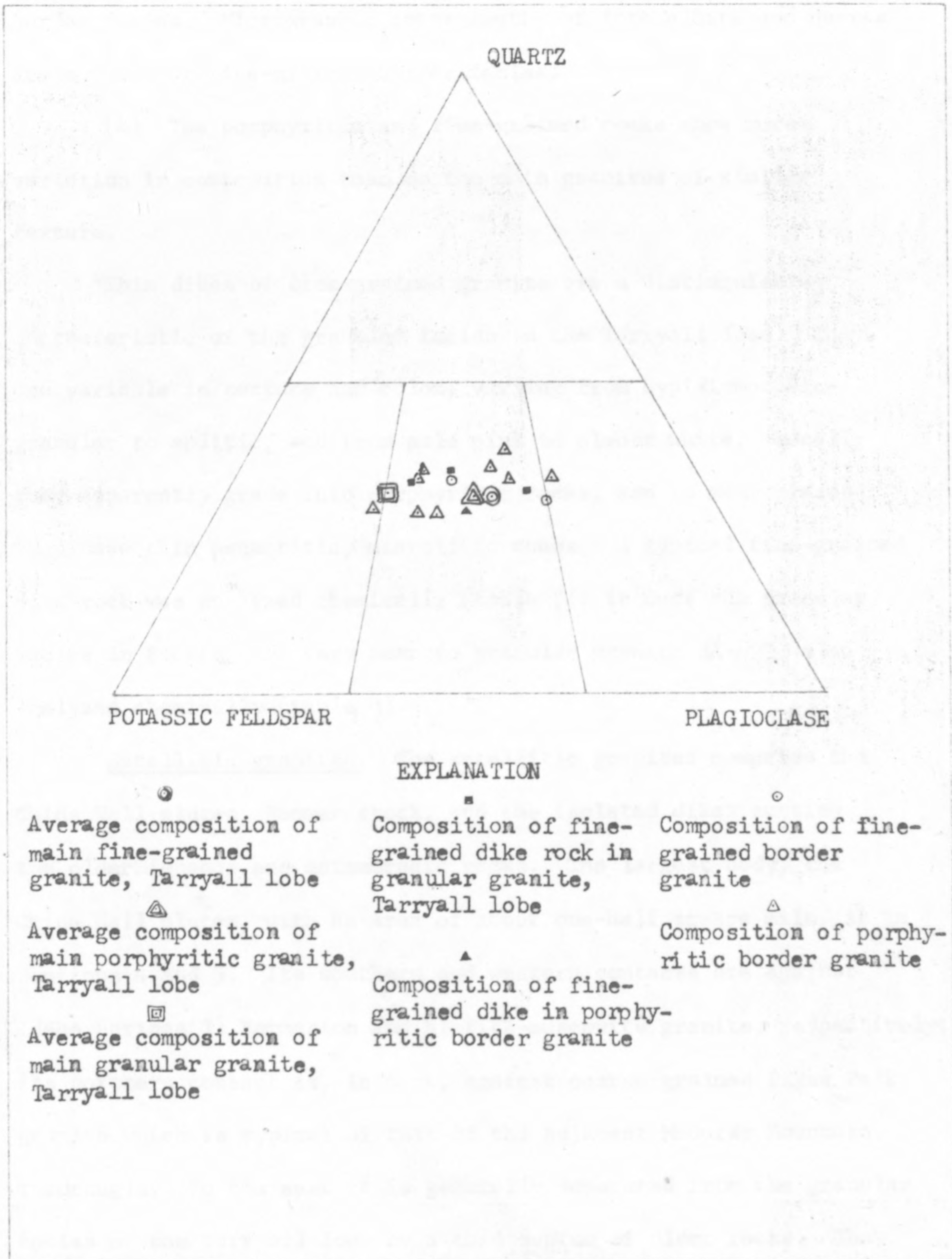


FIGURE 10. MODAL COMPOSITION OF DIKE ROCKS AND BORDER FACIES, TARRYALL LOBE

border facies. Micrographic intergrowths of late albite and quartz are typical of fine-grained border facies.

(4) The porphyritic and fine-grained rocks show more variation in composition than do the main granites of similar texture.

Thin dikes of fine-grained granite are a distinguishing characteristic of the granular facies in the Tarryall lobe. They are variable in texture and color, varying from hypidiomorphic-granular to aplitic, and from pale pink to almost white. Locally they apparently grade into porphyritic rocks, and in many places they have thin pegmatitic, miarolitic zones. A typical fine-grained dike-rock was analyzed chemically (table 7); it cuts the granular facies in Section 12, very near to granular granite BA-822, also analyzed chemically (table 6).

Satellitic granites. The satellitic granites comprise the China Wall pluton, Boomer stock, and the isolated dikes cutting the older igneous and metamorphic rocks. The largest body, the China Wall pluton, with an area of about one-half square mile, is in Sections 4 and 5. Its southern and western contacts are against Idaho Springs(?) Formation and biotite-muscovite granite, respectively; its northern contact is, in part, against coarse-grained Pikes Peak granite which is typical of that of the adjacent McCurdy Mountain quadrangle. To the east it is generally separated from the granular facies of the Tarryall lobe by a thin septum of older rocks. The Boomer stock, a much smaller body, and related granite and aplite dikes are exposed near the center of Section 21 within the metamorphic complex. The major beryllium deposits are in the south part of the

TABLE 7

MODAL COMPOSITION (VOLUME PERCENT), CHEMICAL AND NORMATIVE COMPOSITION (WEIGHT PERCENT) OF FINE-GRAINED GRANITE (BA-821).

	Modal composition	Chemical composition		Norm	
Quartz	35.4	SiO_2	77.96	q	36.8
Sodic plagioclase	30.0	Al_2O_3	12.19	ab	28.3
Potassic feldspar	33.8	Fe_2O_3	0.08	or	32.5
Biotite	0.8	FeO	0.47	an	0
Muscovite	0	MgO	0.01	cor	0.7
Fluorite	0	CaO	0.15	femic	0
Topaz	Tr	Na_2O	3.86	fluorite	.2
		K_2O	4.76		
		H_2O^+	0.10		
		H_2O^-	0.03		
		P_2O_5	0.00		
		MnO	0.02		
		CO_2	0.01		
		Cl	0.01		
		F	0.10		
		Subtotal	99.78		
		Less O	.04		
		Total	99.74		

stock and in the adjacent older rocks.

The China Wall pluton is made up of granular, porphyritic, and fine-grained rocks, which are similar, megascopically, to the comparable facies of the Tarryall lobe. The arrangement of the granite facies is, however, the reverse of that in the Tarryall lobe, with granular rocks forming the inner zone. The Boomer stock and related dikes are composed of fine-grained granite which resembles the fine-grained rocks of the border facies of the Tarryall lobe and the outer fine-grained zone of the China Wall pluton.

Granular, porphyritic, and fine-grained granite facies of the China Wall pluton differ appreciably, at least in the range of their mineralogic composition, from like-textured main granites of the Tarryall lobe (fig. 11). Both samples of granular granite from the China Wall body contain appreciably less potassic alkali feldspar than nearly all the granular samples from the Tarryall lobe, and one of three samples of porphyritic granite from the pluton is abnormally rich in potassic feldspar for any facies (table 3-A, Appendix A). Four samples of fine-grained granite are, on an average, richer in quartz than the texturally comparable granite from the inner zone of the Tarryall lobe. Other differences appear in the relative abundance of biotite and muscovite and in the accessory minerals. Muscovite is relatively less abundant in the porphyritic and fine-grained granites of the China Wall pluton than in comparable main granites, and probably more of the muscovite found in China Wall pluton granites is of secondary type. Topaz, which typically occurs in intergrowths with quartz and plagioclase, is the characteristic accessory of the fine-grained granite of the

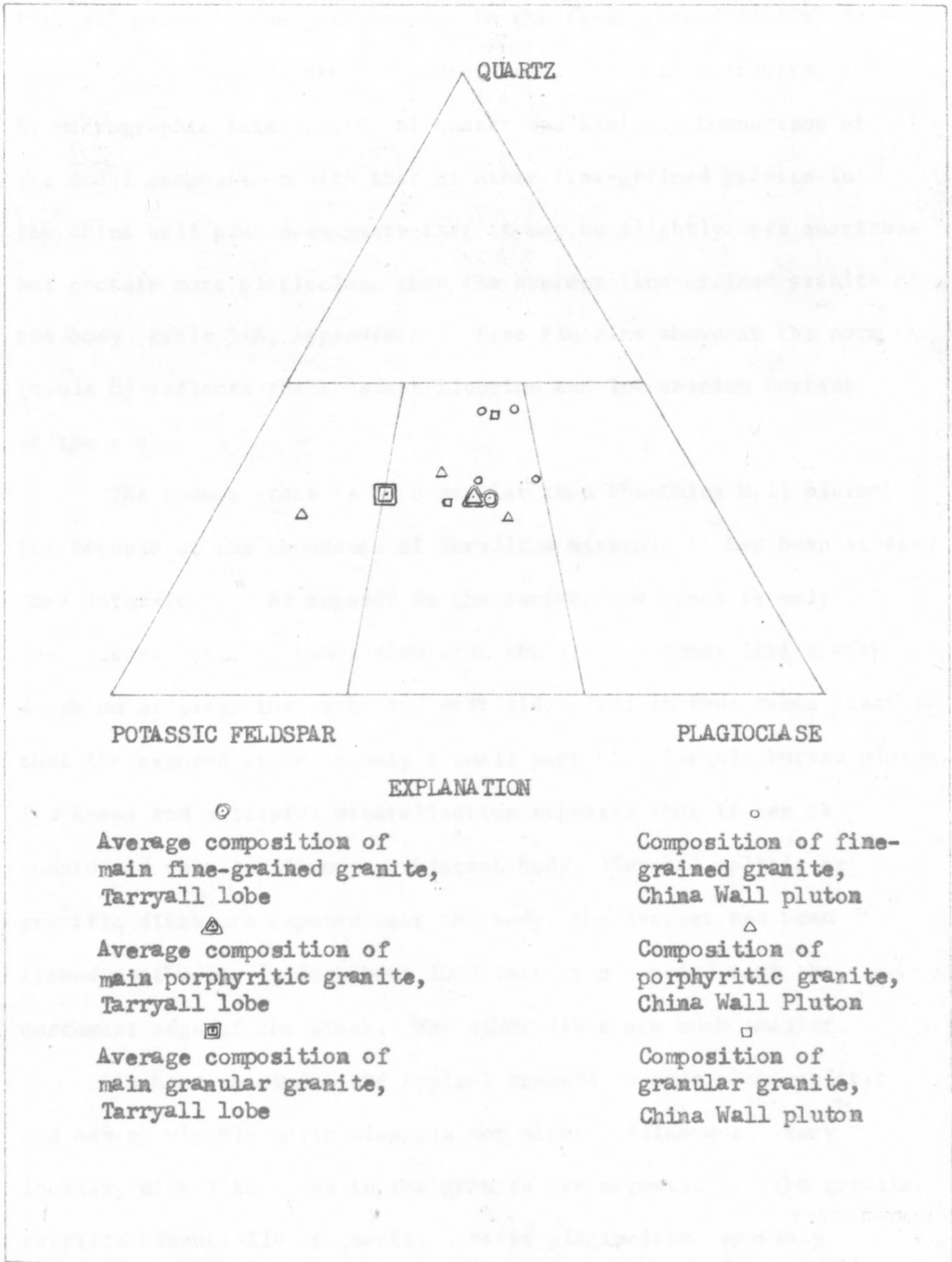


FIGURE 11. MODAL COMPOSITION OF GRANITE FROM THE CHINA WALL PLUTON

Tarryall pluton. The rock belongs to the fine-grained facies, is characterized by moderately abundant topaz and late muscovite, and by micrographic intergrowths of quartz and albite. Comparison of its modal composition with that of other fine-grained granite in the China Wall pluton suggests that it may be slightly less quartzose but contain more plagioclase than the average fine-grained granite of the body (table 3-A, Appendix A). Free Fluorine shown in the norm (table 8) reflects the abundant fluorine and low-calcium content of the rock.

The Boomer stock is much smaller than the China Wall pluton, but because of the abundance of beryllium minerals it has been studied more intensively. As exposed on the surface the stock is only 500 feet across; mine workings show that the stock becomes larger with depth on at least the south and west sides, and it thus seems possible that the exposed stock is only a small part of a largely buried pluton. Its shape and extensive mineralization suggests that it can be considered as a cupola on a subjacent body. Several aplitic or granitic dikes are exposed near the body; the largest has been traced northwesterly for about 1000 feet from a point near the northwest edge of the stock. The other dikes are much smaller.

In hand specimen, the typical granite is pale pink, aplitic, and has no visible mafic minerals nor mineral alinement. Very locally, dike-like zones in the granite are pegmatitic. The granite consists essentially of quartz, albitic plagioclase, sparsely perthitic potassic feldspar, and muscovite, generally in that order of abundance (table 9, table 4-A, Appendix A). There is no primary biotite, but some of the white mica is faintly pleochroic

TABLE 8

MODAL COMPOSITION (VOLUME PERCENT), CHEMICAL AND NORMATIVE COMPOSITION (WEIGHT PERCENT) OF FINE-GRAINED GRANITE (BA-934).

	Modal composition	Chemical composition		Norm	
Quartz	31.6	SiO_2	74.35	q	36.1
Sodic plagioclase	40.2	Al_2O_3	14.07	or	22.2
Potassic feldspar	22.0	Fe_2O_3	0.64	ab	33.5
Biotite	3.8	FeO	1.21	an	0
Muscovite	0.7	MgO	.01	cor	3.5
Fluorite	0.2	CaO	.56	femic	2.6
Topaz	0.7	Na_2O	3.96	fluorite	.8
Zircon	0.8	K_2O	3.72	F	.4
		H_2O^+	0.29		
		H_2O-	.07		
		TiO_2	.04		
		P_2O_5	.01		
		MnO	.04		
		CO_2	.01		
		Cl	.02		
		F	.96		
	Subtotal	......	99.95		
	Less O	......	.40		
	Total	....	99.55		

TABLE 9

MODAL (VOLUME PERCENT), CHEMICAL AND NORMATIVE (WEIGHT PERCENT) COMPOSITION OF REPRESENTATIVE AND AVERAGE ROCKS FROM THE BOOMER STOCK AND ASSOCIATED DIKES

		IV-4	IV-10a-4	B2-7-4	B2-7-5	Average Boomer stock[1]	1-1	Average dikes[2]
Modal (mineral) composition	Quartz	37.9	36.0	-	35.5	37.1	38.8	38.7
	Sodic plagioclase	26.1	30.0	-	35.4	32.2	38.5	40.0
	Potassic alkali feldspar	27.4	27.0	-	18.4	24.0	18.8	14.9
	Biotite	0	0	-	0	.1	.3	.1
	Muscovite	8.0	6.3	-	10.5	6.0	3.6	6.1
	Fluorite	Tr.	0.4	-	0.1	.15	Tr.	.2
	Topaz	0	0	-	0	Tr.	0	0
	Opaque iron oxides	.5	.3	-	.1	.15	0	0
	Beryl (?)	0.1	0	-	0	Tr. (?)	0	0
Chemical composition	SiO_2	76.79	77.48	76.16	77.07	76.88[3]	77.66	
	Al_2O_3	12.51	11.70	12.87	12.18	12.32	12.94	
	Fe_2O_3	0.85	1.64	0.73	0.79	1.00	.10	
	FeO	.40	.47	.86	.69	0.61	.27	
	MgO	.01	.03	.05	.03	.03	.02	
	CaO	.12	.21	.37	.38	.27	.13	
	Na_2O	3.52	3.37	3.97	3.31	3.54	5.07	
	K_2O	4.75	3.77	3.33	4.03	3.97	3.45	
	$H_2O(+)$	.46	.66	.48	.42	.51	.19	
	$H_2O(-)$	.19	.18	.31	.21	.22	.04	
	TiO_2	.03	.92	.02	.02	.02	.02	
	P_2O_5	.01	.01	.01	.01	.01	.01	
	MnO	.02	.06	.03	.02	.03	.03	
	Co_2	.01	.01	.03	.02	.02	.01	
	Cl	.01	.00	.01	.01	.01	.01	
	F	.13	.16	.23	.27	.20	.03	
	Subtotal	99.81	99.77	99.46	99.46	99.64	99.99	
	Less O for F	.05	.07	.10	.11	.08	.01	
	Total	99.76	99.70	99.36	99.35	99.56	99.98	
Normative composition	q	37.9	43.2	40.0	41.9	40.7	34.3	
	or	28.4	22.2	19.5	23.9	23.5	20.6	
	ab	29.3	28.3	33.5	27.8	29.7	43.0	
	an	0	0	0.3	0	0.1	0.6	
	cor	1.6	2.1	2.7	2.4	2.2	0.6	
	femic	1.8	2.5	0.9	2.1	1.8	0.5	
	fluorite	0.2	0.4	0.5	0.7	0.5	Tr.	
	excess F	.1	0	0	0	Tr.	0	

1 Average of 12 modal analyses (table 4-A; Appendix A)
2 Average of 5 modal analyses (table 4-A; Appendix A)
3 Average of the 4 chemical analyses shown

and probably formed by alteration of biotite; there is a very minor amount of a green, pleochroic mica occurring in secondary(?) aggregates in the white mica. Fluorite is sparse, as is topaz; iron-bearing carbonates are found as late accessories in places in the granite.

Microscopic examination shows three main types of texture; hypidiomorphic granular, micrographic, and aplitic. The granular and micrographic textures are dominant, and both may be present in the same thin section. In the dominantly hypidiomorphic rocks plagioclase is the most idiomorphic constituent forming fine-grained euhedral to subhedral tabs; potassic feldspar shows a hyalo-ophitic relation with the plagioclase and is in subhedral to anhedral grains. Both alkali feldspar and quartz locally replace the plagioclase, and quartz also replaces potassic feldspar.

Two types of micrographic texture are present. One type has apparently been formed by extensive replacement of tabular sodic plagioclase by quartz and is of irregular form. The sodic plagioclase in this intergrowth is polysynthetically twinned, and the original tabular outlines of the plagioclase can be inferred from optical continuity of the plagioclase remnants. The second type of micrographic texture involves quartz and clear, untwinned albite and has a radial or rosette-like form, which in places forms about nuclei of the tabular plagioclase or potassic feldspar (plate 5A). In the bulk of the granite both granular and micrographic textures are present; a representative area in thin section B3-11 showed the following modal composition:

	(Volume percent)
Quartz	22.5
Tabular sodic plagioclase	18.3
Quartz micrographically intergrown with sodic plagioclase	14.7
Micrographic sodic plagioclase	19.5
Potassic alkali feldspar	9.3
Muscovite	11.4
Carbonate	3.6
Fluorite	0.6
Total quartz	37.2
Total plagioclase	37.8

The dike rocks are slightly finer-grained than the granites in the stock, but are slightly richer on an average in plagioclase feldspar (table 9), and are dominantly characterized by a granular (hyidiomorphic) texture. It is possibly significant that the only rock from the stock with a totally hypidiomorphic structure resembling that of the dike-rocks (B3-1, table 1-A, Appendix A) occurs as a wallrock of a thin quartz-microcline perthite pegmatite vein.

Muscovite, which is very abundant in the stock and associated dikes, tends to vary inversely with the potassic feldspar. The relations are indicated diagrammatically on a quartz-sodic plagioclase-potassic feldspar diagram (fig. 12) by contours showing the ratio $\frac{\text{muscovite}}{\text{muscovite + potassic feldspar}}$.

Pegmatitic rocks are found in several places in the stock and in layers subparallel to the walls of the dikes. The main

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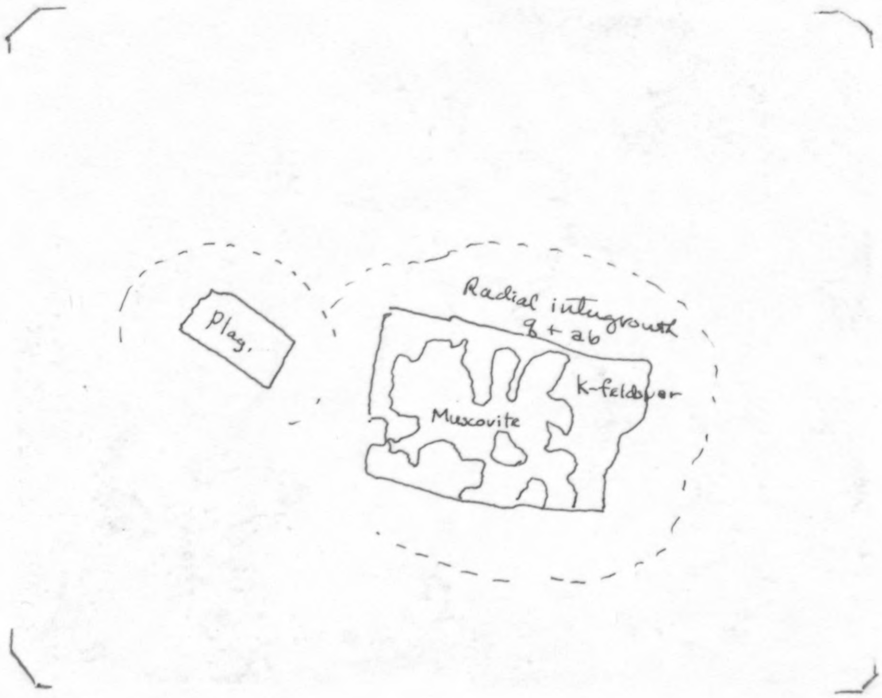
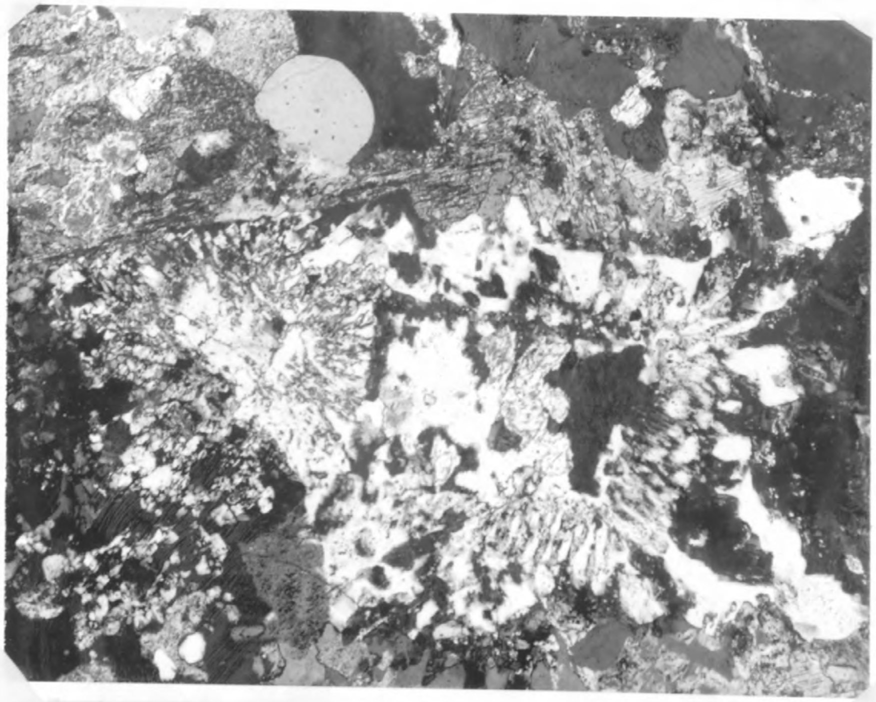
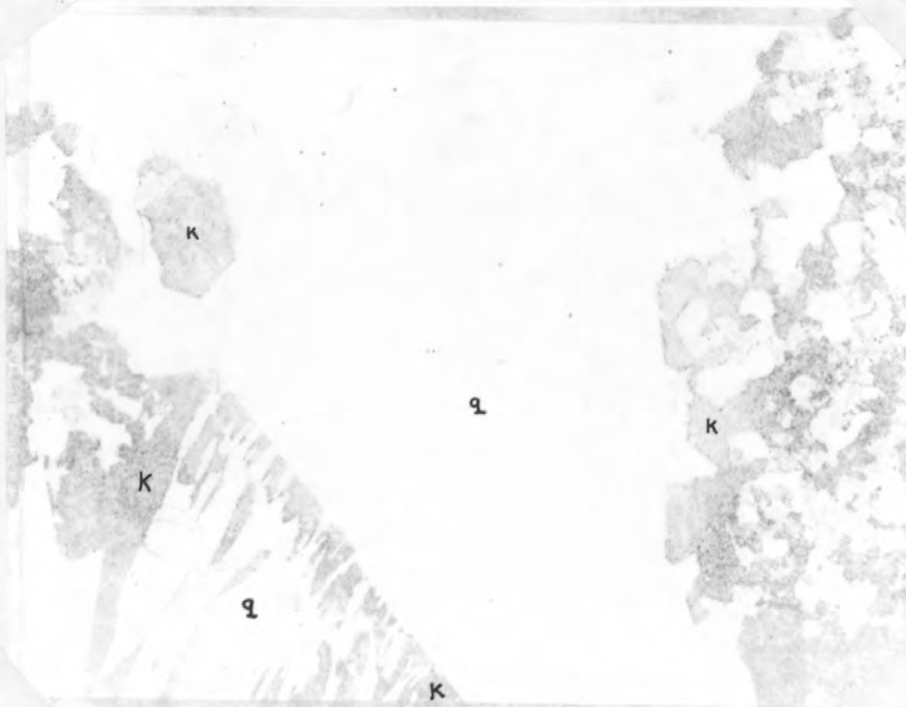




A. 50X



B. 11X

PLATE 5. PHOTOMICROGRAPHS: A. RADIAL MICROGRAPHIC INTERGROWTHS OF QUARTZ AND ALBITE SURROUNDING NUCLEI OF POTASSIC FELDSPAR AND SODIC PLAGIOCLASE. CROSSED NICOLS. B. PEGMATITIC POTASSIC FELDSPAR CRYSTAL REPLACED BY QUARTZ. PLAIN LIGHT.

(K-potassic feldspar; q-quartz)

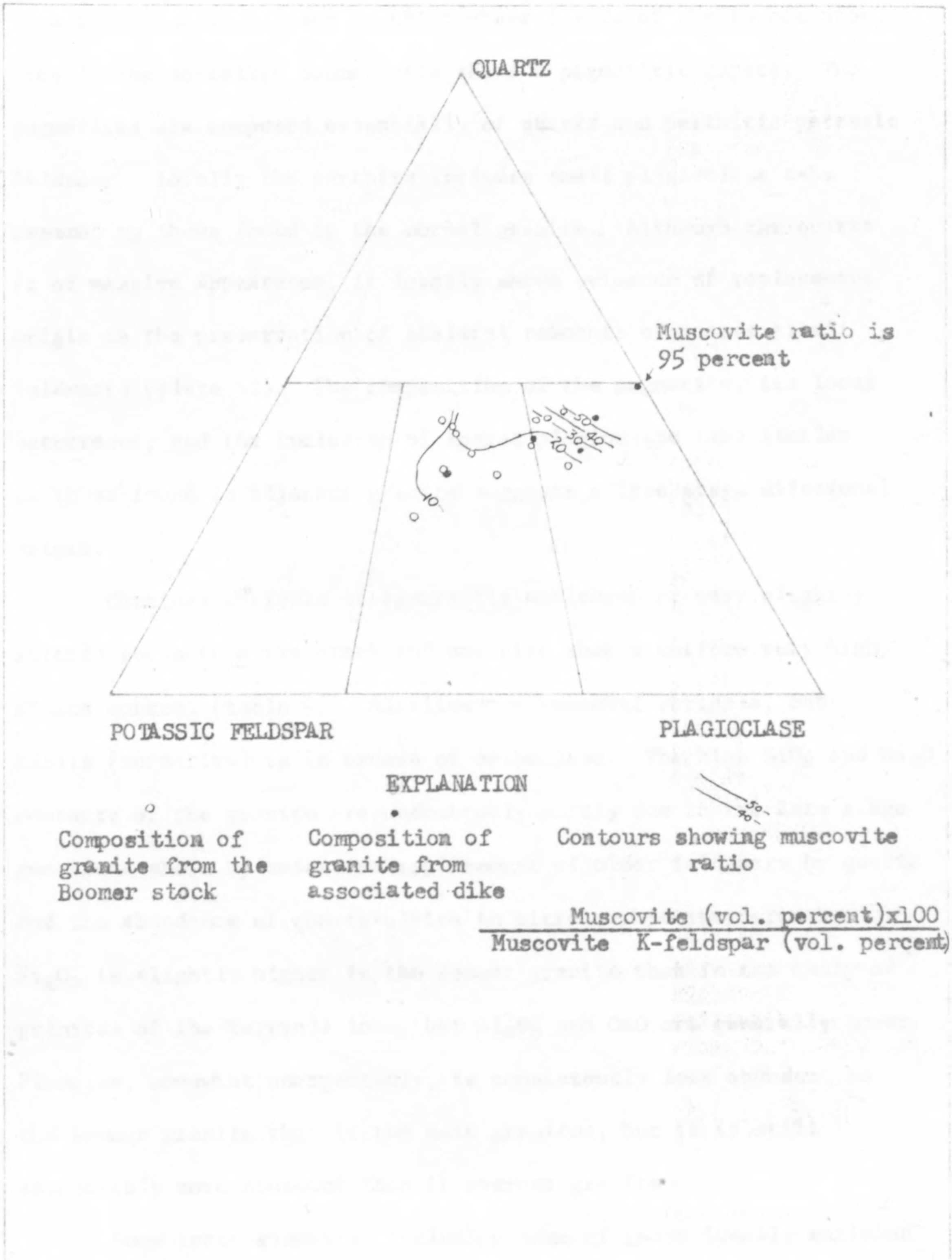


FIGURE 12. MODAL COMPOSITION AND VARIATION IN MUSCOVITE RATIO IN GRANITES FROM THE BOOMER STOCK AND ASSOCIATED DIKES

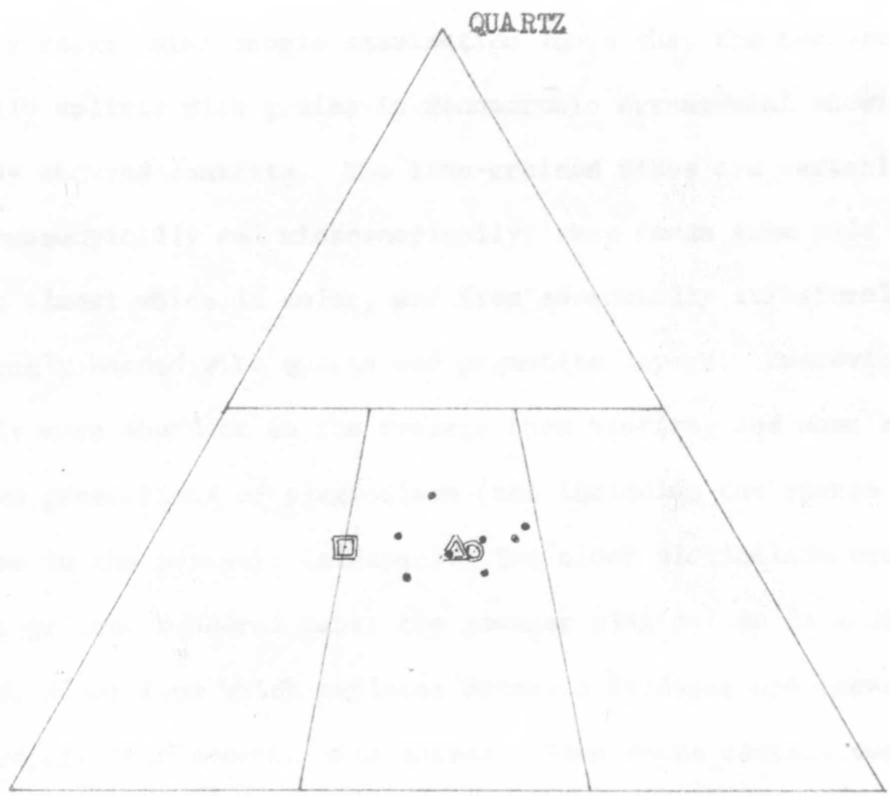
pegmatite zone is exposed in the southwest side of the Boomer stock; locally the so-called Boomer vein shows a pegmatitic aspect. The pegmatites are composed essentially of quartz and perthitic potassic feldspar. Locally the perthite includes small plagioclase tabs resembling those found in the normal granite. Although the quartz is of massive appearance, it locally shows evidence of replacement origin in the preservation of skeletal remnants of coarse alkali feldspars (plate 5B). The composition of the pegmatite, its local occurrence, and the inclusion of sparse plagioclase tabs similar to those found in adjacent granite suggests a late stage dilational origin.

Chemical analysis of apparently unaltered or very slightly altered rocks from the stock and one dike show a uniform very high silica content (table 9). Alkalies are somewhat variable, but albite (normative) is in excess of orthoclase. The high SiO_2 and Na_2O contents of the granite are undoubtedly partly due to the late stage reactions shown by extensive replacement of older feldspars by quartz and the abundance of quartz-albite in micrographic intergrowths. Fe_2O_3 is slightly higher in the Boomer granite than in the analyzed granites of the Tarryall lobe, but Al_2O_3 and CaO are generally lower. Fluorine, somewhat unexpectedly, is consistently less abundant in the Boomer granite than in the main granites, but it is still appreciably more abundant than in average granite.

Some trace elements, including some of those locally enriched in the ore deposits such as Be, Ce, Nb, Sn, and Y, are slightly less abundant in the Boomer granite than in main granites (tables 1-B and 2-B, Appendix B). Others such as Cu, Pb, Zn, and Ag are enriched in the Boomer granite relative to the main granite group.

Other granite dikes are found outside the Boomer area. A major concentration is in the central and west part of Section 16, but small dikes are scattered through the metamorphic complex in all the area thus far mapped. Most of the dike rocks are fine-grained granite; a few are composed partly of medium-grained granular or porphyritic granite. Dikes exposed near the center of Section 16 show at least locally that granular medium-grained granites grade through sparsely porphyritic, finer granites, into typical fine-grained rocks with local pegmatitic and miarolitic zones. These dikes have their origin in the granular facies of the Tarryall lobe, and granular granite forms the parts of the dikes nearest the contact of the lobe; the boundary shown on the map (plate 1) between granular granite and fine-grained granite in two large dikes is gradational. Farther south along the same segment of the main contact in the northeast part of Section 21, dikes paralleling the contact and near the granular facies of the Tarryall lobe are medium-grained and granular in texture; similarly oriented dikes farther from the contact are fine-grained. Tentatively this relation is interpreted as gradational; that is, the fine-grained rocks exposed farther from contact are believed to grade downward into medium-grained granular rocks similar to those found in dikes near the contact.

The few dikes studied in thin section have a considerable range in composition (fig. 13; table 5-A, Appendix A) and in types of texture. A medium-grained granular type (BA-287a) contains more plagioclase and muscovite than most of the main granular



EXPLANATION

Average composition of main fine-grained granite, Tarryall lobe

Average composition of main porphyritic granite, Tarryall lobe

Average composition of main granular granite, Tarryall lobe

Composition of Pikes Peak dike

FIGURE 13. MODAL COMPOSITION OF PIKES PEAK GRANITE DIKES IN THE METAMORPHIC COMPLEX (EXCLUSIVE OF DIKES IN THE BOOMER MINE AREA)

granites. In addition, although similar in megascopic aspect to granular rocks, microscopic examination shows that the texture is typically aplitic with grains in xenomorphic arrangement showing strongly sutured contacts. The fine-grained dikes are variable both megascopically and microscopically; they range from pale pink to almost white in color, and from essentially structureless to strongly banded with quartz and pegmatite layers. Muscovite is probably more abundant on the average than biotite, and most specimens show two generations of plagioclase (not including the sparce albitic lamellae in the potassic feldspar). The older plagioclase occurs as fine-grained euhedral tabs; the younger plagioclase is a non-twinned, clear type which replaces potassic feldspar and occurs in micrographic intergrowths with quartz. Some rocks contain topaz as the most characteristic accessory, and in some very fine white aplites (such as BA-981) it is very abundant and occurs as anhedral crystals scattered through the rock (plate 6).

In summary, it can be stated that there is a strong tendency for the Pikes Peak Granite of the Lake George beryllium area to assume one of the three characteristic textural and grain-size aspects, which have certain general mineralogic and, probably, chemical characteristics. Furthermore there is a tendency for zonal distribution of the facies, both in the main granites and in the satellitic bodies. The main granites of the Tarryall lobe and the fine-grained satellitic granite Boomer stock are the only ones which have extensive enough thin section and chemical control to be adequately known, and so are the source of most of the generalizations and conclusions used as a basis for the discussion

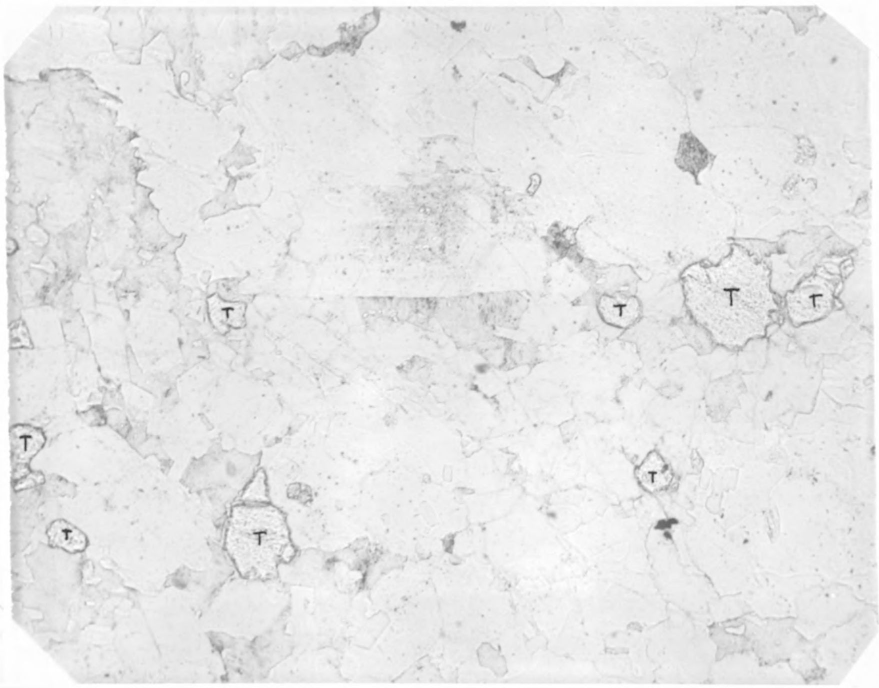


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PLATE 6. PHOTOMICROGRAPH: TOPAZ-BEARING APLITE. PLAIN LIGHT. (T-topaz)

of the petrology of the granite in the next section of this report.

Petrology

General aspects of granite emplacement. Textural, structural, and compositional features of the Pikes Peak Granite of the Lake George beryllium area suggest that it was emplaced as fluid magma, although the mode of emplacement is problematical. The textural and structural criteria include the poorly developed planar flow structures of the granites and the absence of cataclastic or shear foliations, the common granular textures (both equigranular or seriate), the local abundance of sharp-walled inclusions, and the knife edge contacts of all the granites with surrounding older igneous and metamorphic rocks.

The compositional evidence for a magmatic origin is in the close approach of the compositions of granite facies of the area to the minimum between quartz and feldspar in the artificial granite system (Tuttle and Bowen, 1958, p. 75-80). Tuttle and Bowen (ibid., p. 77) pointed out that the narrow range of composition of most granite, and the close relation of this composition with the minimum in the artificial system is in keeping with a magmatic origin for many granites:

> The coincidence between the maxima for rhyolites and granites and the thermal deep of the isobaric equilibrium diagram for lower water-vapor pressures is far too strong to be fortuitous. There can be little doubt that magmatic liquids are involved in the genesis of the granitic rocks, and those who propose that granites are formed primarily by solid diffusion, hydrothermal replacement, or by any other mechanism not involving a magma must demonstrate an alternative method of controlling, to such a strong degree, the compositions of granites.

The chemical compositions of the granular and porphyritic facies in the Tarryall lobe fall into the field of greatest concentration (fig. 14) of chemically analyzed plutonic granites reported by Washington (1917). Although the fine-grained granite of the main granite group has not been analyzed, its modal composition is only slightly different than that of the porphyritic facies and very probably it also would fall into this field. It is proposed here that the field of maximum concentration of natural granite is analogous to the position of the thermal minimum in the artificial granite system, or in other words, that magmatic differentiation would tend to produce portions of granite with this composition. The main granite group is considered to be of wholly magmatic origin, a hypothesis which is in keeping with its texture, structure, and contacts. Some other granite facies of the area do not fall into the field of maximum concentration, although they do lie near the position of the minimum in the artificial granite system. These facies include granite types formed in the Boomer stock and China Wall pluton and in border zones of the Tarryall lobe. Their somewhat anomalous composition, with respect to most plutonic granites, common micrographic textures, and, in some, high muscovite contents suggest extensive metasomatic modification due to residual water and fluorine-bearing solutions.

The close approach of all the granites to the position of the minimum suggests that the magma was derived by selective fusion of deeply buried materials. Origin by crystal fractionation of a mafic magma calls for a parent magma which seems unreasonably large, especially in view of the sparcity of relatively mafic rocks of near Pikes Peak age in the Front Range. On the other hand the spatial association of granite with gabbro in the area and the coincidence of the Pikes Peak batholith with a positive gravity anomaly, (Hutchinso, 1960a, p. 177) indicates that mafic magma may have had an indirect effect, for example, as a heat bringer on the genesis of the Pikes Peak Granite.

As noted above, the average normative compositions of both the main porphyritic and granular facies (fig. 14) are within the area of greatest concentration of 571 chemically analyzed plutonic granites (Tuttle and Bowen, 1958, p. 77, and fig. 42), Figure 14 also shows the position of the isobaric minimum of the liquidus surface in the artificial granite system at different water-vapor pressures (Tuttle and Bowen, 1958, fig. 38). The data of the artificial system shows that, with increasing water-vapor pressures, the minima approaches the albite corner with a nearly constant ratio of orthoclase to quartz. A line can be drawn through the normative compositions of the granular and porphyritic facies in the Tarryall lobe which parallels the trend of the minima at different water pressures, and the data are thus consistent with a hypothesis that the porphyritic facies crystallized from a melt with a slightly higher water content than did the granular facies[1]. The trend

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[1]Other data do not fit the artificial relations as simply; later (p. 120-122) it is argued that the sodic plagioclase and potassic feldspar crystallized separately, as would be the case only if the alkali feldspar solvus had been intersected. Studies in the artificial system suggest that this happens only slightly below 5000 bars water-vapor pressure, however, it can also be inferred that the water-vapor pressures in the Lake George area attained a maximum of only about 2000 bars. It is assumed, therefore, that other components such as fluorine, or excess alumina, not present in the artificial system, acted as fluxes paralleling the effect of water.

EXPLANATION

Average normative composition of main granular granite, Tarryall lobe

Average normative composition of main porphyritic granite, Tarryall lobe

(1) Average normative composition of fine-grained granite from the Boomer stock, and (2) normative composition of fine-grained granite from the China Wall pluton

Trend of the isobaric minimum in the artificial granite system. Position of the minimum shown at 500, 1000, 2000, 3000, and 4000 kg/cm^2 water vapor pressure. From Tuttle and Bowen, 1958, fig. 38.

Field of greatest concentration of plutonic granites. From Tuttle and Bowen, 1958, figs. 38 and 42.

FIGURE 14. COMPARISON OF THE NORMATIVE COMPOSITIONS OF PIKES PEAK GRANITES WITH OTHER PLUTONIC GRANITES AND THE ISOBARIC MINIMUM IN THE ARTIFICIAL GRANITE SYSTEM

of the modal compositions of granular, porphyritic, and fine-grained main granites (fig. 8) suggests that the fine-grained facies would be on the same trend, nearly superposed on the porphyritic facies, but, perhaps, slightly farther towards the albite corner.

The country rocks at the contacts of Pikes Peak Granites in the Lake George beryllium area are not apparently deformed due to the granite, nor are they "granitized", so the mode of emplacement is uncertain, but it is inferred to have been largely passive in nature. One control of emplacement was, possibly, pre-granite fault structures. There is a marked parallelism of the western contact of the Tarryall lobe with the pre-granite Badger Flats fault about one-half mile west of the contact. Perhaps a similar fault structure existed at about the present site of the contact and guided the granite, accompanied either by foundering of the rocks from the fault surface or by uplift of an intruded block of older rocks. In any event, this control apparently explains only a small part of the granite emplacement, and the "room problem" in the area must still be regarded as partly unsolved.

Variation in mineralogic and chemical composition. All varieties of the Pikes Peak Granite of the area are silicic rocks relatively rich in alkalies and poor in calcium; at least in a chemical sense they are granites. They do vary slightly in mineralogic and chemical composition. Small changes in the amounts of SiO_2, K_2O, and Na_2O in the main granites of the Tarryall lobe are probably to be explained as magmatic features due to slight changes in the chemical composition of the melt; the relative abundance of

SiO_2 and locally Na_2O in some of the satellitic bodies are likely due to metasomatic modifications of the granite. The variations in the main granites cannot, however, be easily explained by commonly cited modes of magma diversification such as assimilation and crystal fractionation, and are more probably related to the accumulation and transfer of volatiles.

The abundance of volatiles in the Pikes Peak magma is indicated by the abundance and modes of occurrence of fluorine in the rocks, by the local presence of primary muscovite, and several other features of the granite. For example, the sparcity of contact metamorphism associated with the Pikes Peak batholith as a whole suggests that it was emplaced at a relatively low temperature and hence by direct inference had a high volatile content.

Some of the compositional and mineralogic variations of the granite are probably due to a progressive enrichment of volatiles in successively younger fractions of the Pikes Peak magma. The fact of association of greisens with metasomatically modified and relatively young granites is perhaps the simplest and most direct line of evidence for a very high volatile content in the youngest magma fractions. But the variations in chemical composition, muscovite-biotite ratio, and plagioclase fraction in perthite in the main granites of the Tarryall lobe, are at least consistent with the hypothesis that increasing water-vapor pressures in the magma fractions gave rise, respectively, in the order of decreasing age, to the granular, porphyritic, and fine-grained main granites.

The inference of increased water-vapor pressures in the main series granular-porphyritic-fine-grained granite is also borne out by the relative amounts of muscovite in rocks of the series. Accordint to Yoder and Eugster (1955, p. 266-269) muscovite forms, at magmatic temperatures, only at relatively high water-vapor pressures, and further only a granitic melt with high volatile content will have a low enough freezing point to be liquid at a geologically reasonable temperature and pressure for muscovite formation. Using the beginning of melting of natural granites in hydrous systems as a guide, the water-vapor pressures necessary for the formation of primary muscovite in a melt are about 1500 atmospheres. Primary muscovite is sparse in rocks of the granular facies, but occurs with biotite or rarely as the only mica in rocks belonging to the porphyritic and fine-grained facies.

Primary muscovite is also significant in indicating that the water-vapor pressure was about equal to the total pressure on the magma. The stability curve drawn for muscovite by Yoder and Eugster (<u>ibid</u>., fig. 16) is the univariant curve for the reaction:

$$\text{Muscovite}_{(s)} \leftrightarrow \text{sanidine}_{(s)} + \text{corundum}_{(s)} + H_2O_{(v)}$$

Qualitatively it can be seen that if water-vapor pressures are less than load pressures, the reaction will tend to be shifted towards the right, and the decomposition of muscovite will take place at temperatures less than indicated by the univariant curve. Since both the univariant curve for mica and the incipient melting curve for granite are steep, and since both are affected by water-vapor pressures, a relatively small departure from $P_{H_2O}=P_{load}$ will cause the curves to separate, and Yoder and Eugster concluded that (ibid., p. 267): "At water pressures less than the total pressures, muscovite could form only in the solid state."

Secondary muscovites are also relatively abundant in certain porphyritic and fine-grained rocks, occurring chiefly as alteration products of biotite and of potassic feldspar. Hemley (1959, p. 244) demonstrated that muscovite and K-feldspar are related according to the equilibrium reaction,

$$3/2\ K\ Al\ Si_3O_8 + H^+ \leftrightarrow 1/2\ K\ Al_2AL\ Si_3O_{10}(OH)_2 + 3SiO_2 + K^+$$

in which the phase formed is a function only of the K^+/H^+ ratio and the temperature at a given pressure. It can be postulated, from results obtained by Hemley, that mica forms either by reactions due simply to decreasing temperature at a constant K^+/H^+ ratio, or due to increasing H^+ or decreasing K^+ at a constant temperature. In any event, the local abundance of secondary mica is believed to indicate that these rocks had a relatively high water content. Kaolinite(?) occurs, rarely, as an interstitial mineral in the mica-rich areas in the granites, and if correctly identified does indicate that some of the secondary reactions took place at relatively low temperatures.

Another line of evidence which possibly indicates higher water-vapor pressures in the younger granites is the sparsely perthitic nature of the potassic feldspar of the younger rocks. In part the decrease in plagioclase fraction in the potassic feldspars of the younger granites may be due to cryptoperthitic nature of the potassic alkali feldpar, but the apparent variation with changes in composition within a facies, particularly the granular type (fig. 15), suggests that it also actually reflects lesser amounts of plagioclase fraction and more potassic fraction in the younger perthitic alkali feldspar. And in turn this indicates that the solidus curve of the crystallizing granite was depressed farther on the potassic feldspar-plagioclase solvus in the younger rocks, presumably because of higher water-vapor pressures.

Certain of the granites cannot be explained simply as crystallization products of a granitic melt. These rocks are mainly fine-grained and occur, rarely, in dikes, and, commonly, in the fine-grained border facies of the Tarryall lobe and in fine-grained facies of the China Wall pluton, and the Boomer stock. Both compositional and textural features of the rocks are anomalous. The normative composition of average Boomer granite, and a fine-grained granite from the China Wall pluton is plotted on the diagram showing the isobaric minima in the artificial system (fig. 14), and the norms of the main granular and porphyritic granite. The norms of the fine-grained rocks are appreciably more siliceous than any compositions along the trend of the minima, and do not show any apparent simple relation to the trend of the main granites. Mineralogically some of these rocks are characterized by very high muscovite-potassic feldspar ratios, and texturally they are characterized by late micrographic intergrowths of albite and quartz, which surround the early plagioclase and potassic feldspar, and by extensive replacement of early plagioclase by quartz and of potassic

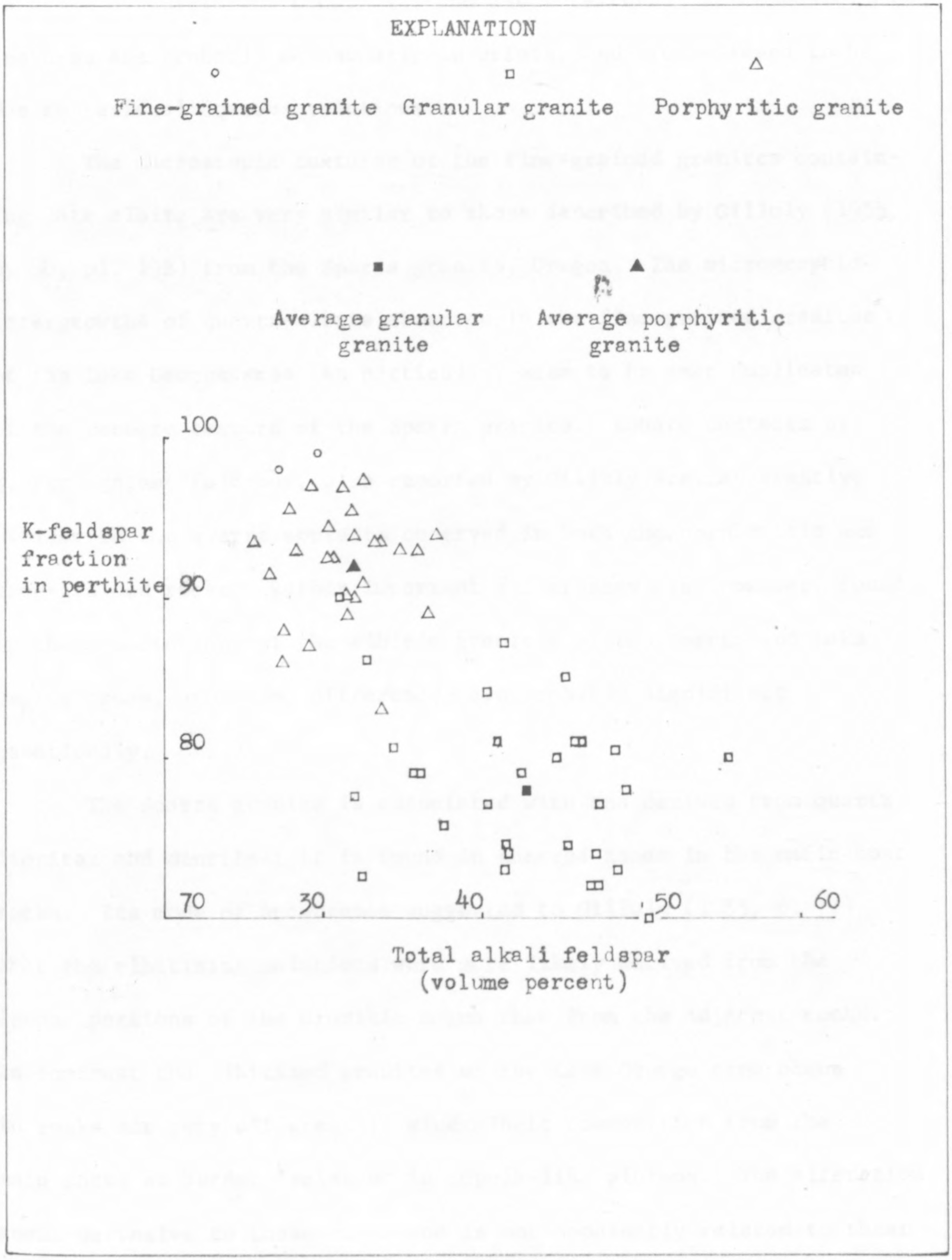

FIGURE 15 .- K-FELDSPAR IN PERTHITE VS. TOTAL ALKALI FELDSPAR, MAIN GRANITES, TARRYALL LOBE

feldspar by quartz and mica. The anomalous textural and compositional features are probably metasomatic in origin, and are believed to be due to residual aqueous solutions.

The microscopic textures of the fine-grained granites containing late albite are very similar to those described by Gilluly (1933, p. 68, pl. 19B) from the Sparta granite, Oregon. The micrographic intergrowths of quartz-albite observed in the fine-grained granites of the Lake George area, in particular, seem to be near duplicates of the rosette texture of the Sparta granite. Lobate contacts of quartz against feldspar, also reported by Gilluly are, apparently, similar to the quartz contacts observed in both the porphyritic and fine-grained rocks. Rather important differences are, however, found in the associations of the albitic granites of the Sparta and Lake George areas, and these differences are probably significant genetically.

The Sparta granite is associated with and derived from quartz diorites and diorites; it is found in sheared zones in the mafic host rocks. Its mode of occurrence suggested to Gilluly (1933, p. 77) that the albitizing solutions were more likely derived from the deeper portions of the dioritic magma than from the adjacent rocks. In contrast the albitized granites of the Lake George area occur in rocks not very different in mineralogic composition from the main rocks as border facies or in cupola-like plutons. The alteration seems pervasive to these rocks and is not apparently related to shear zones; the weight of the evidence may thus favor a local source of the solutions causing silicification and albitization of the granites.

Texturally the evidence seems clear that the sequence of beginning of crystallization in all the main granites and in the non-albitized zones in other rocks was plagioclase, then potassic feldspar and quartz. The potassic feldspar later unmixed further plagioclase as perthitic lamellae. Most of the old single grains of plagioclase are in tabular form, commonly mantled and rarely veined and replaced by alkali feldspar; in general the textural relations of the feldspars are similar to those described or figured elsewhere in rocks containing an early plagioclase and a later, perthitic potassic feldspar, as, for example, in monzonites and syenites investigated by Yagi (1953, p. 795-796, pl. 2, fig. 4). Unlike these rocks, however, where the initial composition of plagioclase is labradorite, the initial plagioclase in the Pikes Peak Granite of the Lake George area was sodic oligoclase or albite.

Tuttle (1952, p. 117) pointed out that granites with a relatively high lime content nearly always contained a plagioclase in addition to a potassic feldspar, but that most granites poor in lime contained either no plagioclase except in perthite or only small amounts of plagioclase. He concluded, tentatively, that all the plagioclase in the low-lime granites may have unmixed from sodic anorthoclase. Although the boundary curve separating lime-poor and lime-rich granites (Tuttle, ibid, fig. 4) in a K_2O-Na_2O-CaO diagram has been accepted by some as an adequate criterion for primary one-feldspar and two-feldspar granite, Tuttle (ibid, p. 119-20) also noted the possibility of some primary two feldspar granites in the lime-poor region:

> It is conceivable that extreme fluxing by volatiles would lower the liquidus sufficiently to permit simultaneous crystallization of orthoclase and plagioclase, in which case there would be two types of magmatic granites: (1) "wet" granites consisting of Or-Pl-Qtz in nearly equal amounts, and (2) "dry" granites consisting of perthite and quartz.

Recent experimental work shows that it is possible for high water-vapor pressures to cause the liquidus to intersect the orthoclase-albite solvus. Yoder, Stewart, and Smith (1957) found that the solvus was intersected at a pressure of 5000 bars, and a temperature of about 700°C. along the orthoclase-albite boundary; somewhat lower pressures cause intersection with the solvus in an orthoclase-sodic plagioclase region.

These experimental data do not, however, seem directly applicable to the Lake George granites. For one thing muscovite would be expected as a primary phase in all the granites with such pressures; furthermore the normative ab-or-an content of the granite falls in the field of initial orthoclase crystallization in the high pressure system rather than the plagioclase field as inferred from textures.

Other possible explanations for two-feldspar crystallization that might be applicable to the Lake George granites are the abundance of an unusual volatile constituent that would also have a fluxing effect on the liquidus, such as fluorine, or the peraluminous nature of the granites. Tuttle (1952, p. 120) pointed out that the two-feldspar granites within the lime-poor field on the Na_2O-K_2O-CaO diagram had alumina ". . . in excess of the Al_2O_3 to SiO_2 ratio in soda and potash feldspars", and that the alumina might ". . . thus be effective in permitting two feldspars to crystallize at the liquidus". The initial plagioclase feldspar in most of the main granites of the Lake George area is not a pure albite, and so may be the combination of moderately high water-vapor pressures, fluorine, and high alumina combined to lower the solidus on the orthoclase-plagioclase solvus in a low-lime region.

In summary, it is proposed as a working hypothesis that the Pikes Peak Granite of the Lake George area originated as a crystallization product of granitic melt. The oldest granites, those of the granular facies, crystallized at relatively low water-vapor pressures, and their textures are largely "magmatic". The main porphyritic and fine-grained granites crystallized with somewhat higher water contents, but the textures are also dominantly of magmatic origin. The main evidences of late reactions are in the local replacement of potassic feldspar by muscovite, plagioclase by potassic feldspar, and the replacement of both feldspars by quartz. The fine-grained rocks of the border facies and satellitic plutons apparently began to crystallize as normal igneous rocks, forming tabular plagioclase and subhedral potassic feldspar, but at a late stage were modified pervasively by residual solutions and in places have a texture that is mainly of metasomatic origin.

Variation in grain-size. One interesting aspect of the sequence of main granites is the general decrease in grain size which parallels the textural changes and increasing plagioclase and muscovite contents of the progressively younger granites. A similar sequence of changes in grain-size and chemical and mineralogic composition has been reported from Cornish granites by Ghosh (1927,

1934) and Richardson (1923). Perhaps a similar tendency can be inferred from observations by Blanchard (1947, p. 267-268) and others on the granites of the Australian tin province, and the association of coarse-grained granite, medium-grained alaskite, and aplite described by White (1940, p. 969-973) from the Ackeley batholith, Newfoundland.

A commonly accepted view of the origin of fine-grained (aplitic) rocks associated with granites invokes rapid crystallization after emplacement and loss of volatiles (Emmons, 1940, p. 5-8; Vance, 1961, p. 1726). One variation of this hypothesis has been outlined in some detail by White (1940, p. 973 and 975):

> During the last stages of crystallization...the residual liquid became much enriched in the volatile constituents, with a resultant rapid increase in the internal vapor pressure. When the pressure of the overlying load was finally equaled... a boiling off...of the volatile components was the natural result....as soon as the boiling process became important, the <u>rate</u> of crystallization increased because removal of heat by escaping super-heated volatiles was <u>added</u> to normal removal of heat by conduction through the wall rock. The increased rate of precipitation resulted in a fine-grained rock--an aplite with a miarolitic texture due to entrapped gases.

Jahns and Tuttle (1962) have proposed three methods for the formation of igneous aplites, all involving fairly rapid crystallization. The three mechanisms may be called, (1) temperature quenching or chilling, (2) pressure release quenching, and (3) compositional quenching. Pressure release quenching is essentially the mechanism proposed by Emmons (1940) and Vance (1961), and is believed by Jahns and Tuttle to account for the formation of most granitic aplites. Essentially it involves loss of volatiles caused by faulting or other mechanisms of pressure relief, and consequent shift of the solidus of the granite. Compositional quenching was proposed specifically to account for the formation of banded soda aplite and giant-textured potassic pegmatite, and involves resurgent boiling and separation of the potassic feldspar into the gas phase, with nearly simultaneous crystallization of albite-rich aplite from coexisting silicate melt (see also Jahns and Burnham, 1958 and 1961).

Most hypotheses of aplite formation seem to make the assumption that fine-grained size is the result of rapid crystallization in the absence of mineralizers. This assumption is not necessarily valid. Although rapid crystallization induced by loss of volatiles or another mechanism perhaps accounts for the formation of some fine-grained aplite dikes of the area, it does not apparently account for the finer-grained size and microtextural features of the late granite facies of the area. The granites of the Lake George beryllium area show a serial decrease in grain-size. The oldest granites are cm-sized rocks; progressively younger facies are, in order, medium-grained equigranular granite, slightly finer-grained porphyritic granite, and less than mm-sized fine-grained granites. Assuming that all the granite was emplaced at about the same time as a fluid melt, it can be inferred that the coarse-grained rocks are those which crystallized most rapidly, and also, that grain-size correlates inversely with the amount of time involved in crystallization. The microtextures of the fine-grained rocks are, also, not consistent with quenched origin, but rather show a distinct sequence of early idiomorphic minerals and late xenomorphic minerals, suggesting a normal crystallization history. Furthermore the abundance of very late metasomatic textures and greisens in the late facies rocks indicates that the fine-grained rocks retained a high proportion of their volatiles essentially to the end of crystallization.

A hypothesis of relatively long-time crystallization of fine-grained rocks can be proposed which appears to explain the serial nature of grain-size decrease and is also consistent with the following physical-chemical factors. Grain-size of igneous rocks is probably largely dependent on the rate of diffusion and on the time available for diffusion to operate, and diffusion, in magmas, is theoretically and experimentally related to viscosity (Bowen, 1921, p. 307, 316-17). Since magmas are almost certainly associated liquids, that is chemically bonded liquids, viscosity is a function of the degree of association as well as of the temperature. Association is probably particularly important in granitic melts; Ringwood (1955, p. 250-51) infers that granitic magmas tend to be composed of 3-dimensional networks of silica tetrahedra, because the relative abundance of silicon necessitates sharing oxygens between the silica groups. The high degree of association and the relatively low freezing temperatures of granitic melts tend to make them highly viscous, and thus of low diffusivity. One other factor, abundance of mineralizers, tends to work in the opposite direction causing a decrease in the viscosity of silicate melts at constant temperature. Fluorine and hydroxyl, both of which can be reasonably inferred to have been relatively abundant in the Pikes Peak magma, break down the bonds between silica groups (Buerger, 1948) and so decrease viscosity. Experimental evidence (R. H. Jahns, 1962, oral communication) shows, however, that the mineralizer effect on viscosity is exceeded by the temperature effect, and so in general low-temperature volatile-rich melts would have greater viscosity than somewhat higher temperature melts.

It may be, therefore, that the decreasing grain-size of progressively younger granites directly reflects higher volatile contents. The higher volatile contents of successively younger magma fractions allow lower freezing temperatures to be reached, which in turn result in progressively higher viscosity, lower diffusivity, and finer-grain size.

This hypothesis is not intended to be a general one, because obviously other factors also affect grain size. Chilling, for example, can produce fine-grained, even glassy rocks. But in plutonic rocks where other serial characteristics, such as increasing muscovite-biotite ratio, indicate increasing water-vapor pressures in a sequence also characterized by decreasing grain-size, it seems to be a reasonable explanation of the phenomena. It particularly seems applicable in the so-called tin granites, or other granites associated with greisens.

It can, of course, be argued from their place of occurrence that the fine-grained border facies are chilled zones, but two lines of evidence suggest that this is not the case. In the first place, the fine-grained border zones have a very limited distribution, and the long border zones along the east and west sides of the Tarryall lobe show no chill effects. In the second place the border facies are characterized by several features which suggest late magmatic origin, namely the abundance of constituents like topaz and muscovite, characteristic micrographic and replacement textures, and an association with greisens and beryllium deposits.

Movement of volatiles and origin of zoning. The increased water-vapor pressure, postulated in the late members of the granite series, is believed to reflect two distinct tendencies of movement of water in a magma. One is the tendency for equipotential distribution of water in a fluid magma column (Kennedy, 1955, p. 490-494), which leads to an enrichment in the amounts of water in the upper and outer parts of the magma. The second is a tendency for inward and possibly local downward migration of water to occur when a magma crystallizes sparsely hydrous border facies in relatively impermeable wall rocks (Vance, 1961, p. 1725-26). Each mechanism has been proposed to account for a different type of zoning; in the first case relatively mafic and calcic core zones, and in the second, relatively mafic borders.

Granites of the Lake George beryllium area show both types of zoning, and it is proposed that both mechanisms have operated. The main granite of the Tarryall lobe shows a zonal distribution of outer, granular rocks which are inferred to have crystallized at relatively low water-vapor pressures, and inner, slightly younger porphyritic and fine-grained types which are postulated to have formed at higher water-vapor pressures. This zoning appears to parallel the trend proposed by Vance, which is partly due to the inward migration of volatiles. The second type of zoning is shown by the border facies near the south end of the Tarryall lobe, the China Wall pluton, and, perhaps, the Boomer stock. The zonal distribution in the south part of the Tarryall lobe and the China Wall pluton is reversed from that of the Tarryall lobe, and possibly reflects the tendency for water to become enriched in the outer, cooler parts of a magma.

The zoning at the south end of the Tarryall lobe is similar to that shown by the small China Wall pluton, and it is proposed that the different zonal patterns are due to the extent to which different granite masses have been unroofed. The China Wall pluton, and the southern end of the Tarryall lobe are inferred to have been unroofed to a much smaller extent than the main, northern part of the Tarryall lobe. The much smaller Boomer stock is possibly a cupola only barely uncovered by erosion, and thus it could represent the nature of the uppermost granites now eroded from the China Wall pluton, and the Tarryall lobe.

This hypothesis assumes that all the control of zoning is chemical, and due to the diffusion of volatiles and relatively mobile components in the melt. There is, however, local evidence of structural control of zoning. This evidence, specifically, is in the location of the large dikes of fine-grained granite and abundant wall-rock inclusions in the main granites of the Tarryall lobe. The dike zone parallels the contact of the granular and porphyritic facies on the west side of the lobe and is perhaps evidence of structural break located about at this contact. Rock inclusions are also found near this contact, both in the fine-grained dike rock and also in the porphyritic main granite.

A hypothesis which accounts for general aspects of the structure and the chemical patterns of zoning is presented graphically (fig. 16). The fractures form in the manner that Billings (1954, p. 316, fig. 263) infers operates in underground cauldron subsidence. Part A shows a magma chamber in which a more volatile-rich cap magma has formed by upward migration of volatiles. Parts B and C show stages of fracture formation and filling of the fracture by less volatile-rich portions of the magma. Part D shows the formation of another ring fracture tapping the more volatile magma (Part E), and also intrusion of a dike-like mass parallel to the original contact of the chamber. F shows the appearance after erosion below the level of the screens.

Obviously many other hypotheses could be proposed to explain the observed and inferred relations, and the hypothesis outlined above attempts only to point out some of the complex structural and chemical processes which probably did take place during the formation of the granite bodies.

Latest stages of magmatic activity. The metasomatic modifications of the later granites, the local miarolitic zones observed in aplites, the greisens and beryllium deposits associated with the granites are believed to represent the culmination of a trend toward volatile-rich magmas, and, in effect, to be the final products of the crystallization of volatile-rich magmas.

The problems involved in the later-stages of magmatic activity have often been neglected, as if they were in a no mans land lying between the provinces of the igneous petrologist and

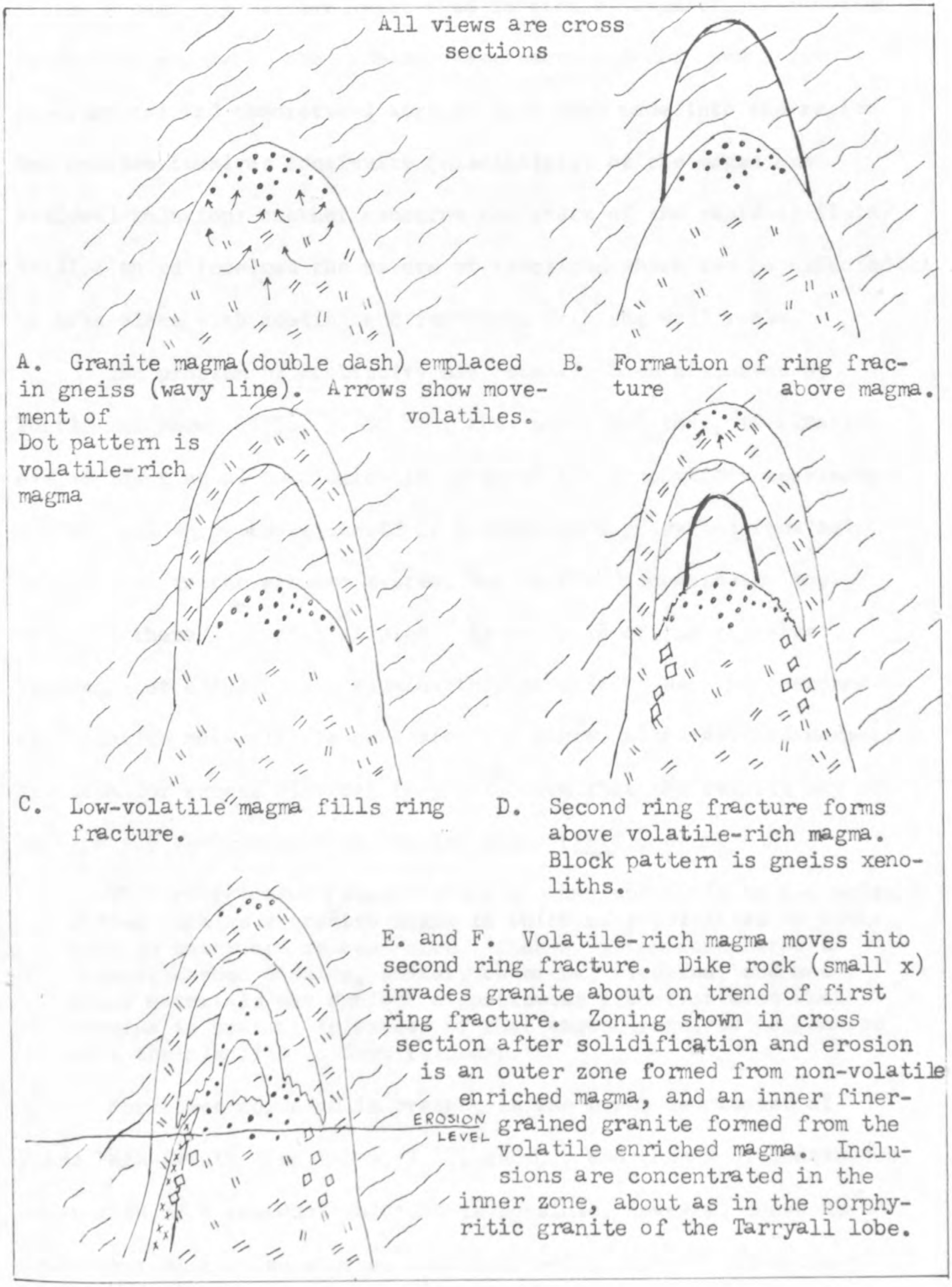

FIGURE 16. HYPOTHETICAL ORIGIN OF ZONED GRANITE BODY DUE TO COMBINED CAULDRON SUBSIDENCE AND VOLATILE FRACTIONATION

of the economic geologist interested in ores of magmatic affiliation. Nevertheless some of the problems have been outlined, and a few experimental and theoretical sorties have been made into the region. One problem involves continuity (miscibility) of the magma and residual solution; another concerns the state of the residual fluid. Still a third involves the nature of reactions which can be expected to take place with cooling and reactions with the wall rocks.

The problem of continuity has recently been discussed by Tuttle and Bowen (1958, p. 84-89); they point out that, if alkalies are at least equal to alumina in terms of the proportions necessary to form feldspar, there should be a continuous gradation from melt to solution in the granite system, but that a discontinuity may exist if there is excess alumina. As criteria of the relative abundance of alkalies vs. alumina they propose to use the presence of normative metasilicate or acmite for excess alkalies, and normative corundum for excess alumina; they also note that the results may not be directly applicable to a complex magma (ibid., p. 89);

> This restriction [excess alkalies] may not apply to a complex system such as a granite magma in which many volatiles in addition to water are concentrated. Such a system concentrating lithia, carbon dioxide, sulfer, chlorine, fluorine, and many other materials may exhibit a continuous gradation even when alumina is present in excess of that amount required to combine with the alkalies to form feldspar.

Normative corundum is present in the norms calculated of Pikes Peak Granite (tables 6, 7, 8, and 9), and thus a discontinuous separation of a residual solution is possible; however, there is no doubt that mineralizers other than water--for example, fluorine--are exceptionally abundant in the Pikes Peak and so a continuous gradation cannot be eliminated from consideration. Furthermore a modified method of norm calculation seems to indicate that alumina was essentially balanced by alkalies. Muscovite is represented in the conventional norm by a combination of corundum and orthoclase; in a modified method of calculation used on two analyses, a normative muscovite was alloted as the first major normative mineral according to the amount of H_2O^+, then the residual K_2O, Al_2O_3, SiO_2, and other components were allotted in normal order. Neither of the norms calculated by this method showed normative corundum, and one showed a small amount of normative acmite, and the second a trace of normative meta-silicate. This type of calculation seems to indicate that alkalies and alumina were essentially in balance at the late stages of crystallization, and together with the abundance of fluorine suggests that immiscibility phenomena most probably were not involved at the end stages of crystallization of the Pikes Peak Granite magma.

It has been generally concluded that critical phenomena are not involved in the late stages of crystallization of complex magmas (Morey, 1922, p. 226), but it has also been generally believed that extremely high pressures can result during crystallization of a hydrous magma. Yoder (1958) pointed out that evidences for extreme pressures were generally not present, and that high pressures need not develop. Necessary conditions for the development of extremely high pressures in a cooling magma are strong, nearly impermeable walls, and the attainment of a univariant condition by the magma at a relatively early stage in its crystallization. But because of the hydrous, complex nature of a granite magma, Yoder (ibid., p. 191) does not believe that early attainment of a univariant condition is likely:

> Recent experiments on basalts and granites suggest that the condition of univariancy is met early in the cooling of a relatively dry magma: the principal phases in both these major magma types appear together within a very narrow temperature interval when only several percent of crystals are present. With increasing water content, however, the principal phases appear together within a much larger temperature interval, and the condition of univariancy is probably met only in the final stages of cooling.

Even if critical phenomena are not involved in the separation of residual solutions, these solutions will undergo gradual changes in properties due to gradual changes in temperature and pressure. In the so-called supercritical region fluids at relatively high temperatures or relatively low pressures will be characterized by a more diffuse type of aggregation than will solutions at lower temperatures and higher pressures. Because the non-volatile substances tend to have a higher solubility in denser fluids than do the volatile substances, which show the converse relation (Smith, 1953, p. 23, 34), and since the volatile substances tend to be acids and non-volatile substances bases, the intrinsic acid properties of residual solutions will change as a results of changes in temperature and pressure (Korzhinskii, 1957), in addition to changes caused by reaction.

It has been postulated (Beus and Sitkin, 1958, p. 37-40; Ginzberg, 1958, p. 8-9), specifically, that the intrinsic changes in the residual solutions cause a change in the late magmatic reactions, with earlier albitization succeeded by greisening, presumably the reason being that the somewhat denser and less volatile sodium would have lesser solubility in the more diffuse, higher temperature residual solutions than would potassium, and thus sodium would tend to be more easily precipitated (as albite) than the potassium as muscovite. But with decreasing temperature and increasing liquid-like character of the fluids, the potassium would become relatively more insoluble, and muscovite would form in preference to albite.

Although there may well be other explanations for the change from albitization to greisening, this explanation appears to offer a method of reasoning which may resolve a conflict existing between the experimental data, and the mineral associations observed in the rocks. The tendency inferred from the late reactions which took place in the Boomer granite seems to have been towards the formation of a quartz-albite-muscovite granite (fig. 12). But the data on the relative stabilities of albite, K-feldspar, muscovite, and paragonite at about 15,000 psi (Hemley, Myer, and Richter, 1961) seem to indicate that the formation of such a rock would be unlikely because albite tends to decompose to paragonite, with either decreasing temperature or increasing acidity, before potassic-feldspar alters to muscovite. The possibility of somewhat different behavior of sodium and potassium under different T-p conditions suggests that there may be a T-p region where albite is more stable with respect to hydrolysis than is potassic feldspar. Another possibility, of course, is that the relative stabilities are altered by components not present in the experimental systems. For example, the white mica of the granites is probably not an ideal muscovite, but an iron-rich muscovite, and would very likely have other stability relations than pure muscovite.

Regardless of the relative stability of potassic feldspar and albite with respect to hydrolysis, the general stability relations of potassic feldspar and muscovite, outlined by Hemley (1959), seem to be directly applicable to the case where secondary muscovite replaces the potassic alkali feldspar, which takes place as a deuteric phenomena in most of the younger granites, and extensively in the more locally developed greisens. At a given temperature and K^+/H^+ ratio potassic feldspar and muscovite may be in equilibrium, but with either declining temperature or a relatively higher H^+ content of the coexisting fluid, the feldspar will become unstable. In general the tendency for alteration increases with decreasing temperature, although at very low temperatures the slowness of the reaction rates may conceal this tendency. The alteration also must tend to deplete the hydrogen ion concentration of the coexisting fluid, and it seems almost certain that in greisening, where all the feldspars are unstable that the reduction in acidity will be reflected in metal transport and precipitation and thus the extent of alteration will be reflected in the associated ore deposits.

CHAPTER V

ORE DEPOSITS

The beryllium deposits of the Lake George area occur as veins, pipes, and irregular replacement bodies in the Pikes Peak Granite and in older rocks near the granite. Nearly all of the deposits are associated with a type of altered rock termed greisen, and the deposits themselves are composed principally of beryl or bertrandite and the typical greisen minerals, quartz, muscovite, topaz, and fluorite. Metallic minerals are locally abundant in greisens near the beryllium ore bodies, but only rarely are abundant in the beryllium ore. Small amounts of silver, molybdenum, and lead-zinc ores have been produced from the greisen deposits.

The area has also been prospected extensively for fluorite-bearing fissure veins, and for scheelite deposits. The fluorite deposits, like the greisens, are associated with the Pikes Peak Granite, but the scheelite deposits are scattered through calc-silicate gneiss layers in the metamorphic complex. The scheelite deposits are older than the greisens; the fluorite deposits are younger.

Distribution of ore deposits and associated altered rocks

The main beryllium deposits are clustered in four parts of the area; veins with small amounts of beryllium minerals have a broader distribution, and greisens with only trace amounts of beryllium are widely if sporadically distributed. The most important beryllium deposits are in or near the Boomer stock near the center of Section 21[1].

Occurrences of ore and altered rocks, locations of mines and prospects, and distribution of facies of the Pikes Peak Granite are shown on plate 7, which also shows the locations of many of the analyzed samples listed in table 1-C (Appendix C).

The fluorite veins which have been prospected most extensively are in the E1/2 of Section 15 and in the NE1/4 of Section 23 (plate 7). The main scheelite deposits are south and west of the mapped area.

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[1]Unless otherwise noted, all Sections are in T. 11 S., R. 72 W.

Distribution of beryllium deposits relative to the Pikes Peak Granite. The most important beryllium deposits are found in four areas in close association with bodies of Pikes Peak Granite. In addition to the deposits associated with the Boomer stock, important areas are in the China Wall pluton in Section 5; in the Redskin Gulch area, and adjacent to the Tarryall lobe in Section 22 about one mile east of the Boomer stock. For convenience in discussion, the main areas of deposits are designated, respectively, 1) the Boomer mine area, 2) Redskin Gulch area, 3) China Wall area, and 4) the Mary Lee mine area. These areas and selected deposits are described in detail in pages 223 to 252.

The beryllium-bearing greisens are found associated only with the porphyritic and fine-grained facies of the Pikes Peak Granite. The somewhat older granular facies of the granite locally contains greisens, but these greisens apparently contain only trace amounts of beryllium. The beryllium deposits in the Boomer mine area are associated either with the fine-grained granite forming the Boomer stock or with fine-grained dike rocks related to the stock. The greisen pipes in the Redskin Gulch area are in the main porphyritic granite of the Tarryall lobe. Beryllium deposits of the China Wall pluton are in or adjacent to fine-grained granites very similar to those found in the Boomer stock, and the deposits in the Mary Lee area are at least in part associated with a fine-grained border facies of the Pikes Peak Granite.

Small beryllium occurrences are found associated with the Pikes Peak Granite in other parts of the Lake George area. Beryllium occurrences near the center of Section 16 in altered biotite-muscovite granite and calc-silicate gneiss are associated with dikes of fine-grained Pikes Peak Granite, and a quartz-beryl vein is found within a fine-grained border zone granite of the Tarryall lobe in Section 23.

In summary, present information on the distribution of beryllium-bearing greisens indicates that the following granite units are favorable for prospecting: in the Tarryall lobe--the main porphyritic granite forming the intermediate zone, and fine-grained granites forming border zones or dikes in the adjacent metamorphic rocks. In the China Wall pluton--the fine-grained granite forming the outer zone and related dikes. The entire Boomer granite body and related dikes are also considered favorable.

The main fine-grained granite of the Tarryall lobe has not been prospected to any extent, and its beryllium-bearing potential is considered as unknown.

Beryl-bearing veins are found at distances of as much as several thousand feet from any known occurrence of the Pikes Peak Granite, but these veins are thin, largely composed of quartz, and have not been productive. In some cases, for example in the southern part of the Mary Lee mine area in the SE1/4 of Section 22, it appears possible that the beryl-bearing veins may be underlain at rather shallow depth by the extension of a Pikes Peak Granite body exposed at the surface (plate 1, south end of section D-D').

Distribution of beryllium deposits relative to other rock units. Beryllium deposits associated with the Boomer stock, China Wall pluton, and those in the Mary Lee mine area have been mined partly from the granite and partly from older rocks of granitic composition in contact with the granite. Biotite-muscovite granite, granitic gneiss, and granite pegmatite appear particularly favorable. In the Boomer mine area replacement deposits have been mined from greisened masses of granite pegmatite and biotite-muscovite granite; in the China Wall pluton all known beryllium deposits occur essentially at the contact of fine-grained Pikes Peak Granite and included masses of the biotite-muscovite granite, and in the Mary Lee mine area the one shoot mined was in granitic gneiss walls. Biotite-rich schistose rocks appear generally unfavorable, but some ore has been mined at the Boomer mine from steeply dipping veins in biotite gneiss (Idaho Springs(?) Formation).

Several small beryllium occurrences, as yet unprospected, were found by W. N. Sharp near the center of Section 16. These deposits occur in metasomatically altered biotite-muscovite granite and calc-silicate gneiss within an area cut by several dikes of Pikes Peak Granite. The occurrence suggests that calc-silicate gneisses may also be favorable host rocks for replacement type deposits.

Distribution of greisens. Although essentially all the beryllium deposits are associated with greisens, many greisens contain only trace amounts of beryllium, and greisens with negligible amounts of beryllium are much more widely scattered than the beryllium-bearing types. The occurrences of beryllium-bearing greisen known thus far suggest that most greisens associated with favorable facies of the Pikes Peak Granite contain at least small amounts of discrete beryllium minerals. In contrast most greisens associated with the unfavorable granular facies of the Pikes Peak Granite, or those in older igneous and metamorphic rocks, contain only trace amounts of beryllium and no concentrations of beryllium minerals.

Greisens nearly barren of beryllium are concentrated in the granular facies of the Tarryall lobe in a small area in the SE 1/4 of Section 15 and also in the southern part of Section 14 and the adjacent part of Section 23. Greisens in older igneous and metamorphic host rocks are relatively abundant in the granitic gneiss and biotite-muscovite granite bodies exposed south and southeast of the Tarryall lobe. Both rock units contain numerous small greisens localized by joints and other fractures; most are too small to map. Greisens also appear to be relatively abundant in biotite-muscovite granite and metamorphic rocks in the E 1/2 of Section 28 and the contiguous part of Section 21; in part these greisens are localized by the Badger Flats fault.

Greisens are also abundant on the southeast flank of Tappen Mountain, in a part of the area not yet mapped. Most of the greisens are in the NW 1/4 of Section 30, T. 11 S., R. 71 W. The area is mainly underlain by biotite-muscovite granite and granite gneiss; the greisens are rich in quartz, contain some topaz, cassiterite, and wolframite, and, locally, abundant pyrite.

Mapping suggests that greisens may also be relatively abundant in the Tarryall lobe near the contact of the main porphyritic and fine-grained granites in Sections 1, 2, and 3 (plate 7).

General character of the ores

Beryllium ores

The beryllium ores of the Lake George area are variable in texture and mineralogy. Some of them are readily recognized as ore, but in other cases beryllium-rich rocks have been overlooked because the valuable minerals were unfamiliar or because the rocks resembled barren greisen or granite.

The first beryllium ore discovered in the Lake George area consisted of subhedral to euhedral beryl crystals in complexly intergrown aggregates accompanied by small amounts of quartz and muscovite. The beryl crystals were first noted on the dump of the Boomer mine, and the first beryllium production was from beryl crystal aggregates sorted from the dump rock, and mined from veins rich in well-crystallized beryl. The miners call this type of ore "crystal beryl". A short time after the initial discovery an almost white granitic-textured rock noted in the Boomer vein was found to consist largely of beryl in anhedral poikoblastic form; this material has been referred to as "massive beryl" ore. Ores composed of well- and poorly-crystallized beryl can occur in the same vein and apparently intergrade. In general the well-crystallized beryl forms sharp-walled veins in greisened rocks; the ore which contains poorly-crystallized beryl grades into barren greisen.

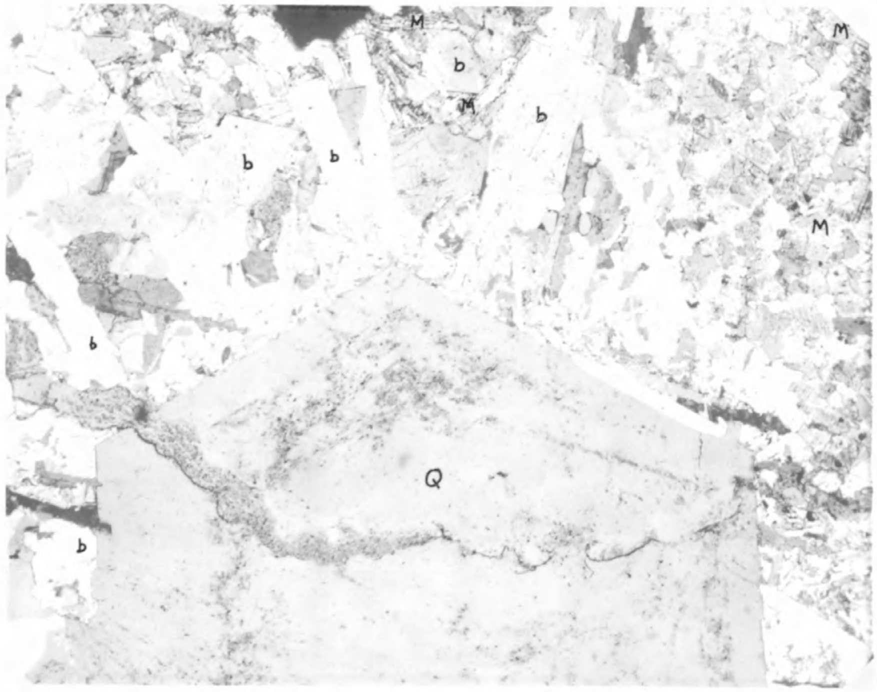
A third type of beryllium ore was discovered in a surface cut at the Boomer mine by L. G. Moyd with a beryllium detector. The ore occurred in a shallow pit partly under an outbuilding to the mine, and the ore body mined, after moving the outbuilding, has generally been referred to as the "Outhouse lode". This type of ore is composed principally of bertrandite, muscovite, and quartz (Sharp and Hawley, 1961). Much of the muscovite is a pale yellow color; it is abundant enough to mask the pale pink color of the bertrandite and to impart a yellowish cast to the ore. Close inspection, however, shows that bertrandite is very abundant and forms small disseminated grains and veinlets. Very similar ore is also found in greisens in Redskin Gulch.

The bertrandite ore at both places forms pipe-like ore bodies encased in barren, gray, mica-rich greisens. Like the so-called "massive beryl" ores, the bertrandite ore grades into barren greisen.

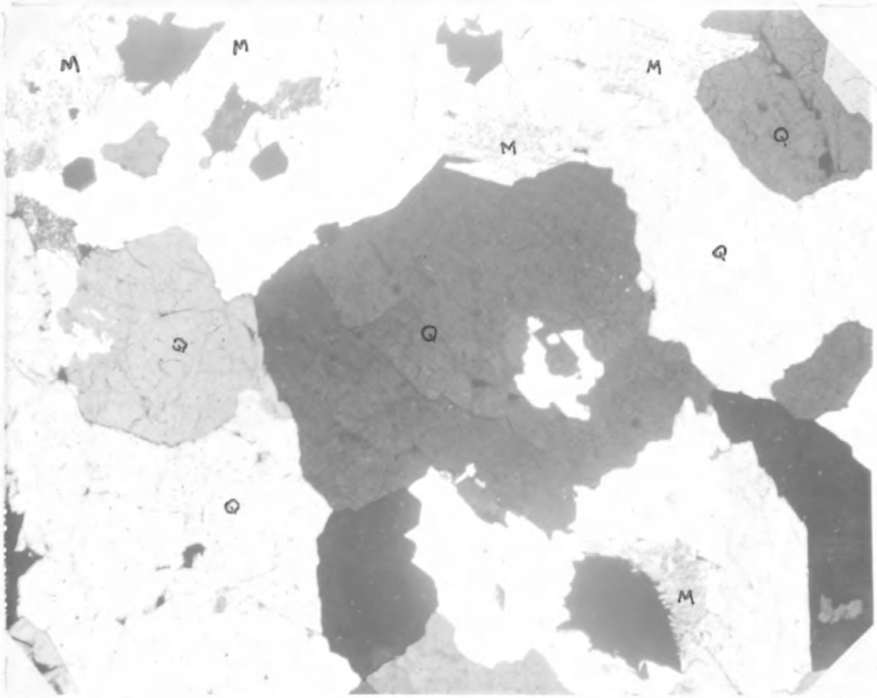
Another type of bertrandite-bearing rock was subsequently recognized in the Redskin Gulch area by W. N. Sharp of the U.S. Geological Survey. It consists of fine-grained euhedral quartz, pink bertrandite, and sparse yellow-green mica (plate 8A). In hand specimen it resembles a slightly altered, vuggy aplite.

Minor varieties of beryllium-bearing rocks are vuggy, white, topaz-quartz-beryl-muscovite greisens found at the Boomer mine, and quartz-topaz-wolframite-beryl veins found at the Mary Lee mine and other prospects in Section 22.

A few beryllium occurrences have a pegmatitic aspect, but feldspars do not occur in strongly greisened rocks or in beryllium ores. Deposits in the China Wall pluton in the north part of the area are small, irregular bodies of medium- to coarse-grained greisen accompanied by pods of massive and crystalline milky quartz similar to quartz segregations found in pegmatites. At the Boomer mine barren portions of the Boomer vein are locally composed of a few inches of quartz and potassic feldspar, and thin pegmatitic zones accompanied by greisened rock locally are found in fine-grained Pikes Peak Granite dikes. Quartz and beryl, greisen, and pegmatite are associated in a small deposit in the NE 1/4, Section 23 (plate 7).



A. 35X

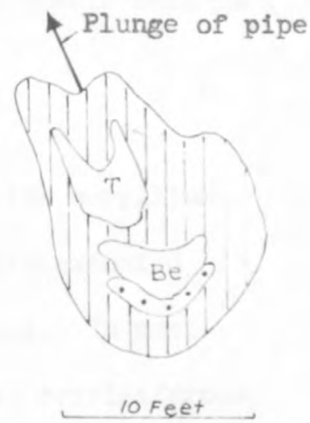


B. 35X

PLATE 8. PHOTOMICROGRAPHS: A. QUARTZ-BERTRANDITE-MUSCOVITE ORE, MINERVA N PROSPECT. B. TYPICAL QUARTZ-MUSCOVITE GREISEN. BOTH CROSSED NICOLS.

(Q-quartz; b-bertrandite; M-muscovite)

Metallic minerals are not abundant in most of the beryllium ores, but rather tend to occur in concentrations in other parts of the deposits. In a few places metallic minerals are found in beryllium ores or at their edges; molybdenite, arsenopyrite, galena and wolframite appear to be the metallic minerals most closely associated with beryllium. At the Boomer mine arsenopyrite formed nodules in beryllium ore on the Boomer vein, and also formed a zone on the footwall of a beryllium-bearing greisen pipe which branches off the Boomer vein. This latter mode of occurrence (fig. 17) is apparently similar to the "footwall gutters" of metallic minerals reported from greisen pipes of the Australian tin province (Blanchard, 1947, p. 272; Garretty, 1953, p. 964).



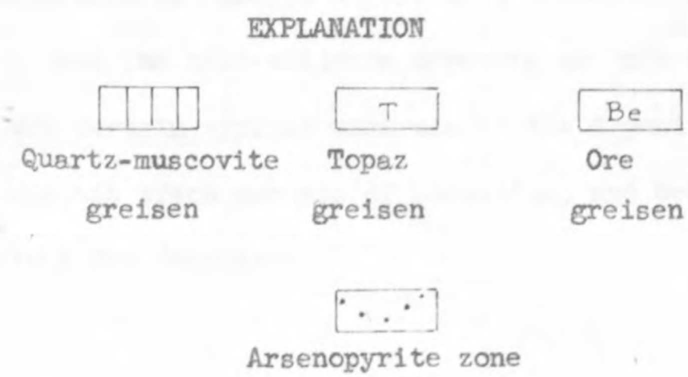


FIGURE 17. MAP OF BERYLLIUM-BEARING GREISEN PIPE BOOMER MINE, SHOWING ARSENOPYRITE "FOOTWALL GUTTER"

Essentially all beryllium deposits have greisened wall rocks. In many places the wall greisens are gray, medium-grained equigranular quartz-muscovite rocks (plate 8B), but locally they include topaz- or fluorite-rich types which grade into quartz-muscovite greisens and beryllium-bearing ore greisens. The beryllium deposits have a general central distribution in greisens, although the amount of greisening and the types of greisen present may not be exactly symmetrical with reference to the beryllium deposit. The only beryllium occurrences found thus far without greisened wall rocks are quartz-beryl veins in dikes associated with the Boomer granite stock. The adjacent dike rocks are, however, of ususual composition consisting mostly of quartz, albite, and muscovite, and only sparse remnants of potassic feldspar.

Other deposits

Scheelite occurs sparsely with wolframite in the beryllium-bearing greisens, but is found chiefly with sparse disseminated sulfides in layered deposits in calc-silicate gneisses. In most places the calc-silicate deposits are not appreciably berylliferous, but certain typical minerals of the deposits, such as vesuvianite, contain trace amounts of beryllium, and bertrandite has been found in a few deposits.

The scheelite deposits show no recognized spatial relations to igneous rocks or to the beryllium-bearing greisens, but rather appear to be scattered through the metamorphic complex within belts containing calcic rocks. Tweto (1960, p. 1412-20, 1423-25) shows that these deposits are older than the Pikes Peak Granite, and suggests that the tungsten was derived from the original sedimentary rocks and concentrated during regional metamorphism and successive plutonic episodes. Bertrandite has been found only where the calc-silicate gneisses are cut by Pikes Peak Granite, and is inferred to have been introduced after the formation of the scheelite deposits.

Fluorite forms sharp-walled fissure vein deposits in and near the Pikes Peak Granite, in addition to its occurrences as an accessory mineral of the granite, and a common mineral in the greisens. The fluorite vein deposits contain small concentrations of galena, sphalerite, and copper minerals, but in general only extremely small amounts of beryllium (table 1-C; Appendix C). Anomalous amounts of beryllium were, however, found in one fluorite vein (0.003 percent Be; Tl-17), and this and a spatial association of greisens and fluorite veins in two areas indicates that the fluorite veins and greisens may be indirectly related, and that fluorite veins may be guides to areas containing greisens. The two areas in which there is a very close association of fluorite veins and greisens are in the SW 1/4 of Section 15, and the NE 1/4 of Section 23 and the contiguous area of Section 14.

Small amounts of molybdenum, silver, lead and zinc ores have been produced from the mines and prospects now being prospected for beryllium, and some fluorite has been shipped from the fissure-vein deposits. At present none of the fluorite veins, scheelite deposits in calc-silicate gneisses, or metallic mineral deposits are of economic importance, and most of the data presented in the succeeding pages are concerned with the beryllium deposits and their associated greisens.

Form, size, and structural relations of the beryllium-bearing greisens

The beryllium deposits are in the form of veins, pipes, and complex, irregular bodies. They are, apparently, partly localized by fissures, contacts, and rock units of favorable composition or orientation. The vein deposits are obviously fissure-controlled, but the pipe deposits and complex deposits show less well defined ore controls. In most of the pipes, a "part" of the ore control appears definite: For example, a pipe may follow or parallel the dip of an obvious fracture, but a second fracture inferred as necessary to control the bearing of the plunge may not be well developed if present at all.

Greisen pipes, like those of the Lake George area, are apparently very uncommon in the United States, but are a very common type of deposit in many greisen areas, as the Australian tin province (Blanchard, 1947); in many places their manner of formation, particularly with reference to structural control, is an unsolved problem.

Greisen pipes. Greisen pipes of the Lake George area are practically confined to the Pikes Peak Granite. Most of the known pipes are in the porphyritic facies of the granite in the Tarryall lobe. Pipes are also found in the fine-grained granite forming the Boomer stock, and a pipe, which contains only small amounts of beryllium, at the Happy Thought mine is mostly in the granular type of granite.

The greisen pipes range from about 1 foot to more than 10 feet across, and are generally oval-shaped in cross section. Some pipes are essentially circular in cross-section, and the pipe at the Minerva N prospect is approximately pear-shaped. The pipe at the Redskin mine has been followed down an irregular course for about 200 feet, and pipes at the Minerva J. and Black Prince have been followed, respectively, about 135 and 100 feet. There seems to be a definite tendency for the pipes to occur in clusters, as in the Redskin Gulch area, and for the pipes in any one cluster to have a subparallel plunge.

The beryllium deposits and deposits of other valuable constituents occur as irregular disseminations and vein-like zones in the central part of the pipes. In general the beryllium ore grades outward into nearly barren, dark gray, muscovite-rich greisens. Particularly in the pipes in the Redskin Gulch area, the contact of the greisen and the granite is very sharp, and in places where the muscovite-rich barren greisen has been removed in mining the greisen contact clearly shows the cylindrical nature of the pipe (plate 9).

PLATE 9. PHOTOGRAPH: SOUTH EDGE OF MAIN REDSKIN PIPE

(Hammer is about on quartzose contact of greisen. Quartzose greisen grades out to the right into granite. Dark gray material is micaceous greisen which is in knife edge contact with quartzose greisen. Hammer parallels plunge of greisen pipe)

At the Boomer mine pipes form small parts of complex ore bodies. One pipe, which is as much as 10 feet across, has been followed to the surface from the hanging wall of the Boomer vein (plate 13, section E-E'). A second pipe, partly shown near the east end of section B-B' (plate 13), was followed from the 8565-foot level to the surface. Both of these pipes were ore-bearing; the beryllium ore zone is approximately in the center of the pipes and in both pipes is as much as 2 feet across. The so-called "Outhouse lode" ore body is also pipe-like in form.

The relations of several pipes to fracture zones or joints are shown diagrammatically in figure 18. In all the cases shown, the fractures are partly in greisen and partly in barren granite; in other cases, as the almost perfectly oval Minerva O pipe, no discernible fracture extends from pipe to wall rock.

Vein deposits. Tabular fissure-veins filled with quartz, topaz, and smaller amounts of beryl and wolframite are typical of deposits found in the Mary Lee mine and nearby prospects in Section 22. Similar veins containing relatively more beryl are found in the Boomer mine. The generally nonberylliferous fluorite deposits of the area are also of fissure-vein type.

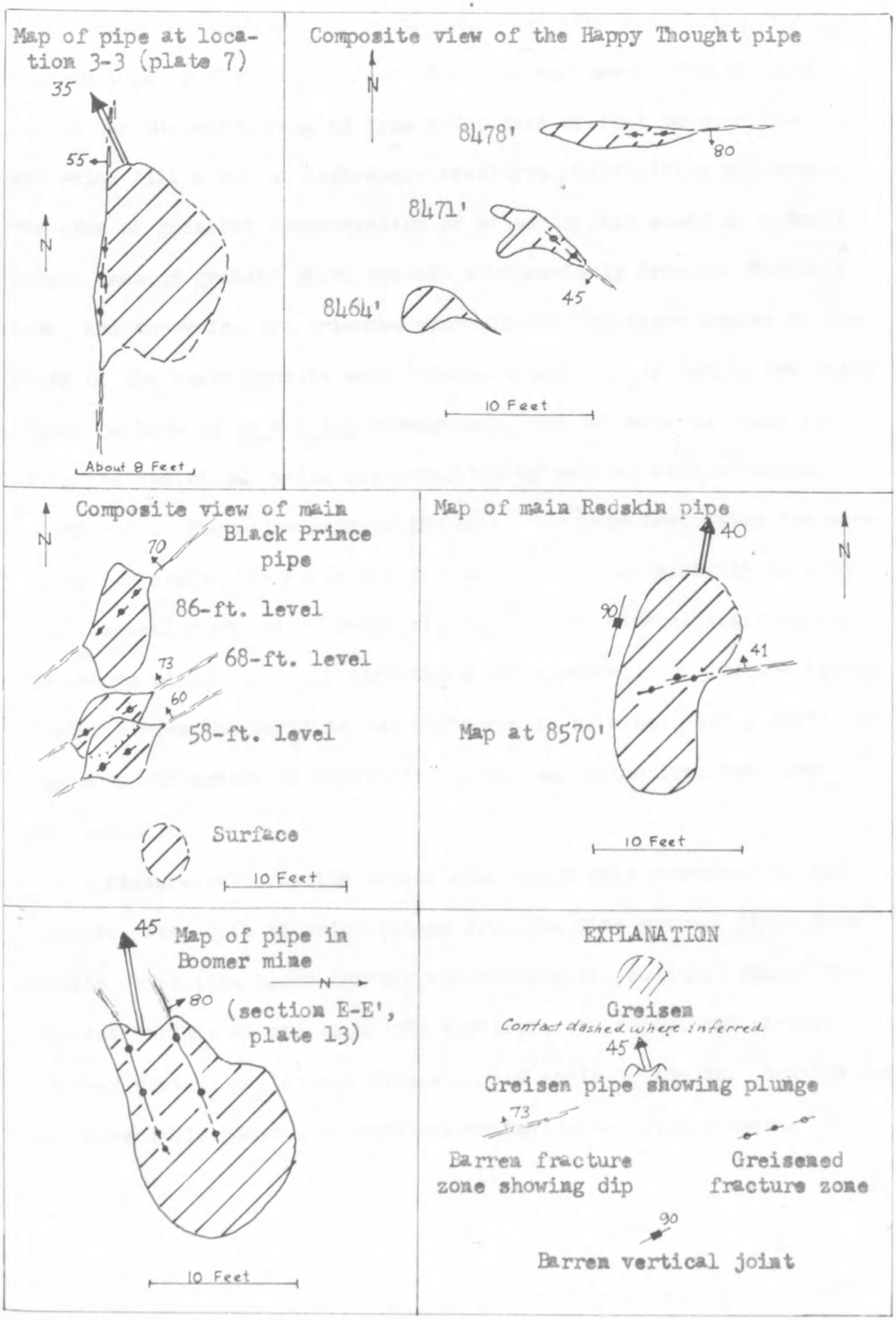


FIGURE 18. MAPS SHOWING RELATIONS OF GREISEN PIPES AND FRACTURES

Fissure-vein deposits of the Mary Lee mine area range from less than an inch to about 2-1/2 feet in width, and can be traced along strike for distances ranging from a few tens of feet to over 1000 feet. The veins fill a set of high-angle fractures which strike northeast. The area of greatest concentration of veins is just south of a small lobate mass of granite which extends southeasterly from the Tarryall lobe, and the veins are oriented approximately at right angles to the trend of the small granite mass (plates 1 and 7). In detail the veins appear to have an en echelon arrangement, and to occur in zones in which the individual veins are separated by several feet of nearly barren rock. The major vein of the area, the Mary Lee, which has been traced for reasonable certainty for about 1400 feet probably is a lode zone consisting of nearly parallel, en echelon, mineralized fissures. Ore shoots within the vein structures are apparently of limited extent. In most places the beryl is too scattered to be mined, but a small ore body composed mainly of crystalline beryl was mined from the lower Mary Lee adit.

Fissure-veins in the Boomer mine are mostly contained in two fracture sets, both of which extend from the fine-grained Pikes Peak Granite stock into older igneous and metamorphic country rocks. One vein set strikes NE and is nearly vertical; the second set strikes slightly west of north, and dips at a low angle to the NE. Neither set has appreciable amounts of vertical or horizontal displacement.

The northeast set contains quartz-beryl veins, most of which are too thin to mine, and fine-grained granite dikes which locally contain greisens and beryl veinlets. The main northeast-trending vein in the mine is best exposed on the 8518-foot level (plate 13) where it has been followed for about 120 feet. The southern part of the vein is a simple vein as much as 8 inches wide in sparsely greisened gneissic wall rocks. In places the vein-filling is an interlocking aggregate of beryl crystals. The northern part of the vein is partly in extensively greisened rocks, and partly in fine-grained granite. The fissure, as such, cannot be traced directly through the extensively greisened area, but is apparently marked by discontinuous beryl veins some of which have been mined.

The major mineralized zone on the low-angle northerly striking vein-fissure set is the so-called Boomer vein. At various places in the mine, the fissure is marked by thin seams of pegmatitic material in unaltered granite, by sharp-walled quartz-crystalline beryl veins as much as 2 feet wide in greisened rock, by massive beryl replacement ores at least as much as 6 feet across grading outward from beryl-bearing fissures (fig. 22), and, in the metasedimentary rocks, by partly greisenized granite dikes. The vein is exposed on three levels in the mine, but is strongly mineralized only on the 8533-foot level (plate 13), and the main ore-body in the vein probably has a flattened pipe-like shape as in section D-D'.

<u>Deposits partly localized by favorably oriented rock units and contacts</u>. Greisens, locally containing important amounts of beryllium, are localized along the contacts of Pikes Peak Granite with older granitic rocks at several places in the Lake George area. Examples of contact or wall-rock control of mineralization are found in the Boomer mine, at several prospects in the China Wall area, and at the Happy Thought and Tennessee mines in Section 22.

The south edge of the Boomer stock is in contact with an older granite pegmatite. At the surface the contact is nearly vertical, but at about 50 feet, the contact begins to flatten abruptly, and in cross section (plate 13, sections A-A', B-B', C-C', and D-D') the pegmatite appears to be a remnant lying between fine-grained Pikes Peak Granite and gneissic rocks and completely underlain by the granite. The contact of the granite and pegmatite is mineralized at several places, but most extensively at the collar of the Boomer shaft, on the 8565-foot level, and on the 8518-foot level. The very small remnant mass of pegmatite exposed on the 8518-foot level has been almost completely replaced by beryllium-bearing greisen forming an ore body about 35 feet long.

The granites of the China Wall pluton were emplaced between the Tarryall pluton and an extensive mass of the biotite-muscovite granite, and, particularly near the western edge of the pluton, contain numerous inclusions of biotite-muscovite granite. The beryllium-bearing greisens are found near or at the contacts of the inclusions with fine-grained Pikes Peak Granite, or, as at the A & C mine, in a thin dike of fine-grained Pikes Peak Granite which cuts a large mass of the biotite-muscovite granite.

A greisen pipe which contains trace amounts of beryllium at the Happy Thought prospect lies nearly on the contact of the main granite of the Tarryall lobe with Idaho Springs(?) Formation and granitic pegmatites, and in part is apparently controlled by the contact. A few hundred feet south along the contact, beryl-bearing veins and greisens are found in the Tennessee prospect. Still farther along the same contact, the beryl-shoot in the Mary Lee vein deposit lies within 50 feet of the granite contact, within granitic gneiss wall rocks.

Mineralogy

The beryllium ores are generally composed of only a few minerals. Most consist of beryl or bertrandite and other silicates typical of the greisens such as quartz, mica, fluorite, and topaz. The associated greisens and related deposits of other metals, however, may be complex mineralogically. In addition to common sulfide minerals, the deposits contain arsenopyrite, molybdenite, wolframite, and rarely cassiterite and uraninite. Euclase is a rare component of some of the beryllium ores.

The minerals found in the deposits are divided into two groups: (1) ore minerals comprising the beryllium-bearing silicates and the metallic minerals, and (2) gangue minerals consisting of non-metallic minerals including topaz, fluorite, and muscovite.

Ore minerals

Sulfides. The sulfides found in the greisens and associated ore deposits are, in approximate order of abundance, galena, sphalerite, arsenopyrite, molybdenite, pyrite, chalcopyrite, and covellite. The sulfides most closely associated with the beryllium minerals are probably arsenopyrite, molybdenite, and galena.

Galena is found at the Boomer, Happy Thought, and Black Prince mines. At the Boomer it occurs in two ways, as disseminated grains and aggregates in greisens and altered granite, and in massive pods and veins in greisened rocks. In places such as the raise between the Boomer vein and the so-called "Outhouse lode" open cut (plate 13, section E-E') and in the greisen on the hanging wall of the Boomer vein on the 8533-foot level, solid masses of galena were found as much as several inches across. The massive galena is apparently nearly pure; semiquantitative analyses indicate that it contains about 0.3 percent Ag and Bi, 0.7 percent Cu, and very small amounts of other elements.

Disseminated galena in the greisen is found with sphalerite in the Happy Thought pipe, in small amounts at the Black Prince pipe, and in several places at the Boomer mine. Galena and sphalerite are found in a quartz-beryl-mica zone forming the footwall of the Boomer vein on the 8533-foot level near one occurrence of massive galena.

Small amounts of galena are also found in the fluorite-fissure veins of the area.

Sphalerite is found with galena or chalcopyrite and is probably most abundant at the Boomer mine and in the main Black Prince pipe. The sphalerite is a dark iron-bearing variety and contains minute exsolved blebs of chalcopyrite. Disseminated sphalerite accompanied by chalcopyrite and pyrite is also found in slightly altered granite in the northern part of the 8533-foot and on the 8494-foot levels at the Boomer mine and at the Redskin mine.

Arsenopyrite has been observed only at the Boomer mine. It was first observed as nodules and crystals 1-2 inches across in greisen on the dump; similar material was seen in place in the Boomer vein on the 8533-foot level, and in the footwall of the pipe-like ore body connecting the Boomer vein with the surface greisen.

Molybdenite occurs principally in the Redskin Gulch area; it has also been reported from the Boomer mine. Only small amounts of molybdenite are found on the Redskin dump, but vein-like zones of solid molybdenite as much as 2 inches thick were found during the exploration of the mine for beryllium in 1961, and it is assumed that similar material was mined and shipped during the molybdenum activity about the time of World War I. Some of the molybdenite found at the mine was intimately associated with bertrandite.

Pyrite occurs sparsely in the Boomer ores and also in the greisens from the Redskin Gulch area, generally in disseminated form in greisens and in altered granite. Massive pyrite was noted only at the Lucky Boy mine, a tungsten (wolframite vein) prospect south of Tappen Mountain (area not mapped). Chalcopyrite is found with pyrite or sphalerite and is never abundant; it is also a trace component of some of the calc-silicate tungsten deposits, and probably the fluorite-fissure veins. Covellite is found as thin, late veinlets cutting sulfide-bearing materials from the Boomer mine.

Oxides. Oxide minerals found in the greisens are cassiterite, uraninite, and the iron oxides, goethite, hematite, and limonite.

Cassiterite is reported from a prospect near the Mary Lee mine (Bob Beal, oral communication, 1960), and was found in a prospect in the Tappen Mountain area. It probably occurs as a microscopic component of the gray muscovite-quartz greisens which generally contain tin in amounts on the order of 100's ppm.

Uraninite has been found in small amounts at the Redskin mine, the Black Prince mine, and at the Boomer mine. Apparently most of the uraninite is of the sooty variety; in the only locale presently accessible sooty uraninite is found in a 1-2 inch vein with greisened walls on the 8494-foot level of the Boomer mine.

Very fine disseminated hematite appears to be a characteristic associate of greisens in the old pegmatite wall rocks. The pegmatites, which generally are almost white, are distinctly reddish approaching a greisened zone. Small amounts of specular hematite are locally found in the greisens. Goethite was identified by composition and X-ray powder pattern from the Mary Lee vein where it forms small needle-like crystals in vugs; most of the hydrated iron oxides are, however, confined to partly oxidized ores and seem definitely supergene. In places the limonite apparently has psuedomorphically replaced an older carbonate mineral which is assumed to have been siderite. Limonite in this occurrence is interstitial, filling spaces between beryl crystals and other crystalline components of the greisens.

Silicates--beryl, bertrandite, and euclase. The silicate minerals classed as ore minerals are the three beryllium minerals thus far identified from the deposits. Beryl is the major component of most of the ores, but bertrandite is widely distributed and contains most of the beryllium in certain ore bodies or parts of ore bodies. Euclase has been found in small amounts at the Boomer mine, and in deposits in the Redskin Gulch area.

Beryl is commonly represented by the formula $Be_3Al_2Si_6O_{18}$. Natural beryls deviate from this formula because of the substitution of other chemical elements for beryllium, aluminum, and possibly silicon. The structure of beryl was solved by Bragg and West in 1926, and a concise summary of the structure has been presented by Schaller, Stevens, and Jahns (1962, p. 685-87):

> Beryl has a fundamentally columnar, honeycomblike structure . . . Each column is hollow, and consists of stacked hexagonal rings that are formed by linked silicon-oxygen tetrahedra . . . the columns are arranged in a hexagonal pattern, and their long axes are parallel to the c-axis of the crystal. Each ring . . . is bonded by means of beryllium and aluminum ions to the rings above and below it in the column, and to other rings in adjacent columns, as well.
>
> Each beryllium ion occupies a position of tetrahedral coordination between two columns and is surrounded by four oxygen ions from four different rings . . . . Each oxygen ion not involved in linkage of the silicon-oxygen tetrahedra is bonded to one Be^{2+} ion, one Al^{3+} ion, and one Si^{4+} ion.

Most beryls deviate from the ideal composition by substitution of alkali elements which are, commonly, lithium, cesium, sodium, and, less commonly potassium and rubidium. Cesium, sodium, and potassium are very large ions and probably can only be accomodated in the beryl structure in the open-spaces within the silicon-oxygen rings. Lithium is slightly smaller, and has been proposed to substitute for either aluminum (Schaller, Stevens, and Jahns, 1962, p. 685-692; Beus, 1959) or for beryllium (Belov, 1959; Frank-Kamenetskii, 1959). Simple formulae which represent these two views are, respectively:

$$(R^{1+})\ (Be_2Al)(Li\ Al)Si_6O_{18}$$

$$(R^{1+})(Be_2Li)(Al_2)Si_6O_{18}$$

where (R^{1+}) represents the large alkali cations.

The beryllium contents of common beryls (as used by Schaller, Stevens, and Jahns, 1962, table 6) can be estimated from measurements of the N_o (omega) refractive index of beryl. The index varies from about 1.570 to 1.590 in common beryls, corresponding to BeO contents of about 13.7 to 11.8 percent (Norton, Griffitts, and Wilmarth, 1958, p. 23). It has also been proposed that the unit cell edges (a_o and c_o) determined from X-ray measurements reflect composition, but the data are sparse and conflicting. Schaller, Stevens, and Jahns (1962, p. 683) state that a_o increases with increasing alkali content, and that c_o is nearly constant. Frank-Kamenetskii and Sosedko (1958) apparently found that a_o remained nearly constant and c_o varied with alkalies.

Refractive indices, d-spacings and cell edges were determined on several beryl samples from the Lake George area (table 10 and fig. 19). Four of the specimens are from the greisen deposits; the fifth is from a pegmatite deposit probably related to the Silver Plume Granite. The refractive index measurements show that the greisen beryls are all high-beryllium, low-alkali types and are thus similar to beryls from tin- and molybdenum-bearing vein deposits investigated by Adams (1953, p. 108, 117). The greisen beryls probably contain about 13.5 percent BeO. Refractive index measurement on the pegmatite beryl suggests a BeO content of about 13.3 percent.

X-ray data are from powder photographs made with CuKα radiation. Two photographs (samples B2-8 and BJ-1) had sharply defined back reflections showing doublets, and for these extrapolated a_o values are given (fig. 19); the other three photographs had diffuse back reflections, and only the measured $\underline{a}$ and $\underline{c}$ values are given (table 10). The d-values, intensities, and cell edges of the Lake George beryl are very similar to the standard beryl of Swanson and others (1960, p. 13-15) and their indexing was used. The extrapolation was graphical (fig. 19) and was weighted towards the d-values arising from only one plane, namely the 310 and 610 reflections for the calculation of a_o .

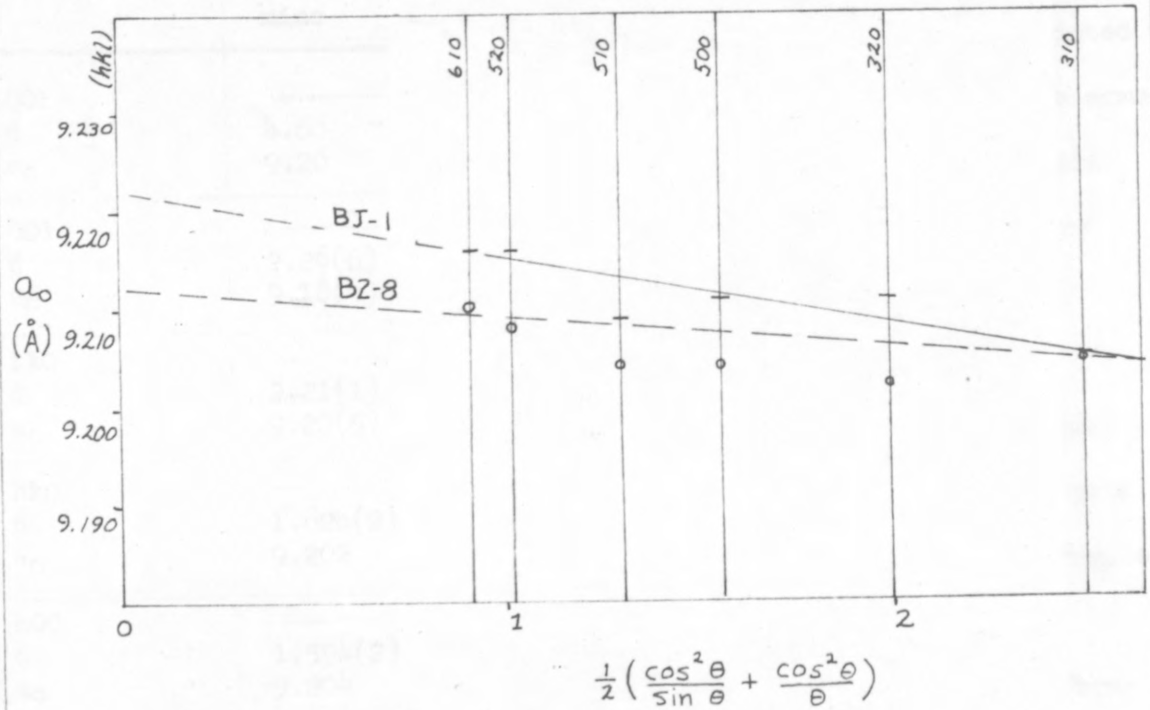


FIGURE 19. GRAPHICAL EXTRAPOLATION OF BERYL CELL EDGE (a_o)

TABLE 10

RESULTS OF X-RAY POWDER DIFFRACTION ANALYSIS OF BERYL, LAKE GEORGE AREA

Sample number Location	B2-8 Boomer mine	BJ-1 Blue Jay mine	TR-24 Pegmatite	B1-17 Boomer mine	LJ-1 Little John mine	Standard beryl (Swanson and others, 1960, p. 13-15)
001			002			
d	4.60	4.59	4.60	4.60	4.60	4.60
c_o	9.20	9.18	9.20	9.20	9.20	9.20
001			004			
d	2.29(6)	2.29(6)	2.30	---	2.30	2.293
c_o	9.18(4)	9.18(4)	9.19	---	9.19	---
hk0			310			
d	2.21(1)	2.21(1)	2.21(4)	---	2.21	2.213
a_o	9.20(5)	9.20(5)	9.21	---	---	---
hk0			320			
d	1.828(2)	1.830(2)	1.831	---	1.830	1.8308
a_o	9.202	9.211	9.21	---	---	---
h00			500			
d	1.594(2)	1.595(5)	1.596	---	1.594	1.5953
a_o	9.204	9.211	9.21	---	---	---
001			006			
d	1.531(1)	1.532(1)	---	---	1.532	1.5320
c_o	9.186	9.193	---	---	9.19	---
hk0			520			
d	1.276(9)	1.278(1)	1.278	1.277	1.276	1.2774
a_o	9.208	9.216	9.22	9.21	9.20	---
hk0			610			
d	1.216(3)	1.217(4)	---	---	---	1.2170
a_o	9.210	9.218	---	---	---	---

The beryl occurs in both massive and crystalline form; it varies from almost white in color to pale blue, yellowish green, and bluish-green. Some of the blue beryl is aquamarine, although practically none is of gem quality. The beryl crystals range in size from almost microscopic to about 10 inches long and 3 inches across; probably most are less than an inch across. Nearly all beryl crystals have striated prism faces, and on close inspection striated faces can be seen on some massive, poikoblastic crystals disseminated in greisen. Many of the crystals from veins in the Boomer mine show zoning; the interior of the crystals is clear and pale-bluish; the outer parts are nearly white. In part the difference in color is due to the presence of minute, abundant fluid inclusions in the white, less clear material.

Beryl in topaz-bearing ores at the Boomer mine forms very pale bluish or greenish crystals, which typically occur in porous aggregates of very small, but well-formed crystals.

Beryl commonly occurs with quartz and muscovite; it also forms nearly monomineralic aggregates, and in a few places it is associated with quartz and topaz. Bertrandite and yellow mica occur, in part, as psuedomorphic replacements after beryl, and very locally bertrandite occurs with unaltered beryl. In a few places beryl is associated with metallic minerals. Beryl was found in pods of wolframite-topaz greisen on the 8565-foot level of the Boomer mine, and at other places was found with arsenopyrite, galena, and sphalerite. The galena and sphalerite fill interstices of mats of beryl crystals and thus seem definitely younger than the beryl.

Bertrandite, a hydrous beryllium silicate ($Be_4(OH)_2Si_2O_7$), is the major beryllium mineral in the so-called "Outhouse lode" ore body at the Boomer mine, and in the greisen pipes of the Redskin area. It also occurs with beryl in the Boomer vein. Most natural varieties of bertrandite probably approach the ideal formula which contains about 42 percent BeO.

The bertrandite forms flesh-colored to pink sub- to euhedral crystals. Some of the bertrandite occurs as crystals easily visible in hand specimen, but much of it occurs in apparently massive form as disseminations and veinlets in the greisen. Thin sections show that most of the apparently massive material is composed of aggregates of minute well-formed crystals.

Bertrandite is generally associated with quartz and mica. It has not been noticed in association with topaz. At the Redskin mine molybdenite and other sulfides are locally found in very rich bertrandite-bearing ore. The closest associate of bertrandite is fine-grained yellow mica which, in detail, appears to replace the bertrandite. Both the bertrandite and the yellow mica are younger than the coarser white mica which is a major component of the barren greisen. In hand specimens in most of the bertrandite-bearing ores the pink color of the bertrandite is masked by the color of the yellow mica.

Bertrandite also occurs in beryl-bearing ores where it is found, with mica, as a psuedomorphic replacement of beryl and also in disseminated crystals. Most of the bertrandite in this association is interpreted as a hypogene alteration product of beryl. Bertrandite also occurs in some ores as the earliest hypogene beryllium mineral. This type of ore shows no remnants of beryl or the elongate zones of bertrandite diagnostic of psuedomorphic replacement of beryl. One example of a "primary" bertrandite ore is that from the Minerva N pipe in the Redskin Gulch area. Here euhedral crystals were deposited on quartz crystals (plate 8A). Similar ore was also found in the Redskin pipe.

Euclase (Be Si $AlO_4(OH)$) has been found in small amounts in ore mined from the Boomer vein, and in the deposits of the Redskin Gulch area (Sharp, 1961). It typically occurs as minute euhedral crystals deposited on quartz and fluorite crystals in vugs. It is interpreted as a late hypogene mineral.

Tungstates. Wolframite occurs sporadically in massive topaz-bearing greisens, and in quartz-beryl-topaz veins in greisened wall rocks. It is accompanied by small amounts of scheelite, which forms coatings or veinlets in the wolframite and is probably a late hypogene or supergene alteration product. Scheelite containing variable amounts of the analogous calcium molybdate, powellite, is also found in the tungsten deposits in calc-silicate rocks (Tweto, 1960, p. 1411).

The wolframite at the Mary Lee mine forms crystals as much as two inches across in a vein composed of quartz and topaz in greisened wall rocks; it is most abundant in the upper adit. At the Boomer mine wolframite is found in disseminated plates about 1/4 inch long in topaz greisens exposed at the surface, and in somewhat coarser form with topaz and beryl in pods on the 8565-foot level of the mine.

Gangue minerals

The gangue is dominantly composed of quartz, muscovite, fluorite, and topaz; siderite is locally abundant, and barite, apatite, and monazite are present very locally.

Halides. The halide group is represented by fluorite, which occurs in most of the greisens, and is the major component of the fluorite-fissure veins.

Fluorite forms small disseminated grains in the barren quartz-muscovite greisens, massive aggregates or veins in greisens near ore, and euhedral cubes in vugs; it is generally less abundant in the beryllium-bearing greisen than in barren greisen. It is very abundant in a central muscovite-rich greisen in a barren part of the Boomer vein on the 8518-foot level, and in the greisen exposed in the open cut 60 feet east of the Boomer shaft; a quartz-fluorite vein formed the hanging wall of the bertrandite ore body in the "Outhouse lode" open cut (fig. 24).

Most of the fluorite found as disseminated grains or massive or vein-like bodies is poorly crystalline and green in color. The euhedral fluorite found in vugs is a zoned type, with the older part of the crystal composed of clear fluorite forming an octahedron, and purple fluorite filling out the cube.

Fluorite disseminated in the greisens is interstitial to quartz and mica and is inferred to be younger than the quartz and muscovite. The zoned crystals are found in vugs in barren and ore-bearing greisen, and are probably among the youngest hypogene minerals.

Fluorite in the fissure-vein deposits generally forms interlocking pale green anhedral crystals, and rarely white or purple crystals. The weathered vein material is almost white. Analyses of samples from the vein deposits show appreciable amounts of yttrium (table 1-C; Appendix C) and rare earths; undoubtedly most of the rare elements occur in the fluorite.

Carbonates. Siderite or a closely related iron-bearing carbonate is a characteristic accessory mineral in metasomatically altered granites near greisens, and siderite occurs in beryl-bearing greisens at the Boomer mine and in several bodies in the China Wall pluton. Siderite in greisens is interstitial to well-formed crystals of beryl or topaz; most of it has been altered to limonite.

Silicates. Quartz and muscovite are commonly the most abundant constituents of the greisens, although locally greisens are mainly composed of the hydroxy-fluosilicate, topaz, the beryllium silicates, or fluorite.

Quartz is most common in gray, equigranular, medium-grained crystals locally with strongly sutured outlines; it also occurs in vuggy greisens as clear medium- to coarse-grained euhedral crystals of low-quartz, and in 1-2 inch veins as a cryptocrystalline variety. The cryptocrystalline quartz cuts across the more crystalline minerals of the greisens.

Muscovites belong to at least two structural and compositional types. The most common variety is gray, forms psuedohexagonal crystals, and is paragenetically early. Somewhat less abundant is a pale yellowish-green mica which forms fine-grained aggregates; the yellowish mica characterizes the bertrandite-bearing ores and some barren greisens. It forms partly by the replacement of the gray muscovite. Both varieties are nearly non-pleochroic in thin section.

A third type of mica, noted only in thin section, is a green pleochroic type found in poorly crystalline aggregates along the partings of the gray muscovite.

The gray muscovite is probably a 2M polymorph. Reflections were found at about 31.2 and 32.0°2θ, and these are believed to arise from characteristic 2M planes--115 and $11\bar{6}$, respectively. Observed 2θ values from diffractometer measurements of gray muscovites from the Boomer mine are compared with observed values from synthetic 2M muscovite (Yoder and Eugster, 1955, table 4) below:

Gray muscovite, greisen, Boomer mine		Synthetic 2M muscovite (Yoder and Eugster, 1955)	
$2\theta_{obs}$	"I"[1]	$2\theta_{obs}$	I[2]
8.9	> 70	8.830	> 100
17.8	20	17.665	55
19.8	15	19.825	55
		19.915	65
22.9	5	22.865	37
23.7	10	23.820	32
25.4	15	25.450	44
26.8	> 75	26.600	> 100
27.8	15	27.810	47
29.8	20	29.795	47
31.2	15	31.160	35
32.0	10	31.925	22
34.8	20	34.640	50
		34.770	45
		35.025	90
36	20	35.720	20
		36.555	19
		37.545	10
42	8	42.045	10
		42.390	23
45.5	50	45.100	75

[1] Intensity is height above diffractometer background

[2] "Relative intensity based on arbitrary linear scale", ibid., p. 247

Chemically the gray muscovite contains too much iron to be considered as ideal muscovite ($K[Al_2(OH)_2Si_3Al\ O_{10}]$): a semiquantitative analysis of gray muscovite submitted by W. N. Sharp showed:

Si > 10%; Al > 10%; K > 10%; Fe-- 7%; Mn-- 0.15%; Li-- 0.15%; Sn-- 0.03%; Zr-- 0.015%, and smaller amounts of other elements.

The chemical composition of the gray muscovite can be approximated more closely from the rock analyses of barren quartz-muscovite greisens. These rocks consist essentially of muscovite and two nearly stoichiometric minerals, quartz and fluorite, and modal analyses and the amount of CaO determined chemically can be used, respectively, to assign amounts of SiO_2 and F to be subtracted from the analysis. An average calculated composition is given below.

Calculated composition of gray muscovite, barren greisen, Boomer mine

(Average of 2 compositions calculated from rock analyses, IV-10a-g and B2-7-2, table 11)

SiO_2	48.8
Al_2O_3	28.8
Fe_2O_3	1.6
FeO	5.7
MgO	0.2
Li_2O	0.1
Na_2O	1.1
K_2O	10.2
H_2O	2.9
F	0.6
Total	100.0

Neglecting the relative amounts of H_2O and F, the analysis converts to a half-cell formula after the method outlined by Foster (1960, p. 13-14):

$$[(Al_{1.5}Fe^{3+}_{0.05}Fe^{2+}_{.35}Li_{.05}Mg_{.05})(Si_{3.3}Al_{0.7})O_{10}(OH,F)_2]^{-1.25}(K_{.90}Na_{.15})^{+1.05}_{1.05}$$

The elements in the first parenthesis within the brackets are the cations in octahedral coordination; the elements in the second are those in tetrahedral coordination.

The available chemical and X-ray data suggest that the gray muscovite characteristic of barren greisen is a 2M ferrophengite.

The yellow mica lacks several of the characteristic 2M X-ray peaks, but the diffractometer data are inadequate to resolve its structure; possibly it is an interlayered type containing some 3T polymorph. An association of late finely crystalline 3T mica with early coarsely crystalline mica, has been reported by Victor (1957, p. 161, 165) from a greisen deposit. Semiquantitative spectrographic analysis of yellow mica indicates that it contains much less iron than the gray mica, and probably that it approaches the K-Al muscovite end member in composition.

Topaz is found as an accessory mineral in some fine-grained Pikes Peak Granite, in coarse euhedral crystals in miarolitic Pikes Peak Granite, and in the greisens and beryl-bearing veins. At the Boomer mine it occurs sparsely in the barren quartz-muscovite greisens, but it is the most abundant mineral in some less widely distributed greisens. Most of the topaz at the Boomer mine is in medium-grained cloudy to white subhedral grains, and the topaz-rich greisens are almost white rocks, typically more porous than the muscovite-rich greisens. The topaz-rich greisens are apparently more abundant on the surface and in near surface greisens at the Boomer mine than they are in the deeper levels of the mine. They tend to be located centrally in barren quartz-muscovite greisen envelopes in nearly symmetrical pipes and veins, but locally occur on the footwall portions of asymmetric pipes and irregular tabular deposits, and in small pods in slightly altered granite.

Coarse-grained topaz is found in greisens of the China Wall area, and in the Mary Lee vein. According to Bob Beal (oral communication, 1962) topaz in greisens of the China Wall area is as much as 2 inches across; most of it is iron-stained and fractured, but a few pieces of gem quality material have been recovered in mining. Coarse-grained topaz also is found as a rock-forming mineral in pegmatite dikes exposed near the China Wall pluton. At least locally topaz is more abundant than muscovite in wall greisens at the Mary Lee mine.

Minerals associated with topaz are quartz, muscovite, beryl, and wolframite. Nearly all the wolframite found in the greisen deposits and veins of the area is accompanied by topaz.

Other minerals. The barium sulfate, barite, was found in small amounts in the "Outhouse lode" at the Boomer mine; it also occurs with fluorite and small amounts of metallic minerals in deposits west of the mapped area near Tarryall.

Apatite is found in the biotite-muscovite granite and in some of the older metamorphic rocks, but it is not common as an accessory in the Pikes Peak Granite. Apatite occurs in quartz-diorite gneiss and in the greisen at the Little John No. 1 claim, and in small euhedral crystals in another greisen in the same area which is also in quartz diorite gneiss walls.

Monazite(?) probably occurs in microscopic crystals in some ores from the Boomer mine.

Paragenetic sequence

Certain minerals of the greisens, such as beryl, gray muscovite, and topaz, are consistently relatively early; others such as fluorite, yellow mica, euclase, and galena and sphalerite are consistently relatively late. Still other minerals do not show consistent relations, and probably do not occupy a definite place in any general paragenetic scheme. A case in point is bertrandite--bertrandite partly forms psuedomorphs after beryl and is in turn replaced by yellow muscovite; in places, however, it was the first and perhaps only beryllium mineral deposited. Quartz and to some extent fluorite and muscovite have several distinctive modes of occurrence suggestive of long continued deposition; diagnostic contacts have not been found between certain pairs of minerals so their paragenetic relations are unknown.

Beryl shows different relations in the so-called massive and crystalline ores, but a difference in age may be only apparent and reflect the mode of origin of the beryl. The crystalline beryl ores typically fill fissures encased in barren greisen; contacts between the ore and barren greisen are sharp. Beryl was the first mineral deposited in the veins and was succeeded by one or more of the following following minerals, quartz, topaz, siderite, bertrandite, muscovite, and rarely galena and sphalerite. In many places it was extensively replaced by quartz, mica (plate 10), or bertrandite. Its contacts with topaz show little or no evidence of replacement, but the topaz is partly interstitial and is believed to be slightly younger.

In the massive ores, beryl forms poikoblastic grains partly in vein-fissures and partly in the walls of the fissures, and replacement of early barren greisen by beryl is borne out by megascopic and microscopic relations. Megascopically replacement is suggested by the distribution and pattern of ore-bearing and barren greisens. The ore-bearing greisens are centrally located in an envelope of barren greisen; at the extreme edge of the beryl-bearing zone beryl occurs as anhedral poikoblasts scattered through barren greisen. The amounts of barren greisen decrease as the beryl poikoblasts coalesce towards the high-grade central beryl-rich zone. The relations were clearly shown in the Boomer vein on the 8533-foot level (fig. 23). Microscopically quartz-muscovite remnants, partly replaced by beryl, are scattered through the ore. Microscopic examination also shows, however, that some quartz and mica fill vugs in the ore and are

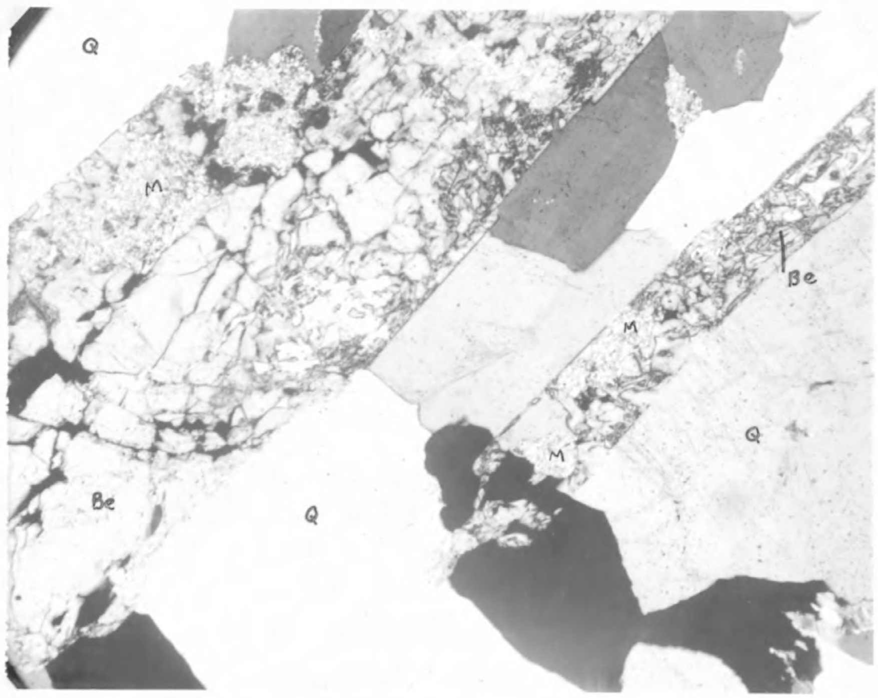


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PLATE 10. PHOTOMICROGRAPH: BERYL REPLACED BY QUARTZ AND FINE-GRAINED MUSCOVITE. CROSSED NICOLS.

(Be-beryl; q- quartz; M- fine-grained muscovite) younger than the beryl. The relations can be interpreted as, formation of the massive beryl and well-crystallized beryl at about the same time in different parts of the vein structure, but with replacement of barren greisen walls by beryl in the massive ores, and simple fissure-filling by beryl in the well-crystallized beryl ores. The more abundant late quartz and muscovite of the well-crystallized ores is explained in this interpretation by a more porous vein structure.

Bertrandite, like beryl, shows partly conflicting relations. Beryl at the Boomer mine and other places is locally replaced psuedomorphically by bertrandite and muscovite. In the ores richest in bertrandite, however, beryl is absent, and the sequence is quartz, bertrandite, and yellow mica (plate 8).

Quartz, in particular, gives every indication of long continued formation. It is replaced by beryl in the massive greisens, and replaces beryl or fills vugs in both massive and well-crystallized ore. It also lines vugs, where it is succeeded only locally by other minerals, and all of these are late types, namely, yellow, fine-grained mica, well-crystallized fluorite, and euclase. Finally, cryptocrystalline quartz forms veins cutting through the ore-bearing vein-fissures in the central parts of the greisens.

Muscovite and fluorite both are present in more than one form suggestive of deposition at different times. Fluorite is a late mineral in barren greisens, forming interstitially to quartz and muscovite; it is not generally abundant in ore-bearing greisens so its relations there are uncertain. Cubic crystals of clear and purple fluorite in vugs are, however, among the youngest minerals of the deposits.

The gray muscovite of the deposits is partly older than some beryl, as it is replaced by massive beryl ores; it is also locally replaced by bertrandite in very rich bertrandite ores. The yellow mica replaces gray muscovite, beryl, bertrandite, and forms on euhedral quartz crystals in vugs. It is older than at least some of the fluorite and some of the euclase.

Composition of greisens

On an average the greisens of the Lake George area are mainly composed of the common rock-forming components SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, K_2O, and H_2O, and also F and the major ore component BeO. These components form the essential part of all minerals commonly found in the greisens. In addition, the greisens contain small amounts of other rock-forming substances such as Mg, Na, and Mn which do not form separate mineral phases, and a characteristic suite of trace elements. Trace elements which occur in virtually all the greisens are Ba, Cu, Ga, Li, Nb, Pb, Sc, Sn, Sr, Y, and Yb.

Al_2O_3, K_2O, CaO, F, and the iron oxides are commonly enriched in the greisens relative to adjacent unaltered wall rocks; in contrast Na_2O is much less abundant in the greisens than in the adjacent rocks. Appreciable differences in composition also exist between the ore-bearing greisen and barren greisen. Differences in the distribution of chemical components in unaltered rocks, barren greisen, and ore-bearing greisen can be at least partly attributed to varying mobilities of the components at different places in the system.

<u>Major and trace element composition of barren and ore-bearing greisen</u>

Results of analyses of greisens are presented mainly in four tables; table 11 gives chemical composition in weight percent and mineralogic composition in volume percent; table 12 gives results of the chemical analyses in terms of grams/100 cc, and tables 1-C and 2-C in Appendix C give the results of semiquantitative spectrographic analysis of many greisens. Analyses of comparable unaltered rocks are also given in tables 11 and 12.

The analyses indicate that the ore-bearing greisens differ appreciably in composition from the barren greisens. Besides a difference in BeO contents, the barren greisen appears to contain more Fe_2O_3, FeO, CaO, and F than the ore-bearing greisens. This conclusion is based in part upon the chemical analyses calculated from mineralogic analyses (analyses 7, 8, and 9, table 11), and for this reason may be suspect. The components in question are, however, largely contained in fluorite and in muscovite in the barren greisens and there seems little doubt that fluorite and muscovite are much less abundant in ore greisen than in barren greisen. It is believed therefore that as a general rule the ore-bearing greisens are composed mainly of five components SiO_2, Al_2O_3, BeO, K_2O, and (H_2O, F). H_2O and F are listed as one component because they occur in ore-bearing greisen mainly in two minerals, namely, topaz and muscovite, in which they occupy the same structural positions.

TABLE 11

CHEMICAL (WEIGHT PERCENT) AND MODAL (VOLUME PERCENT) COMPOSITION OF REPRESENTATIVE BARREN GREISENS, ORE-BEARING GREISENS, AND EQUIVALENT UNALTERED ROCKS

	Boomer Granite suite								Porphyritic Granite suite		Granitic Gneiss suite		
	1	2	3	4	5	6	7	8	9[1]	10	11	12	13
Sample Numbers	IV-10a-2	IV-10a-g	IV-10a-y	Average Boomer Granite	B2-7-1	B2-7-2	B1-17	C2-B2	Minerva N	Average porphyritic granite	ML-4-2	ML-4-3	ML-4-1 (Unaltered)
Chemical analyses													
SiO_2	67.64	62.87	56.35	76.88	81.12	47.12	56.1	65.5	75.4	74.11	72.79	67.88	75.20
BeO	.02	.00	13.06	.00	.00	.00	7.1	11.3	14.3	.00	.00	.00	.00
Al_2O_3	13.37	17.93	16.92	12.32	10.03	25.62	30.5	20.5	5.4	13.47	13.41	20.57	12.98
Fe_2O_3	6.21	1.27	.91	1.00	.69	2.34	1.8	0	0	.69	1.81	3.55	.50
FeO	.25	4.74	1.25	.61	1.49	3.54	0	0	0	.88	2.89	.00	1.39
MgO	.05	.02	.21	.03	.07	.14	0	0	0	.05	.23	.11	.30
CaO	1.41	2.15	.19	.27	.56	5.58	0	0	0	.78	1.40	1.42	1.20
Na_2O	.23	.32	.11	3.54	.57	.36	0	0	0	4.21	.46	.04	3.07
K_2O	3.70	6.64	5.96	3.97	3.43	7.80	0.2	1.9	1.7	4.76	2.81	.43	4.19
H_2O^+	2.73	1.97	3.51	.51	.96	3.35	0.1	0.8	3.2	.22	1.02	1.25	.30
H_2O^-	1.09	.08	.25	.22	.13	.60	N.D.	N.D.	N.D.	.09	.17	.14	.17
TiO_2	.04	.03	.02	.02	.02	.03	0	0	0	.10	.21	.04	.22
P_2O_5	.02	.01	.01	.01	.01	.03	0	0	0	.01	.01	.01	.04
MnO	1.18	.15	.04	.03	.04	.13	0	0	0	.03	.11	.36	.07
Cl	.01	.02	.01	.01	.01	.02	0	0	0	.01	.01	.01	.01
CO_2	.62	.01	.00	.01	.01	.01	0	0	0	.01	.00	.09	.01
F	1.31	2.00	.40	.20	.60	4.48	7.5	0	0	.47	3.37	7.11	.11
Subtotal	99.88	100.21	99.20	99.64	99.74	101.15	103.3	100	100	99.89	100.70	103.01	99.76
Less O	.55	.84	.19	.08	.25	1.89	3.2	---	---	.20	1.42	2.99	.05
Total	99.33	99.37	99.01	99.56	99.49	99.26	100.1	100	100	99.69	99.28	100.02	99.71
Modal analyses													
Plagioclase	No thin section	0	0	32.2	0	0	0	0	0	33.65	0.5	No thin section	40.5
Potassic feldspar		0	0	24.0	0	0	0	0	0	31.25	0		16.6
Quartz		27.0	16.3	37.1	66.8	0	10.8	7.1	51.6	30.25	61.6		31.6
Beryl		0	0	Tr.	0	0	55.3	75.6	0	0	0		0
Bertrandite		0	32.2	0	0	0	0	1.8	34.8	0	0		0
Muscovite		69.5	51.2	6.0	31.4	95.8	1.8	15.5	13.6	4.05[x]	25.1[y]		11.3[z]
Topaz		0	0	Tr.	0	1.8	30.7	0	0	.01	12.2		0
Fluorite		2.8	.3	.15	1.9	1.8	0	0	0	.5	0.4		0
Opaques		0.5	0	.15	0	.4	0	0	0	.04	0.3		Tr.
Zircon		0.2	0	Tr.	0	0	0	0	0	.03	Tr.		Tr.
Cassiterite(?)		Tr.	0	0	0	0	0	0	0	0	0		0
Monazite(?)		0	0	0	0	.2	0	0	0	0	0		0

IV-10a-2: Brownish quartz-muscovite greisened granite, sheeted structure, forms footwall of "Outhouse lode" ore body (fig. 24).

IV-10a-g: Gray quartz-muscovite greisen, hanging wall of above greisen.

IV-10a-y: Yellow quartz-muscovite-bertrandite greisen, centrally located in "Outhouse lode" greisen.

B2-7-1: Gray quartz-muscovite greisen; marginal greisen on Boomer vein (fig. 20).

B2-7-2: Purplish muscovite-fluorite vein zone, barren part of Boomer vein.

[1] Composition calculated from modal analysis, all other compositions from rock analyses

B1-17: Quartz-topaz-beryl-muscovite greisen, 8533-foot level, Boomer mine.

C2-B2: Quartz-beryl-muscovite-bertrandite greisen, pipe in hanging wall of Boomer vein.

Minerva N: Pink aplite-like quartz-bertrandite-muscovite greisen.

ML-4-2: Quartz-topaz-muscovite greisen, upper adit, Mary Lee vein.

ML-4-3: Quartz-topaz vein, adjacent to -4-2.

ML-4-1: Unaltered granitic gneiss adjacent to -4-2.

[x] = biotite and muscovite

[y] = biotite

[z] = 3/5 biotite + 2/5 muscovite.

TABLE 12

CHEMICAL COMPOSITION (GRAMS/100 CC) OF REPRESENTATIVE BARREN GREISENS, ORE-BEARING GREISENS, AND EQUIVALENT UNALTERED ROCKS

	Boomer granite suite						Granitic gneiss suite		
	IV-10a-2	IV-10-g	IV-10-y	Boomer granite	B2-7-1	B2-7-2	ML-4-2	ML-4-3	ML-4-1 (Unaltered)
SiO_2	208.33	168.49	136.93	196.81	218.21	122.03	196.53	205.68	194.02
BeO	.06	0	31.74	0	0	0	0	0	0
Al_2O_3	41.18	48.05	41.12	31.54	26.98	66.36	36.21	62.33	33.48
Fe_2O_3	19.13	3.40	2.21	2.56	2.25	6.06	4.89	10.76	1.29
FeO	.77	12.70	3.04	1.56	4.01	9.17	7.80	0	3.59
MgO	.15	.05	.51	.08	.19	.36	.62	.33	.77
CaO	4.34	5.76	.46	.69	1.51	14.45	3.78	4.31	3.10
Na_2O	.71	.86	.27	9.06	1.53	.93	1.42	.12	7.92
K_2O	11.40	17.80	14.48	10.16	9.23	20.20	7.59	1.30	10.81
$H_2O(+)$	8.41	5.28	8.53	1.31	2.58	8.68	2.75	3.79	.77
$H_2O(-)$	3.36	.21	.61	.56	.35	1.54	.46	.42	.44
TiO_2	.12	-	-	.05	.05	.08	.57	.12	.57
P_2O_5	.06	-	-	.03	.02	.08	.03	.03	.10
MnO	3.63	.40	-	.08	.11	.34	.30	1.09	.18
Cl	.03	-	-	.03	.03	.05	.03	.03	.03
CO_2	1.91	-	-	.05	.03	.03	0	.27	.03
F	4.03	5.36	.97	.51	1.61	11.60	9.10	7.11	.28
Porosity	5.5	6.5	1.1	2.7	0.6	13.4	3.8	2.0	2.4
Grain density	3.26	2.87	2.76	2.64	2.71	2.94	2.80	3.09	2.64
Bulk density	3.08	2.68	2.45	2.56	2.69	2.59	2.70	3.03	2.58

See table 11 for sample descriptions

The trace elements which characterize many of the greisens including those nearly ubiquitous elements named above, are Ag, Ba, B, Cu, Ce, Ga, Ge, La, Li, Mo, Nb, Pb, Sc, Sn, Sr, W, Y, Yb, and Zn. Of these elements a few such as Ag, Mo, Pb, and Zn are locally abundant enough to have been recovered in the past from the area.

Composition as related to greisening

Neither the major nor trace elements are distributed equally through the larger greisens, and, in fact, a zonal distribution of elements seems as characteristic of greisens as it is in the alteration zones found around more typical hydrothermal ore deposits. In as much as the greisening has affected nearly homogenous igneous rocks, the zoning is assumed as due to the greisening process.

In many places the marginal greisens are composed principally of quartz with subordinate amounts of muscovite and fluorite; examples are found in the greisen pipes of the Redskin Gulch area and at the Boomer mine. The resultant greisen contains more silica and less alumina than either the adjacent granite or the more centrally located greisen (as for example in analyses 4, 5, and 6, table 11). Greisens lying between the siliceous border greisen and the locally developed ore greisen are predominantly composed of either muscovite or topaz, or, in a few places, fluorite; in general these rocks contain more aluminum and less silicon than the equivalent unaltered or other altered rocks. The ore-bearing greisens, which tend to be centrally located, locally show a decrease in Al_2O_3, which apparently varies inversely with BeO.

The chemical and mineralogic changes involved in greisening are presented in the following pages by means of representative examples drawn from both ore-bearing and non-ore-bearing suites of greisens.

The simplest relations are shown by low-beryllium greisens localized by vein-fissures, and are represented by two series of samples, one from the Boomer mine, the other from the Mary Lee mine. The series in the Boomer mine was across a nearly barren portion of the Boomer vein on the 8518-foot level. Megascopically the greisen consists of quartz-muscovite greisen symmetrically located around a muscovite-fluorite-rich vein zone; the greisen grades outward into unaltered fine-grained Pikes Peak Granite. The sequence is also symmetrical chemically (fig. 20). Silica increases slightly over its level in the granite in the quartz-muscovite greisen, and decreases sharply in the vein zone; Al_2O_3 shows an inverse relation decreasing slightly in the quartz-muscovite greisen. Total iron oxides and K_2O increase towards the vein zone, though with different slopes. Fluorine is approximately paralleled by $H_2O^{(+)}$ and CaO (the latter two components were not plotted), and increases generally towards the vein zone. In contrast to K_2O, Na_2O decreases sharply going from granite to greisen, but is essentially constant in quartz-muscovite greisen and the central muscovite-rich zone.

Although the greisen contains very small amounts of Be, both spectrographic analyses and fluorometric analyses show that it is more abundant in the central vein zone than in the adjacent greisen wall rock or in the granite. The semiquantitative spectrographic

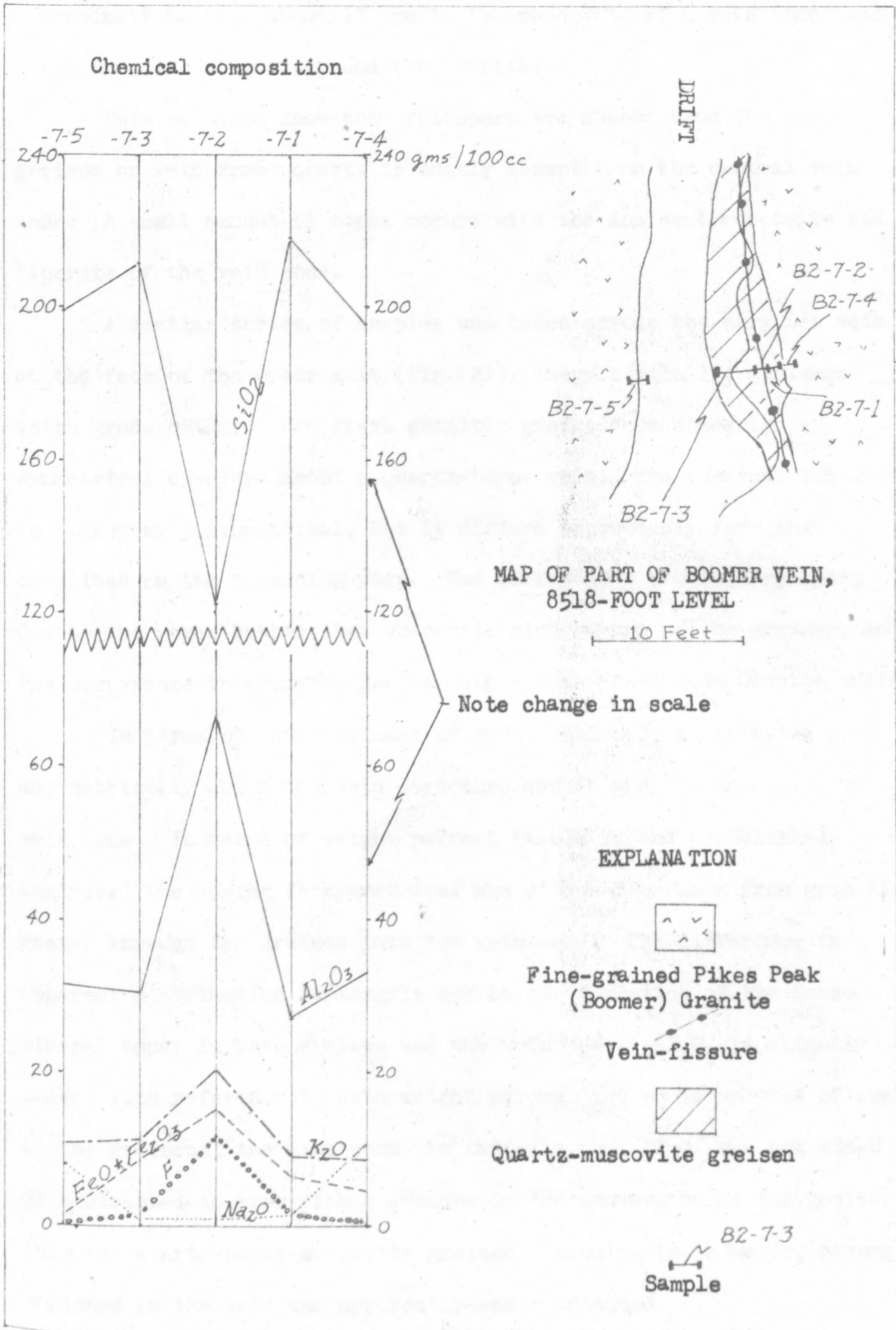


FIGURE 20. VARIATION IN CHEMICAL COMPOSITION, BOOMER VEIN, 8518-FOOT LEVEL, BOOMER MINE

determinations show about 15 ppm in the muscovite-rich vein zone, and 7 ppm in adjacent greisen and the granite.

Thin sections show that feldspars are absent from the border greisen or vein zone; quartz is nearly absent from the central vein zone. A small amount of topaz occurs with the dominant muscovite and fluorite of the vein zone.

A similar series of samples was taken across the Mary Lee vein at the face of the upper adit (fig. 21). Megascopically, greisens which grade outward into fresh granitic gneiss form a nearly symmetrical envelope about a quartz-topaz vein. The chemical pattern is also nearly symmetrical, but it differs appreciably from that described on the preceding page. The differences are in large part due to the topaz rather than muscovite-rich nature of the greisen, and the occurrence in granitic gneiss rather than Pikes Peak Granite walls.

In terms of equal volumes of rock, silica is distributed asymmetrically about the vein structure and is most abundant in the vein zone. In terms of weight percent (table 11 and unpublished analyses) the zoning is symmetrical and silica decreases from granitic gneiss through the greisen into the vein zone. The difference in apparent distribution is largely due to the formation of the dense mineral topaz in both greisen and the vein zone. Al_2O_3 is slightly skewed with reference to both weight percent and equal volumes of rock in the greisens; the data seem to indicate that Al_2O_3 was not added or subtracted in appreciable amounts in the conversion of the gneiss into the quartz-topaz-muscovite greisen. Alumina is, however, strongly enriched in the vein and apparently was introduced.

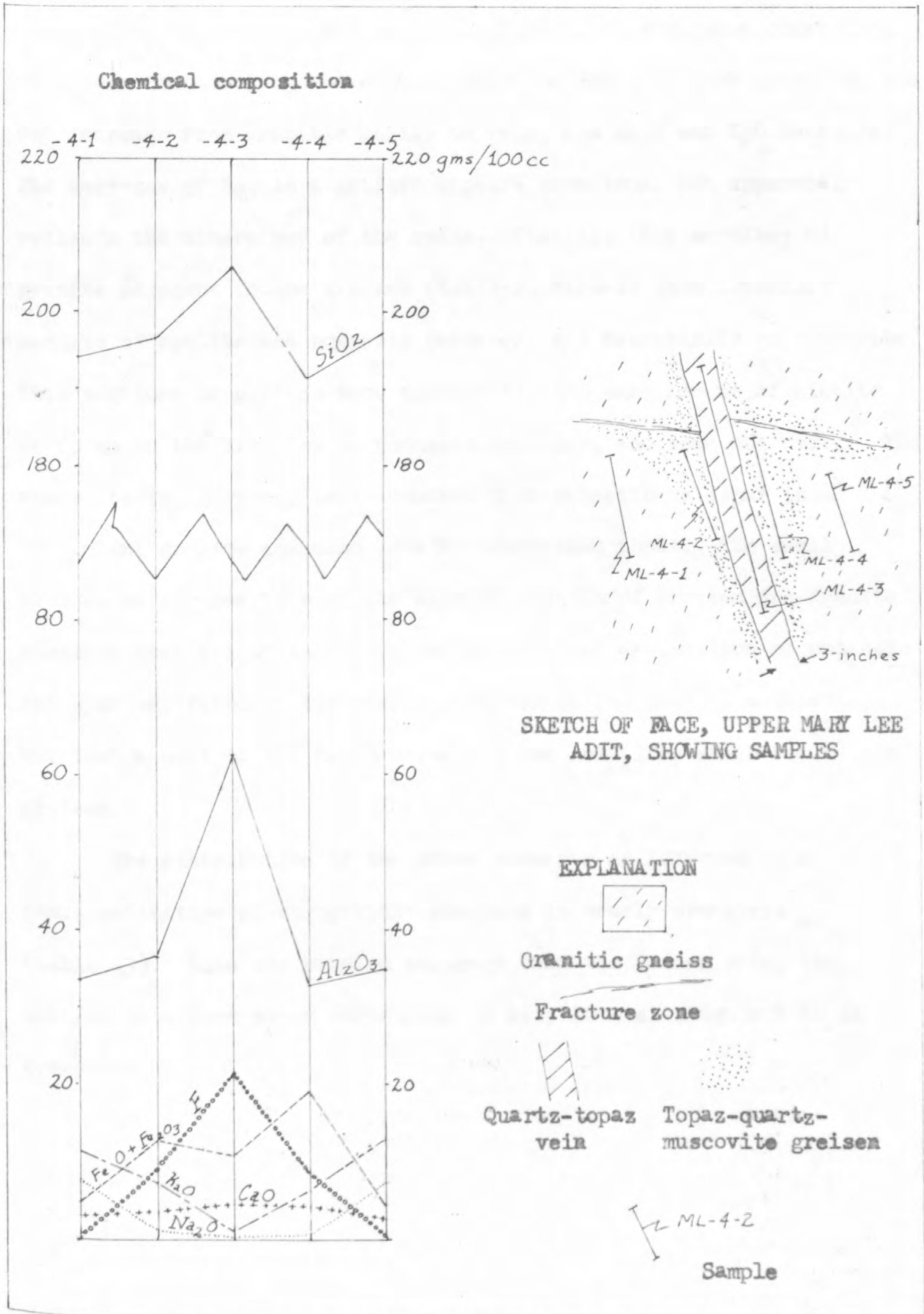


FIGURE 21. VARIATION IN CHEMICAL COMPOSITION, MARY LEE VEIN, UPPER MARY LEE ADIT

The other components of the sampled zones show more consistent relations than do SiO_2 and Al_2O_3. Fluorine and to a much lesser degree CaO increase from granitic gneiss to vein, and Na_2O and K_2O decrease. The decrease of K_2O in a greisen appears anomalous, but apparently reflects the mineralogy of the rocks. That is, thin sections of granite adjacent to the greisen (table 2, ML-4-1) show important amounts of biotite and potassic feldspar, but essentially no muscovite. Thin sections of greisen show essentially the same amount of biotite as found in the granite, no potassic feldspar, and some muscovite. The muscovite is, however, less abundant than potassic feldspar in equivalent granite and also less abundant than topaz. The small average difference between the alumina content of greisen and granite suggests that all of the Al_2O_3 released by the destruction of potassic feldspar was fixed in the greisen, either in topaz or in muscovite, but that a part of the K_2O was lost to the solutions which formed the greisen.

The distribution of the trace elements as inferred from semiquantitative spectrographic analyses is nearly symmetric (table 13). Like the sampled sequence from the Boomer vein, the central vein zone shows enrichment in beryllium although not to an ore-grade.

TABLE 13

DISTRIBUTION OF SOME TRACE ELEMENTS IN THE MARY LEE VEIN, ADJACENT GREISEN, AND GRANITIC GNEISS WALL ROCKS

Sample Numbers:	ML-4-1 H3237	ML-4-2 H3238	ML-4-3 H3239	ML-4-4 H3240	ML-4-5 H3241
Description:	Unaltered granitic gneiss	Quartz-topaz-muscovite greisen	Quartz-topaz vein	Quartz-topaz-muscovite greisen	Unaltered granitic gneiss
Ag	0.0	0.00007	0.0003	0.00007	0.0
Ba	.03	.007	.003	.007	.03
Be	.00015	.0007	.0015	.0007	.00015
Cu	.0015	.015	.07	.07	.0015
Ga	.0015	.003	.00015	.003	.0015
Ge	0	0	.003	0	0
Li	< .005	.05	.009	.05	< .005
Mo	0	0	.007	.0015	0
Nb	.0015	.003	.0007	.003	.0015
Pb	.007	.07	.15	.15	.007
Sn	.0007	.007	.0007	.007	0
Y	.003	.007	.003	.007	.007
Zn	.03	.03	.03	.07	.03

The elements which appear to be relatively enriched in the vein zone are Ag, Be, Ge, Mo, and probably Cu and Pb. Elements characteristic of the greisen walls are Li, Nb, Sn, and possibly Ga.

More complex relations are shown by ore-bearing greisens localized by vein-fissures. An ore-bearing greisen suite was collected from an exceptionally rich and wide ore zone on the 8533-foot level of the Boomer mine, and the samples were submitted for thin sections, semiquantitative spectrographic analyses, and quantitative analyses for Be. The greisen is localized by the Boomer vein-fissure which here consists of two distinct splits about 2 feet apart. The beryllium minerals fill both splits, replace barren greisen between the splits and barren greisen on the hanging wall of the composite vein-fissure. Zones of barren quartz-muscovite rich greisen separate the ore zone from wall rocks composed of fine-grained Pikes Peak Granite (Boomer granite). The samples taken are representative of the (1) barren footwall greisen, (2) both fissure zones, (3) the barren greisen between the fissures, and (4) the beryl-bearing hanging wall greisen (fig. 22). The equivalent barren hanging wall greisen was not exposed along the sample trend. The samples are compared mineralogically and chemically with average Boomer granite; it is important to note that the only quantitative chemical data shown on the figure are the average composition of the granite and the Be content; Al, Ca, Fe, K, and Na are based on the semiquantitative results. The approximate chemical analyses are, however, consistent with the results of modal analyses.

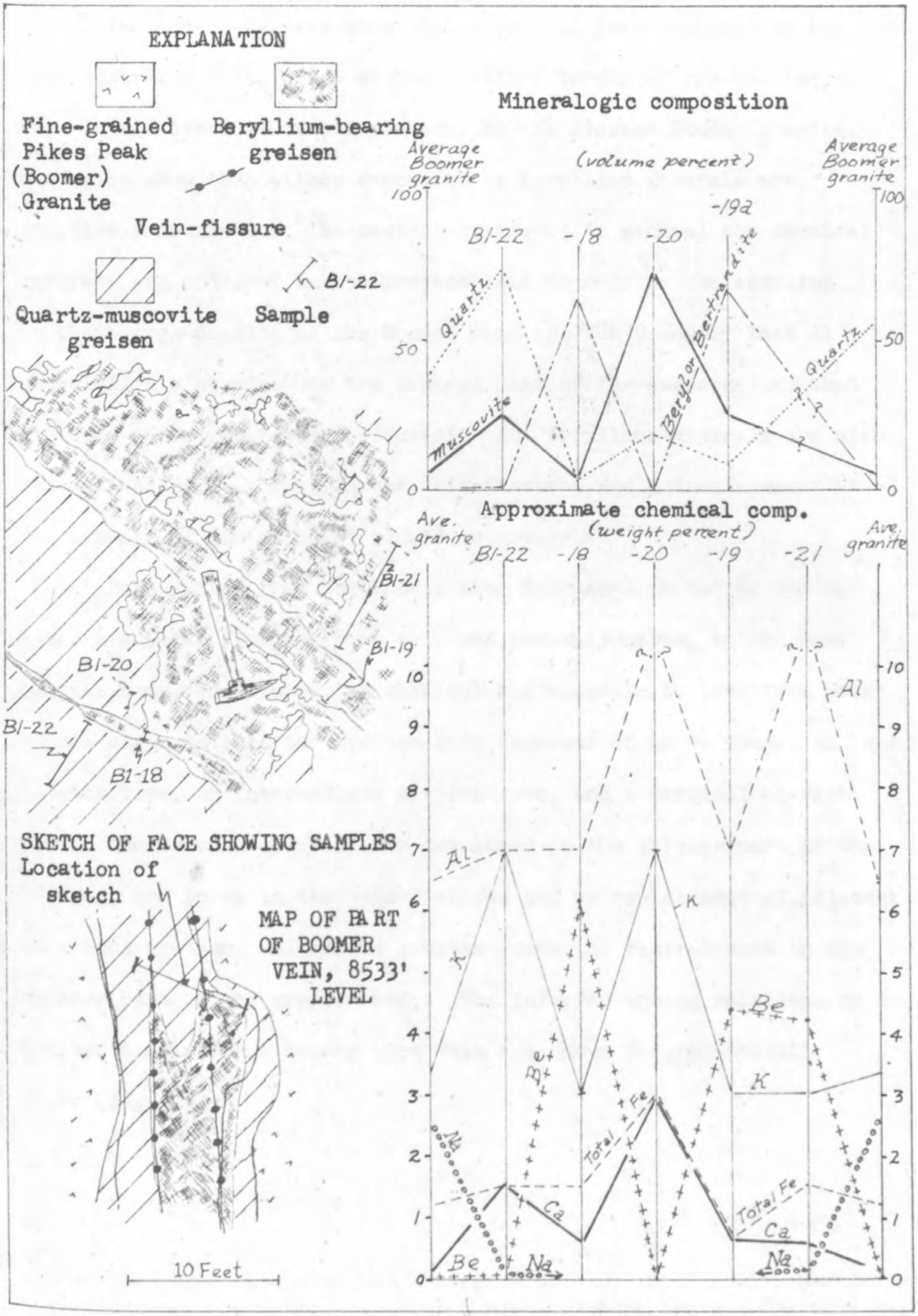
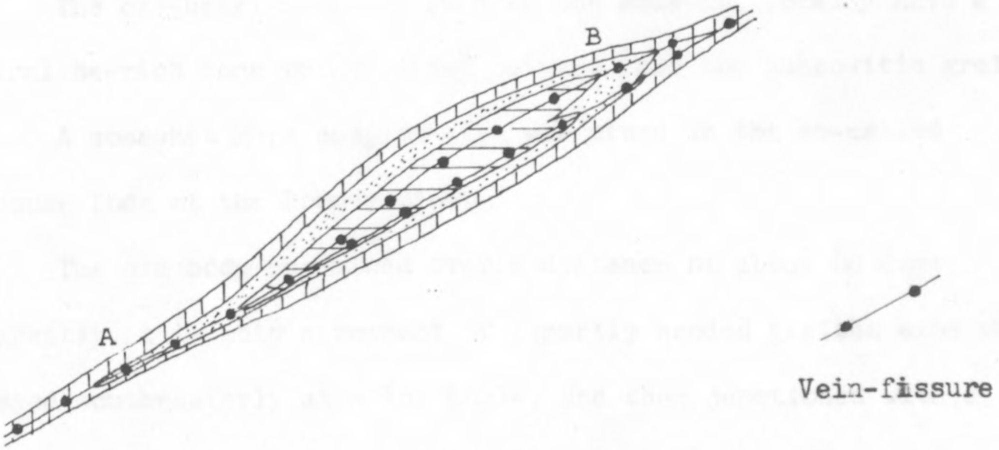


FIGURE 22. VARIATION IN CHEMICAL AND MINERALOGIC COMPOSITION, BOOMER VEIN, 8533-FOOT LEVEL, BOOMER MINE

The modal analyses show that quartz is less abundant in the more centrally distributed greisen, either barren or ore-bearing, than in the barren footwall greisen, or the average Boomer granite. They also show that either muscovite or beryllium minerals are relatively abundant in the central greisen. In general the chemical analyses and modes of barren greisen tend to confirm the sampling on the barren portion of the Boomer vein (p. 186), namely that Al is relatively abundant in the central part of the greisens and that Si tends to be relatively deficient. But beryllium minerals are also present and tend to form in the vein-fissures and by replacement at the expense of the adjacent aluminous greisens.

Both suites from the Boomer mine discussed in the preceding pages are taken from the same vein and probably belong to the same greisen body. Combining the chemical and mineralogic data from both suites suggests that the greisen body consists of three zones, an inner Be-rich zone, an intermediate Al-rich zone, and a marginal Si-rich zone. The Be-rich zone is only developed in the thicker part of the greisen, and forms in the vein-fissures and by replacement of adjacent aluminous greisen. Aluminous greisen forms the central zone in the thinner part of the greisen body. The inferred zoning relations of a greisen body along a Boomer type vein are shown diagrammatically below (fig. 23).



Horizontal lined pattern is beryllium-rich zone; dotted pattern is aluminous zone, and vertical lined pattern is silica-rich zone. Locality A represents the pattern of metal distribution found on the 8518-foot level, and B represents that found on the 8533-foot level, figures 20 and 22, respectively.

FIGURE 23. ZONAL PATTERN IN A HYPOTHETICAL GREISEN BODY

The distribution of minerals in nearly barren greisen pipes found in the Redskin Gulch area indicates that the pattern of zoning of elements is approximately that found in the barren portion of the Boomer vein discussed on page 186. The outer part of the pipes is composed of a very thin rim of silicic greisen and silicified granite; the main body by very muscovite-rich fluorite-bearing greisen with only scattered grains of quartz. The pipes are therefore believed to be characterized by a very thin outer zone enriched in SiO_2 and an interior zone rich in Al_2O_3, K_2O, and the iron oxides.

The ore-bearing pipes, such as the Redskin, locally have a central Be-rich zone which grades outward into the muscovitic greisen.

A somewhat more complex pipe was mined in the so-called Outhouse lode at the Boomer mine.

The ore body was mined over a distance of about 40 feet; apparently it is only a remnant of a partly eroded greisen pipe which plunged southeasterly at a low angle, and then junctioned with a westerly plunging pipe which in turn was followed to the hanging wall of the Boomer vein. Most of the ore in the part of the body mined on the surface was a quartz-bertrandite-mica greisen which was enclosed in and locally graded into a barren quartz-muscovite greisen.

In detail the relations are more complex, as can be seen from a sketch section of a face made during the mining operations (fig. 24). In cross section the greisen consists of a lower or footwall zone of micaceous, sheeted greisened granite, and an upper part consisting mainly of quartz-muscovite-fluorite greisen and smaller amounts of mica-topaz greisen, and a central mass of quartz-mica-bertrandite

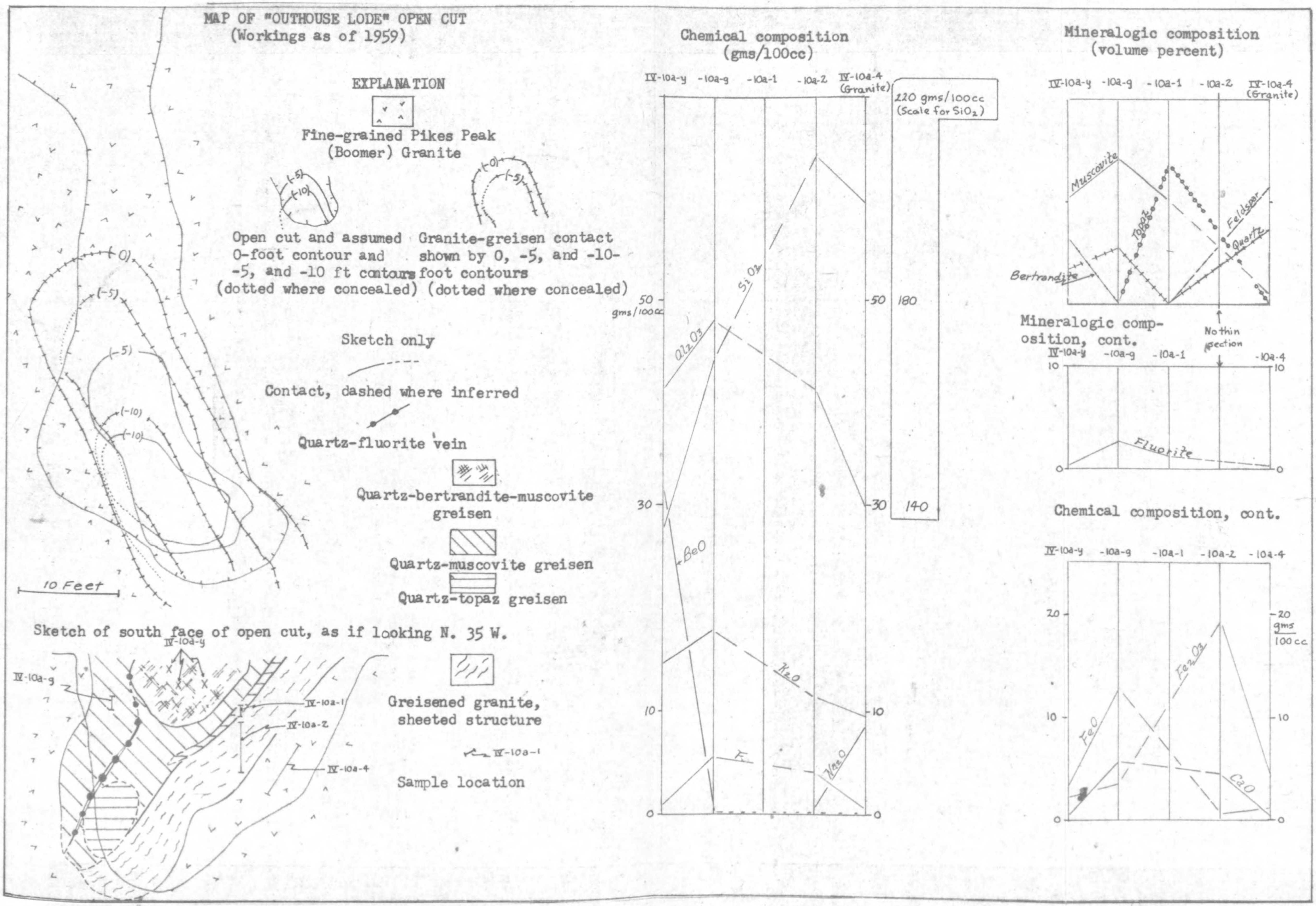


FIGURE 24. VARIATION IN CHEMICAL AND MINERALOGIC COMPOSITION, "OUTHOUSE LODE", BOOMER MINE

greisen. A quartz-fluorite vein locally was exposed in the barren greisen below the ore and also formed the hanging wall contact of the ore greisen.

Chemically analyzed samples show that Al_2O_3 increases, in equivalent volumes of rock, going from granite into the barren greisen, and probably generally increases throughout the barren zone to the edge of the ore-bearing greisen at which point it begins to decrease. Silica is slightly enriched (over the equivalent granite) in footwall greisen, but decreases sharply and apparently consistently through most of the barren greisen into the ore-bearing greisen. In general the ore zone is characterized by an enrichment only of BeO and H_2O, but decreased SiO_2, Al_2O_3, FeO, Fe_2O_3, K_2O, CaO, and F. In terms of mineralogy the ore mineral (bertrandite) appears to increase at the expense of all other minerals.

Certain of the trace elements seem to correlate with rock-forming elements rather than beryllium, and to be more abundant in border or intermediate greisen zones than the beryllium-bearing greisen. Certain trace elements are also more abundant in the adjacent granite than in either the ore greisen or the gray muscovite-rich greisen found next to ore (table 14):

TABLE 14

TRACE ELEMENTS IN GRANITE, BARREN GREISEN, AND BERYLLIUM-BEARING GREISEN, OUTHOUSE LODE, BOOMER MINE

	IV-10a-4 (granite)	IV-10a-2 (barren footwall greisen)	IV-10a-g (barren gray, muscovite greisen)	IV-10a-y (bertrandite-bearing ore greisen)
		(percent)		
Ag	0.0003	0.0015	0.0	0.00015
B	0	.0015	0	.003
Ce	0	.15	0	0
Cu	.007	.07	.0015	.001
Mo	.007	.03	0	0
Pb	.07	1.5	.02	.01
Sn	.0015	.007	.01	.003
Zn	.007	.15	0	0

Tin is slightly higher in the barren, gray, muscovite greisen, than in the equivalent rocks.

Certain aspects of the asymmetric zoning of the Outhouse lode greisen are shared by other greisen bodies of the Boomer mine. The main ore body mined on the 8518-foot level of the mine has a footwall sheeted zone very similar to the footwall zone of the Outhouse body, and greisen mined in the open cut east of the Boomer shaft shows a beryllium-bearing greisen lying above topaz-rich greisen, and, in turn, overlain by quartz-muscovite greisen, or nearly the same relations found in the Outhouse lode body.

At other places in the Boomer mine greisen bodies have central zones consisting of topaz or fluorite-rich greisens. One of the topaz-rich greisens occurs along a steep northeast-striking vein; a calculated analysis (B1-17, table 11) indicates that the greisen is highly aluminous. A central topaz-rich zone which contains beryl is also found in the pipe mined between the 8565-foot level and the surface (section B-B', plate 13).

Summary

The results of the chemical analyses and mineralogic observations seem to indicate conclusively that there is a chemical pattern in the greisening. The main component of greisens, ores, and granites, SiO_2, is enriched relative to granite only generally in peripheral greisens and rarely in thin quartz veins cutting the greisens. Al_2O_3 tends to vary inversely to SiO_2, and in general increases towards a central zone. Where no ore minerals are present in the central part of the greisens, Al_2O_3 may be very abundant, but in the ore zones it tends to decrease as BeO increases. Na_2O is essentially eliminated as a greisen component in the peripheral zone; K_2O parallels Al_2O_3, except where the topaz-rich greisens are formed. Calcium (reported as CaO) and F tend to vary together and are enriched progressively from the edge of the greisen up to the central zone where, as with Al_2O_3, they may be further enriched if there is no central ore-bearing facies. Both Fe_2O_3 and FeO are generally enriched in the barren greisens relative to granite and ore-bearing greisen. It also seems generally true that some of the trace elements such as Sn and possibly Nb are more abundant in the so-called barren greisen than in the beryllium-bearing greisens.

With the exception of the formation of the beryllium-bearing ore greisens, the greisening in the Lake George area is generally compatable with the concepts of greisening held by Lindgren (1901, p. 621-623) and Sainsbury, (1960, p. 1483-1493), namely that SiO_2 is not necessarily enriched in the most intensely greisened rocks, and that Al_2O_3, F, and at least one of the iron oxides is strongly enriched. The behavior of K_2O contrasts to some extent with that found by Sainsbury. Topaz-bearing greisens formed at Lake George show a decrease in K_2O, but since the muscovite-bearing greisens are much more widely developed, K_2O in general tends to increase. Sainsbury found a general depletion of K_2O in the formation of the topaz-rich greisens of the Lost River area.

Paragenetic analysis

The mineralogy and chemical analyses of the beryllium-bearing greisens indicate that they are somewhat simpler chemically than the barren greisens. They do contain much more beryllium, but as the beryllium minerals tend to form at the expense of fluorite, muscovite, and quartz the overall complexity is reduced, and at least some of the beryllium-bearing greisens are essentially composed of only five components, BeO, Al_2O_3, SiO_2, K_2O, and (H_2O, F). The relative simplicity of the system suggests the possibility of phase rule analysis.

In recent years there has been increasing application of Gibb's phase rule to problems of the mineral assemblages found in ore deposits, for example, by Kennedy and McKinstry (1957), Bartholomé (1958), and Markham (1960, especially, p. 1460-1465). Probably the most intensive studies along this line have been made by D. S. Korzhinskii, who has modified and clarified certain aspects of the phase rule, and termed the study of natural mineral assemblages "paragenetic analysis" (1959, p. 5). Among other things Korzhinskii shows:

1. The phase rule applies in most general form to open systems, that is, to systems which can exchange matter as well as energy with their surroundings (p. 7-8, 11-12).
2. The statement of the phase rule can be modified to include internal as well as external degrees of freedom, where, in general, the internal degrees of freedom are concentrations of

inert components, and the external factors are the common intensive thermodynamic variables, T, P, and the chemical potentials of perfectly mobile components $\mu_k \ldots \mu_n$. The inert components are defined as those whose equilibrium factors are extensive properties (masses); the mobile components are those with intensive equilibrium factors (chemical potentials, concentrations, or activities). Korzhinskii's phase rule can be written as:

$$f = f_{inter} + j_{in} = c_i + c_m + 2 - p$$

where f_{inter} = internal degrees of freedom; j_{in} = external factors (intensive variables); c_i = inert components; c_m = mobile components; p = number of phases, and f = the total variance or degrees of freedom. The internal factors can be considered as those relating to the inert components, or " . . . as the number of intensive parameters which could change independently of each other under constant external conditions if the system were not restricted by a definite content of inert components" (p. 62): They can, perhaps, be visualized as the compositional degrees of freedom in a system composed only of inert components. For example, the compositions of three phases coexisting in equilibrium in a three component system are fixed (there are no "compositional degrees of freedom").

3. A system undergoing irreversible, nonstationary changes of state, in which the rate of reaction exceeds the rate of change of states, may sometimes be in "mosaic equilibrium"; that is, even though a large system is not in equilibrium throughout, it can

be considered as divided into sufficiently small units in each of which equilibrium is attained (p. 19).

4. The phase rule can be modified to apply to a system of diffusion metasomatism. Such a system will be characterized by constant volume, and the equilibrium factors will be T, V, the masses of the inert components, and the chemical potentials of the mobile components; in this case the number of external conditions (or intensive variables) reduces to $c_m + 1$ because volume is an extensive property. The phase rule applicable to such a system can be derived from the general rule:

$$f = f_{inter} + j_{in} = c_i + c_m + 2-p$$

$$f_{inter} = c_i + c_m + 2-p-(c_m + 1)$$

$$= c_i + 1-p$$

The system is defined completely by the number of inert components in a given volume of rock under constant external conditions. The maximum number of phases is attained at invariant conditions, and so is

$$P_{max} = c_i + 1$$

The phase due to the (+1) term in the equation can be considered as a "perfectly mobile mineral", whose amount is due only to the volume of the system. For many examples, the perfectly mobile mineral is quartz (p. 18, 63-64).

Since greisening almost certainly involves diffusion metasomatism, this modification of the phase rule appears to offer a method for looking at an ideal system resembling the natural greisens. The assumption of constant volume appears to be met, particularly in the pipe-like greisens of the Lake George area, and it can be postulated that the intensive variables (temperature and chemical potentials of the perfectly mobile components) were constant at least over certain intervals of time. As an approximation it may also be valid to think of each zone of a greisen as in a state of mosaic equilibrium.

The most common assemblages observed in the beryllium ores are quartz-beryl-muscovite, quartz-bertrandite-muscovite, and monomineralic beryl; a less common assemblage noted in a few places at the Boomer mine is quartz-topaz-beryl and possibly muscovite. Beryl and bertrandite are associated with quartz and muscovite in many ores, but in most cases the beryl is obviously unstable with respect to bertrandite and muscovite which psuedomorphically replace beryl. In a few ores bertrandite occurs interstitially with beryl-quartz-muscovite and shows no apparent reaction with beryl; locally, therefore, a valid four phase assemblage may exist.

The quartz-bertrandite-muscovite assemblage in large part forms by a complete destruction of beryl in a primary quartz-beryl-muscovite assemblage. In places in the Boomer mine and in deposits of the Redskin Gulch area, however, very rich bertrandite-quartz-muscovite ores occur with no microscopic remnants of beryl nor the characteristic elongate pattern of bertrandite-muscovite generally indicative of psuedomorphism after beryl. In these ores the assemblage bertrandite-quartz-muscovite is regarded as the primary beryllium-bearing assemblage of the greisen.

Euclase occurs as a late mineral in vugs with crystalline quartz and muscovite, and the assemblage quartz-euclase-muscovite is possibly a late hypogene assemblage.

If we assume that the ores did form by diffusion metasomatism under conditions of constant volume, then the ores can be analyzed by the phase rule suggested by Korzhinskii. Chemical analyses and analyses calculated from modal analyses indicate that the beryllium ores are of relatively simple mineralogic and chemical composition, and to a very good approximation can be represented by the components Al_2O_3, K_2O, BeO, SiO_2, (H_2O, F) which are the components making up ideal beryl, muscovite, bertrandite, topaz, and quartz. The system can be further simplified by neglecting SiO_2 and (H_2O, F); both of these components would generally be considered as perfectly mobile under Korzhinskii's system, and hence can be neglected in the particular model chosen. The omission of SiO_2 can be justified by the ordinary methods of facies analysis where SiO_2 is omitted in quartz-bearing assemblages.

The composition of representative ore-bearing greisens determined from chemical or modal analyses have been plotted as functions of the three other major components of the greisens, namely K_2O, Al_2O_3, and BeO as have the ideal compositions of beryl, bertrandite, muscovite, and topaz (fig. 25). The three-phase regions (four with the addition of the perfectly mobile mineral) are suggested by the assemblages; possible equilibrium minerals found in the ores are shown in parentheses. It is assumed that external conditions, T and chemical potential terms of the mobile components, were constant.

In terms of the ideal minerals used to approximate the natural ore greisens, there are two possible four-phase equilibrium assemblages, quartz-beryl-topaz-muscovite and quartz-beryl-bertrandite-muscovite, and if they are in fact equilibrium assemblages, then it seems very likely that K_2O, Al_2O_3, and BeO acted as inert components. In the three-phase assemblages it can be assumed that either K_2O or Al_2O_3 acted as a mobile component.

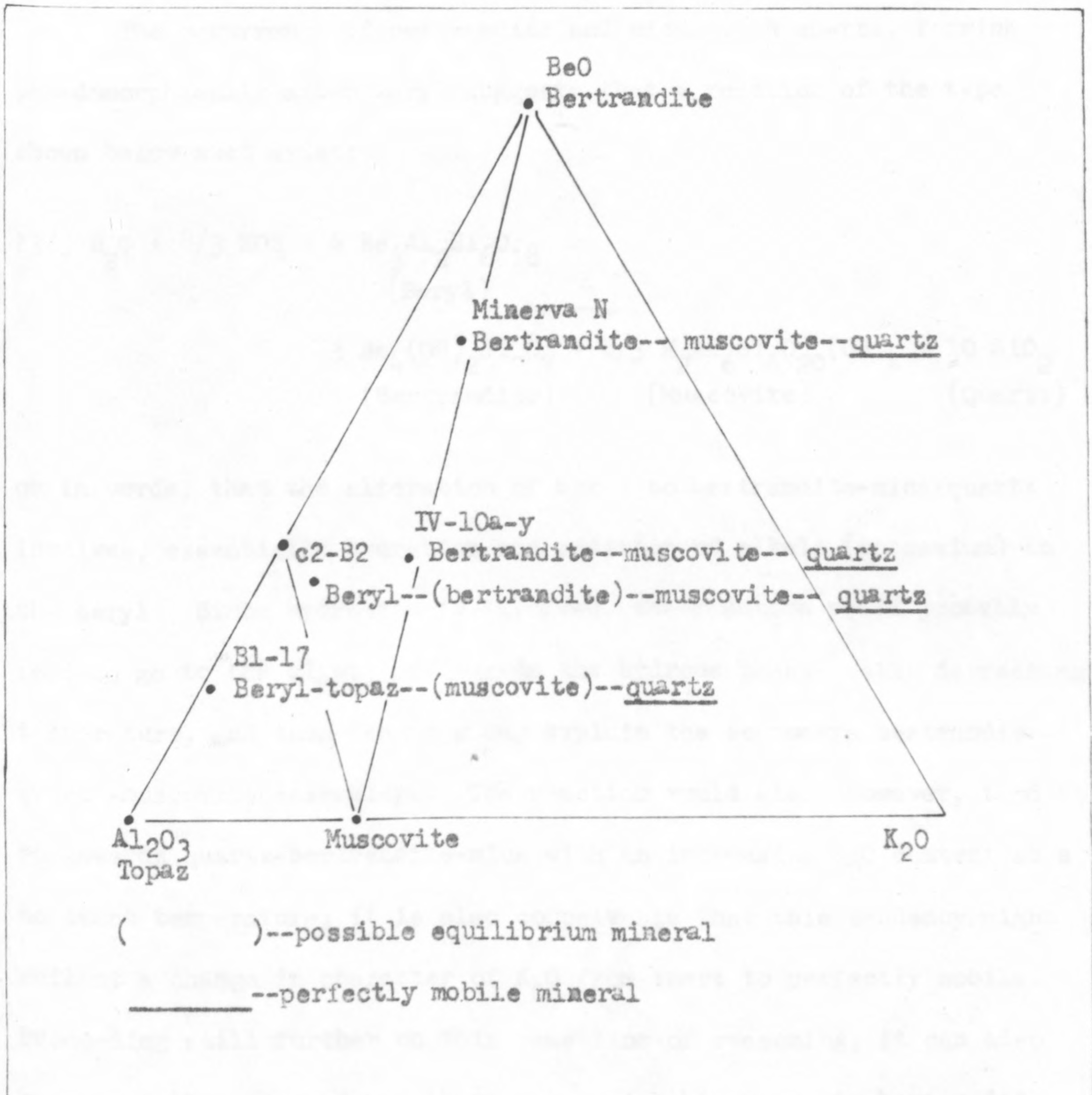


FIGURE 25. CHEMICAL COMPOSITION OF REPRESENTATIVE ORE-BEARING GREISENS IN TERMS OF BeO, K_2O, AND Al_2O_3

The occurrence of bertrandite and mica, with quartz, forming pseudomorphically after beryl suggests that a reaction of the type shown below must exist:

$$13/3\ H_2O + 8/3\ KOH + 4\ \underset{\text{(Beryl)}}{Be_3Al_2Si_6O_{18}} \longleftrightarrow 3\ \underset{\text{(Bertrandite)}}{Be_4(OH)_2Si_2O_7} + 4/3\ \underset{\text{(Muscovite)}}{K_2Al_6Si_6O_{20}(OH)_4} + 10\ \underset{\text{(Quartz)}}{SiO_2}$$

or in words, that the alteration of beryl to bertrandite-mica-quartz involves, essentially, hydration and addition of alkali (potassium) to the beryl. Since hydration is involved, the reaction would probably tend to go to the right, or towards the hydrous phases, with decreasing temperature, and this tendency may explain the secondary bertrandite-quartz-muscovite assemblage. The reaction would also, however, tend to go towards quartz-bertrandite-mica with an increasing K_2O content at a constant temperature; it is also conceivable that this tendency might reflect a change in character of K_2O from inert to perfectly mobile. Proceeding still further on this same line of reasoning, it can also be argued that the primary three phase assemblage quartz-bertrandite-muscovite, as for example found in the Redskin Gulch ores, represents a system with only BeO and Al_2O_3 as inert components.

The barren greisens tend to have a more complex chemical composition than the ore-bearing greisens, and generally contain significant amounts of FeO, Fe_2O_3, and CaF_2 in addition to the K_2O, Al_2O_3, SiO_2, and H_2O which with BeO comprise the bulk of the ore-bearing greisens. The mineralogic composition is, however, nearly as simple as the ore-bearing greisens. Quartz and mica are the main constituents, but locally topaz and fluorite are abundant and can be the predominant constituents of a particular zone. The only somewhat anomalous feature of the chemical and mineralogic composition is that the iron oxides must be tied up largely in the mica. Zoned greisens which show a similar tendency towards lesser chemical complexity in the central zones have been interpreted by Lisitsina and Omel'yanenko (1962, p. 39-41) in terms of a mobility sequence with different elements changing from inert to perfectly mobile at different distances from a central fracture zone. Perhaps this mechanism accounts for certain aspects of the chemical zoning of the Lake George greisens, as for example with components such as K_2O, Na_2O, and Al_2O_3 which are important constituents of the unaltered rocks where they are presumed to be inert components. Other aspects are perhaps due to the change from perfectly mobile to inert status of the components such as FeO, Fe_2O_3, CaO, F, as well as BeO, which were introduced into the greisens.

Quartz locally occurs as essentially the only phase in vuggy greisens within both ore-bearing and barren greisens, and its occurrence in this fashion suggests that all components were perfectly mobile and thus $p_{max} = 1$.

Origin of the beryllium deposits

The beryllium-bearing greisen deposits of the Lake George area seem to be definitely linked to the Pikes Peak Granite by spatial association, chemical composition, and age. The exact manner of relation is, of course, speculative. Hypothetically the deposits are proposed to be directly related to the granites; briefly they are regarded as end members of the crystallization of a volatile-rich acid magma under relatively shallow plutonic conditions. It is also proposed that the deposits were formed from solutions of very local origin. Although it is tempting to call on a fractionating magma at depth for rare metallic components, it is believed that movement from depth of such materials would have left evidence in the form of strong and pervasive alteration of large bodies of granite and in continued mineralization at depth, whereas the alteration is localized in a few areas and the available evidence suggests that mineralization does not extend to appreciable depths.

Age of the deposits. The deposits are of Precambrian age and are probably 1 ± 0.1 b. y. old. A Pikes Peak age suggested by spatial association and chemical composition has been upheld by K^{40}/A^{40} ages from greisen muscovite and lead ages from galena. The precision of the methods does not, however, allow an estimate to be made of the time involved in mineralization. In fact the model age of galena (about 1.05-1.1 b. y.) is older than that of muscovite (1.02 and 1.00 b. y.) even though galena is actually younger than muscovite in the greisens. Isotopically the lead belongs to the ordinary type of Cannon and others (1961, p. 3-9, 17, and A.P. Pierce, oral communication, 1963).

Temperature and pressure conditions. Something of the general pressure-temperature environment of the mineralization can be inferred from the petrography and petrology of the granite associated with the deposits, and from the mineral assemblages of the ore deposits themselves. The local miarolitic nature of the Pikes Peak Granite, its sharp and generally discordant contacts, and lack of granitizing effects indicate that it was emplaced under epizonal (shallow) conditions (Buddington, 1959, p. 677-679). Although epizonal is generally used in a relative sense, it has been suggested that the maximum intensity level of epizonal conditions is equivalent to a depth of about 10 km (Buddington, *ibid*., p. 676).

Somewhat more specific data on temperature-pressure conditions are perhaps suggested by the composition of Pikes Peak Granite and the types of micas present. The oldest widely developed granite facies is the granular facies of the Tarryall lobe. It is essentially a biotite granite which is more potassic and slightly more silicic than most other granite facies of the area. Its normative composition (fig. 14) lies in what can be inferred to be a thermal minimum in a natural granite system at relatively low water-vapor pressures. The normative composition of the younger porphyritic granite is inferred to be the minimum of a natural granite system with intermediate water-vapor pressures. The presence of muscovite as a primary mineral in the porphyritic facies also indicates moderately high water-vapor pressures and furthermore that the water-vapor pressures closely approached load pressures (Yoder and Eugster, 1955). In general, composition of the younger main granites and the presence of muscovite seem to be consistent with pressures of about 1500-2000 kg/cm^2 or, in terms of depth, about 5-6 km.

Experimental work in the artificial granite system of Tuttle and Bowen (1958, fig. 24) at 2000 kg/cm^2 water-vapor pressure suggests that a natural granite at 2000 kg/cm^2 water-vapor pressure with composition near the minimum would be liquid at less than 700° C., and other experimental results (Wyllie and Tuttle, 1962; oral communication, 1962) indicate that natural granite with relatively high F and Li contents would finally freeze at a much lower temperature.

Greisens have generally been regarded as high-temperature ore deposits, in part because of their close association with igneous rocks. Few quantitative or semiquantitative data are, however, available on the temperatures actually involved. Little (1960, p. 490-505) estimated from studies made on fluid inclusions that most tin-bearing greisens formed between 300-500° C. A semiquantitative lower limit on temperature is also provided by the sparcity of early hypogene kaolinite in greisens (Sainsbury, 1960, p. 1483, p. 1499-1503). In an artificial hydrothermal system of ideal muscovite and kaolinite (Hemley, 1959), kaolinite is not stable above about 400°C, hence the inference that sparsity of kaolinite in natural environments indicates that the temperatures were relatively high, i.e., above the stability field for natural kaolinite.

<u>Accumulation and separation of greisen-forming solutions</u>. The Pikes Peak Granite of the area shows either direct or indirect evidence of a relatively high content of volatiles. All contain anomalous amounts of fluorine, and in many cases the fluorine-bearing minerals are interstitial in occurrence suggesting that the fluorine was an indigenous magmatic component. Younger facies are generally more muscovitic and furthermore have unusual textures or compositions which show metasomatic modifications almost certainly due to residual fluids.

Three of the main beryllium areas are associated with satellitic or border granites which belong to the granites characterized by abnormal compositions, with respect to the granite minimum, and textures. Kennedy (1955, p. 489-504) pointed out that volatiles, particularly water, tend to accumulate in the parts of melts at lowest temperatures and pressures. Whether this will actually be the case will depend largely on the rate of cooling of the magma, i.e., time available for volatiles to diffuse through the magma. Geologic factors within the Lake George area were probably ideal for the relatively long persistence of the magma in a liquid state. It seems reasonable to postulate that the geoisotherms were appreciably raised in the area, because the granite facies of the beryllium area were intruded relatively late in the period of emplacement of the great Pikes Peak batholith. Direct evidence that wall rocks of the area were relatively warm prior to emplacement are provided by the long segments of granular granular granite contacts which show no chilled effects. The composition of the granites is also favorable for relatively slow freezing, in as much as the composition is near that of the thermal minimum, and thus the granites would not tend to begin crystallization until relatively low temperatures had been reached.

Under the postulated geologic conditions it seems reasonable to infer that volatiles could locally accumulate in cooler melts lying along borders and in cupolas. The fine-grained granites forming border zones on the Tarryall lobe in the Mary Lee mine area and along the almost flat contact in Section 23 and those on the China Wall pluton, and the fine-grained granite forming the Boomer stock are believed to be, respectively, granites which formed from volatile enriched melts in cooler border zones and in a cupola.

Kennedy (1955, p. 496-498) also points out that metals may tend to coordinate with volatiles and thus be concentrated in the volatile enriched melts. Ringwood (1955, p. 248) has pointed out the possibility that beryllium may be coordinated with fluorine or hydroxyl in a melt. The decreased abundance of F and Be in the youngest granites of the Lake George beryllium area may be evidence that such coordination took place, and that neither Be nor F was as readily available for crystallization in common accessory or rock-forming minerals as in the older, less volatile-rich magmas.

The ore deposits associated with the Boomer stock and with border facies of granite are postulated to have formed from the water- and fluorine-rich solutions left after these volatile melts had largely crystallized. Under this hypothesis the solutions are regarded as of local derivation, although the volatiles and metals accumulated in the melt by diffusion over the long period of time allowed by slow cooling.

This hypothesis possibly applies to other greisen locales where ore deposits are closely associated with certain facies of granites and with definite parts of the granite bodies. Examples which come to mind are greisen pipes of the Australian tin belt which occur in granite within a small distance of the granite contacts (Blanchard, 1947), greisen pipes of the South African area which are associated with certain upper granitic layers of the Bushveld complex (Hall, 1932, p. 488), and deposits of the Soviet Union (Beus and Sitkin, 1958, p. 14-15) and perhaps the Erzgebirge where deposits are confined to the upper parts of cupolas. In all these areas the general distribution of the deposits is consistent with an origin from locally derived fluids.

A variant of the volatile accumulation hypothesis may be used to explain the greisen occurrences in the Redskin Gulch area within the Tarryall lobe. There are long segments of the contact of the Tarryall lobe where no border facies are developed, and where the border zone is formed by normal granular Pikes Peak Granite. These segments of the contact can be regarded as places where a normal, non-volatile enriched magma crystallized. In these locales volatiles would in part be forced to migrate inward into the still liquid melt as proposed by Vance (1961). The main porphyritic and fine-grained granites of the Tarryall lobe are considered to have crystallized from slightly volatile enriched melts, and the greisen pipes characteristic of the main porphyritic granite from residual water-fluorine rich solutions.

The greisens of the area formed after the granite was nearly solid, because they are partly localized by fractures. At least at the Boomer mine and along the main dike of the Boomer area, the deposits formed after the local filling of vein-fissures with thin pegmatite veins composed mainly of quartz and potassic feldspar.

Formation of beryllium-bearing greisens. Substances which were introduced into at least some of the greisens are K_2O, CaO, F, H_2O, iron oxides, SiO_2, Al_2O_3, and BeO and other trace elements. Some of these substances such as SiO_2, Al_2O_3, and possibly K_2O are sufficiently abundant to be derived locally, and although some greisens are enriched in these materials relative to equivalent unaltered rocks, others are relatively deficient suggesting redistribution has in fact taken place. Other substances such as CaO, F, H_2O, iron oxides, and the trace elements are more abundant in almost all greisens than in equivalent unaltered rocks, and are regarded as having been introduced by the solutions that formed the greisens. The dividing line between intrinsic and introduced components is not a hard and fast one; for example Al_2O_3 was locally deposited in vein-fissure fillings as topaz within an envelope of greisened rocks which has nearly the same Al_2O_3 content as the equivalent unaltered rock, and so in this case was introduced.

Megascopic evidence in the pipe-like ore bodies, particularly, seems to suggest that there was only one period of mineral formation involved in greisening, although there were undoubtedly minor interruptions and changes in the character of the mineralization. Ore zones in veins and pipes are more or less centrally located, and in the pipes the ore zones are controlled by small fractures some of which are confined to the pipe and some of which extend beyond the limits of the pipe. Fractures which extend out beyond the contacts of the greisen pipes are not ore-bearing beyond the confines of the pipes, and to me they seem more logically explained as pre-greisen fractures which localized the entire pipe rather than post-barren greisen fractures which localized only a late ore-pulse greisen. Under a single-stage hypothesis the ore-bearing greisens are interpreted as forming centrally at nearly the same time that the barren greisens formed peripherally due to different levels of chemical intensity rather than to differences in solution character with time.

A one-stage mineralization hypothesis is also in keeping with the postulated local source of greisening solutions.

The chemical zoning found in the greisens and the variable mineralogy of the deposits can be at least partly interpreted as due to the relative inertness or mobility of chemical components in different parts of the system. Somewhat similar zoning in vein-like greisens has been ascribed by Lisitsina and Omel'yanenko (1961, p. 39-41) to the varying mobility of components with respect to distance from a central vein-fissure; in the zone nearest the vein-fissure there are no inert components and only the so-called perfectly mobile mineral, quartz, is precipitated. In the beryllium-bearing greisens of the Lake George area, the number of phases found in the ore may be governed by the number of inert components. It is possible that the common occurrence of the three phase assemblage bertrandite-quartz-muscovite, rather than the same assemblage plus beryl is due to the general mobility of K.

Although concepts of mobility and inertness are useful in discussing the greisen system as a thermodynamic model, they are not directly useful in visualizing the processes involved in greisening. Some aspects of the mechanism can, perhaps, be described by the use of a solubility concept related to mobility. Mobile components have been defined in different ways; most generally they are considered as components controlled externally to the system in question, or, in other words, those capable of exchange with the external environment. To a certain degree mobility can be described in terms of solubility, with mobile components relatively soluble and inert components relatively insoluble (Korzhinskii, 1950, p. 68-69). The use of the solubility concept in turn suggests that mobility can be visualized in terms of complexing agents.

The solubilities due to dissociation into simple ions of many ore minerals and silicates are vanishingly small. The actual solubilities, probably due in large part to the formation of complex ions, are appreciable enough for some "relatively insoluble" minerals to have been completely removed in greisening and certain other minerals to have been completely introduced in solution.

Beus (1958) has proposed that beryllium is transported in ore-forming solutions as complex fluoberyllate ion, which seems geologically reasonable in view of the remarkable association of beryllium and fluorine minerals. He has argued that the complex would be pH dependent and would break down with decreasing acidity due to hydrolysis of beryllium. It can also be stated that the complex would be dependent on fluorine concentration, and would tend to become unstable if fluorine is depleted. Fluorine will certainly become depleted during greisening, because of the formation of the fluorine-bearing minerals muscovite, topaz, and fluorite. It can therefore be argued that the abundance of fluorine is the control of mobile (soluble-complexed) or inert (insoluble-noncomplexed) status of beryllium. This view is probably also consistent with the definition of mobility in terms of an external control. Within a given volume of rock which is not reacting with a fluorine-rich berylliferous solution maintained by a large reservoir, as the adjacent portions of a batholith, beryllium would be present as a soluble fluoberyllate complex whose stability is maintained externally by the fluorine content of the reservoir. In the actual case, under this hypothesis, the precipitation of an introduced component, like BeO, is regarded as due to change to inert state due to the inadequacy of the external reservoir to maintain the concentration of the complexing component.

The behaviour of a dominantly intrinsic component such as Al_2O_3 is somewhat different in that Al_2O_3 contained in the host rocks starts as an inert component, then may become mobile with introduction of the greisening solutions. In some ways, however, the chemical behaviour of beryllium and aluminum may be very similar. Both elements behave similarly with regard to hydrolysis (Goldschmidt and Peters, 1932, p. 360-361), and aluminum, like beryllium, also has a strong tendency to complex with fluorine (Kleinberg, Argersinger, and Griswold, 1960, p. 340).

Differences in the behaviour of the two types of components, fundamentally intrinsic like Al, and fundamentally introduced like Be, possibly explains, respectively, part of the zonal pattern found in the barren greisens and the complexity of assemblages found in the ore-bearing greisens. As proposed by Lisitsina and Omel'yanenko (1961) the zoning in the barren wall greisens at least partly reflects the relative distances from the greisen-causing solutions at which certain intrinsic components become mobile. On the other hand the number of and composition of phases present in the central ore-bearing zone reflects the number of components which were initially mobile but become inert. Some of these, like BeO, are fundamentally extrinsic, others like K_2O and Al_2O_3 are fundamentally intrinsic to the greisened rocks. The relative sparcity of some components such as CaO and iron oxides in the ore-bearing greisens and abundance in adjacent barren greisens possibly indicates that these components remained mobile in the central zone, but became inert in the adjacent greisen, farther from the abundant greisening solutions.

In part then it is proposed the origin of the greisens can be visualized in terms of reactions between initially inert components which were intrinsic components of the host rocks, and the initially mobile components contained in the greisening solutions.

PART II

GEOLOGY OF THE PIKES PEAK GRANITE AND ASSOCIATED ORE DEPOSITS, LAKE GEORGE BERYLLIUM AREA, PARK COUNTY, COLORADO

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE PIKES PEAK GRANITE AND ASSOCIATED ORE DEPOSITS, LAKE GEORGE BERYLLIUM AREA, PARK COUNTY, COLORADO

by

Charles C. Hawley

Open-file report

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

CHAPTER VI

DESCRIPTIONS OF SELECTED MINES AND MINE AREAS

Boomer mine area

The Boomer mine area is near the center of Section 21, T. 11 S., R. 72 W., and as mapped comprises an area of about 1/4 square mile (plate 11). Most of the area is underlain by Idaho Springs(?) Formation and a conformable layer of quartz diorite gneiss. Younger gneissoid to massive igneous rocks, namely biotite-muscovite granite, granite pegmatite, and fine-grained Pikes Peak Granite underlie a smaller portion of the area. A welded tuff of Tertiary age covers the Precambrian rocks in a small part of the area north of the Boomer mine.

The Idaho Springs(?) Formation is principally composed of complexly interlayered biotite gneisses and schists, but also contains scattered layers and lenses of amphibolite. Most and perhaps all of the amphibolite bodies are lenticular, but they are conformable and locally serve as marker units. One prominant layer has been traced for about 1000 feet from the northwest side of the Boomer stock; a second layer is exposed in and near the Blue Jay mine. Small bodies of biotite-muscovite granite and granite pegmatite cut the Idaho Springs(?) Formation and the quartz diorite gneiss. One small mass of the granite is exposed as a concordant mass near the Champell mine about at the contact between the Idaho Springs(?) Formation and quartz diorite gneiss; a second body is exposed as a lenticular, discordant unit southwest of the Boomer mine. Light-colored granite pegmatites of homogenous type, which in part are associated with the biotite-muscovite granite, are numerous. One of the pegmatites forms the south contact of the Boomer stock; another body, sharply discordant to the metamorphic foliation, forms part of the west boundary of the stock. Locally the pegmatite and biotite-muscovite granite are altered and mineralized, especially near their contacts with the fine-grained Pikes Peak Granite.

Fine-grained Pikes Peak Granite forms (1) the Boomer stock, (2) a large dike which trends northwest from a point near the northwest edge of the stock, and (3) numerous small dikes. The stock is a roughly circular mass about 500 feet across. Exposures in the Boomer and in the J & S No. 3 mine show that the granite contacts dip outward on at least its south and west sides, and the stock is about 700 feet across measured in the northeasterly direction at a depth of about 100 feet. The abrupt flattening of the south contact of the stock at a depth of about 50 feet (plate 11, section A-A') suggests that the stock may be appreciably larger than this at a depth of a few hundred feet.

The main dike of the Boomer area can be followed as a single dike for about 750 feet from a point near the contact of the Boomer stock where it appears to split into two dikes. The branch which appears to be the extension of the main dike can be followed for about 400 more feet on a north-northwesterly trend. Locally the dike is approximately concordant to the strike of the intruded strata, but it generally dips at a lower angle than the gneissic layers.

Small dikes most of which fill fractures belonging to sets striking NW, NNW, and NE are exposed in other parts of the Boomer area. No dikes have thus far been found in the part of the area west of the Badger Flats fault. Dikes appear to be relatively abundant in a small area south of the Blue Jay mine.

Fine-grained granite dikes are locally greisened and beryllium-bearing. Beryllium-bearing dikes are locally exposed in the Boomer mine, J & S Nos. 1 and 2 mines, the Blue Jay mine, and in the long trench about half-way between the Blue Jay and Boomer mines.

The schists and gneisses of the Idaho Springs(?) Formation and the quartz diorite gneiss strike northwesterly and dip steeply to the northeast except where modified by small scale fold structures. They are cut by the Badger Flats fault and by smaller scale faults, some of which are filled with granite or with vein materials. The Badger Flats fault crosses the western part of the Boomer mine area a few hundred feet west of the J & S No. 1 mine; it is probably exposed in a trench south-southwest of the mine, but in general its position has been inferred from slight topographic depression, sparcity of outcrop, and the offset of rock units. The fault has an apparent left lateral movement of about 200 feet shown by the displacement of the contact between the Idaho Springs(?) Formation and the quartz diorite gneiss.

Greisens, some of which are beryllium-bearing, are found mostly in the fine-grained Pikes Peak Granite or in biotite-muscovite granite or pegmatite near the fine-grained granite. Rarely granite pegmatites and biotite-muscovite granite are greisened at some distance from any known body of granite. The most extensive greisened zones of the area are in the southern part of the Boomer stock.

All the beryllium deposits are closely associated with the fine-grained Pikes Peak Granite, either in the Boomer stock or in the dike rocks; all deposits except those in the quartz-albite-muscovite granite found locally in the main dike also have greisened walls. Small occurrences of beryllium minerals or chemically anomalous amounts of beryllium have been found away from known granite near the Champell mine, and also in the area southeast of the Blue Jay mine.

Boomer mine

The Boomer mine is near the center of Section 21, T. 11 S., R. 72 W. in the southwest part of the Lake George beryllium area (plates 1 and 7). The mine was originally located, probably before 1895, as a silver prospect, and some silver-lead ore was shipped. About 1917 the mine was known as a molybdenum prospect (Worcester, 1919, p. 73), but as far as is known no molybdenum ores were produced. After these early mining and prospecting ventures the mine was abandoned and apparently lay idle until the uranium boom after World War II. In the early 1950's anomalous radioactivity was noted on the mine dump, and in 1955 the mine was partly rehabilitated as a uranium prospect. Only small amounts of uranium were found, but beryl was observed by John Sager, A. G. Bird and probably others. The mine has been in almost continuous operation as a beryllium producer since October, 1956.

The first beryllium ores produced came from well-crystallized beryl aggregates cobbed from the dump and mined underground; these ores are locally termed "crystal beryl". In 1958 so-called "massive ores" were recognized; these ores were first noted in the Boomer vein on the 8533-foot level of the mine, and consist predominantly of almost white, poorly-crystalline beryl with scattered quartz and mica giving the ore a granitic aspect. These ores also contained some bertrandite. In 1959 ores consisting essentially of bertrandite, quartz, and muscovite were found by L. G. Moyd with a beryllium detector. At that time Dr. Moyd was affiliated with Minerva Oil Company.

Mine workings consist of two shafts with a total of seven levels, and numerous open cuts or shallow prospect shafts. The northernmost of the two main shafts (plate 12), called the Boomer shaft, is a steeply inclined shaft about 102 feet deep. The southern shaft, called the Florman, is a vertical shaft about 185 feet deep. The levels are at altitudes of about 8565, 8533, 8518, 8494, 8486, 8440, and 8398 feet, and since the levels are in part interconnecting and are unnamed they are referred to in the text by altitude rather than vertical distance from shaft collar. The 8518-foot level connects both shafts. The upper levels are more important to the geology than the lower levels, and only the upper four levels are shown on the composite plan (plate 12). Geologic maps of all levels are shown on plate 13, and their location relative to the composite view can be inferred from the cross-section lines.

The mine is near the south contact of the Boomer stock. Open cuts at the surface are entirely in the granite of the stock, but the underground workings are partly in granite and partly in granite pegmatite and in gneisses belonging to the Idaho Springs(?) Formation. The 8486-, 8440-, and 8398-foot levels are entirely in granite. The large pegmatite mass exposed on the uppermost three levels of the mine is the continuation of the pegmatite body exposed south of the Boomer stock (plate 11). Near the main shafts the pegmatite bottoms against fine-grained granite at about 70-feet below the surface. The granite-granite pegmatite contact, which is an important ore control, is steep at the surface and in the 8565-foot level, but flattens abruptly about at the 8533-foot level.

Fracture sets which strike northeast or north-northwest contain beryllium veins and granite dikes. The northeasterly set is steeply dipping, and most of the veins are small. The main mineralized fissure, the Boomer vein, belongs to the north-northwest set. In most places the vein is localized by a single fissure dipping on an average 40° NE; locally the vein-fissure splits into two main fractures. A third set of fractures which strikes north-northwest and dips at low-angles to the southwest is locally mineralized in a very wide and complex greisen zone on the 8533-foot level of the mine.

Unmineralized shear zones which belong to an almost flat fracture set are exposed at several places. One such shear zone, partly inferred, is evident on the cross-sections (plate 13); as drawn the zone is post-Pikes Peak Granite, but it is possible that part of the displacement on the zone is pre-Pikes Peak in age.

Bodies of greisened rock are exposed on all except the deepest (8398-foot) level of the mine. Most are dominantly composed of barren quartz-muscovite greisen, and all greisens exposed on the deeper levels (8494-, 8486-, and 8440-foot) contain only trace amounts of beryllium. Topaz-or fluorite-rich greisens and ore-bearing greisens, both distinguished on the map by patterns, are locally distributed within quartz-muscovite greisen zones on the surface and in the 8565-, 8533-, and 8518-foot levels.

Beryl is dominant in all ore bodies except the so-called Outhouse lode body mined on the surface; bertrandite is the major ore mineral in the Outhouse lode, and occurs in considerable abundance in the northern part of the ore body mined from the Boomer vein, particularly in the northern part of the 8533-foot level, and as locally abundant psuedomorphs after beryl in the main body mined on the 8518-foot level. Small amounts of euclase occur in the ore mined from the Boomer vein.

The beryllium-bearing ores locally contain sulfides and other metallic minerals. Small amounts of galena and sphalerite occur in beryllium ore on the footwall of the Boomer vein near sample location B1-13 (8533-foot level), and arsenopyrite is found in the ore about 50 feet to the north along the vein, and also in a footwall mass (fig. 17) in contact with ore in a pipe-like extension of the Boomer vein ore body. Disseminated galena and sphalerite are found in the same pipe near the surface. Beryl is found with wolframite in a quartz-topaz greisen on the 8565-foot level.

Larger concentrations of metallic minerals are scattered through the greisens away from the beryllium ores. Pods of argentiferous galena as much as 6-inches across are found in the greisen body lying between the Boomer vein and the Boomer shaft on the 8533-foot level, and galena and sphalerite were found in a low-beryllium portion of the Boomer vein exposed in a shallow winze just south of the shaft. Sulfides are also found in a partly mined greisen body exposed (not mapped) just above the 8486-foot level near the bottom of the Boomer shaft.

Beryllium ore bodies have been mined from surface workings and from the 8565-, 8533-, and 8518-foot levels. It seems certain that most of the apparently separate ore bodies are actually interconnected and form one large complex body localized by the combined influence of the Boomer vein, fractures of the steep NE set, and the southern contact of the Boomer stock. The ore bodies mined at different places in the mine are discussed separately, but relations indicating possible or probable connections are pointed out.

The two most productive ore bodies have been mined from the 8533-and 8518-foot levels of the mine. One ore body is largely controlled by the Boomer vein-fissure; the second ore body is partly controlled by the contact of the Boomer stock with a granite pegmatite body. The Boomer vein is exposed on the 8533-, 8518-, and 8486-foot levels, but is only strongly mineralized on the 8533-foot level where it has been followed for about 200 feet and where it contains beryllium ore for about 100 feet. The vein has been overhand stoped in one place to within a few feet of the surface and also mined in shallow underhand stopes; it ranges from less than a foot to more than 8 feet wide. The vein is appreciably narrower and less well mineralized on the 8518-foot level; it has been stoped at one place between the 8518- and 8533-foot levels, but the ore zone was much thinner than that found along the upper level. In general the relations suggest that the ore body was a nearly horizontal flattened pipe lying along the vein-fissure. As exposed on the 8486-foot level, the vein consists of a few inches of unaltered pegmatite; it is, however, greisened in a raise driven from near the north end of the level (section C-C', plate 13).

In the widest and most productive part of the ore shoot the vein has two main splits; beryllium minerals fill both splits and replace greisen between them, and, locally, the wall greisen. Near the south end of the ore shoot the most abundant component of the vein is well-crystallized beryl; going northward the beryl becomes anhedral, and bertrandite becomes important, although less abundant than beryl. At the sampled locality shown in figure 22, the footwall split is dominantly bertrandite, and the thicker hanging wall split and replacement ore mostly beryl. Euclase forms small crystals in vuggy zones on the hanging wall of the vein.

The widest mineralized zone in the drift along the Boomer vein on the 8533-foot level is at section C-C' (plate 13). At this point two other structures contribute to the mineralized zone. One of these is the southern contact of the Boomer stock; the second is a low-angle fracture set which parallels the strike of the Boomer vein, but dips to the SW. The relations of the three structures and the ore are best visualized in cross section (C-C'). Another strongly mineralized zone is about at section E-E'. Here a pipe-like ore body junctions with the hanging wall of the Boomer vein. Exposures in the raise driven along the pipe show that the bearing of the pipe locally follows steeply dipping fractures which strike about N. 70° E.

The second main ore body was mined between the 8518-foot and 8533-foot levels. As exposed on the lower level it is a pod-like body about 35 feet long and 10 feet wide elongated along the contact of the Boomer stock and granite pegmatite. The footwall of the zone is formed by a greisened granite with a marked sheeted structure lying parallel with the base of the ore. The hanging wall is greisened pegmatite. Between the two levels, the ore body enlarged into an irregular body mined from a bench level (outline partly shown on 8518-foot map). The ore was largely composed of massive quartz and beryl which was locally psuedomorphically replaced by bertrandite. Some gem aquamarine was found in vugs in the greisen. A small amount of beryllium ore has been left on the floor of the 8518-foot level, but thinning of the ore zone, and thickening of basal sheeted zone is believed to essentially mark the limit of the ore body to the east. A small pod-like extension of the ore zone in the floor was formed at the junction of the granite-pegmatite contact with a steep northeast vein-fissure, and some ore was mined from this minor pod in the winze sunk about 35 feet northeast of the Florman shaft on the 8518-foot level.

The contact between pegmatite and the fine-grained granite at the south edge of the stock is also an important control of ore on the surface and on the 8565-foot level. The collar of the Boomer shaft was apparently sunk in high-grade beryllium ore, which, however, was discarded at that time as waste. Aggregates of crystalline beryl as much as 3-feet across and weighing several hundred pounds have been recovered from the dump rock within a few feet of the shaft and resemble beryl ore left in place in the shaft. On the 8565-foot level the contact is nearly barren on the east side of the shaft, but west of a mineralized vein belonging to the steep northeast set the contact contained beryl-bearing veins and the pegmatite contained disseminated beryl crystals and was extensively greisened. Greisen associated with mineralized northeast trending fractures exposed on the same level apparently led into a pipe-like ore body that was mined from the 8565-foot level to the surface in a raise driven from the north end of the level (partly shown at the east end of Section B-B', plate 13). Small pods of quartz-topaz-wolframite-beryl greisen were found near the end of the pipe on the 8565-foot level; at its eastern end, the ore consisted of a vein-like mass of white to pale green beryl associated with fluorite (on the footwall) and with quartz and topaz.

Beryl veins localized by steep northeast fissures are exposed on the upper three levels of the mine, and have been mined near intersections with the Boomer vein or with the granite-pegmatite contact on the south edge of the Boomer stock.

Two ore-bodies, the so-called "Mammoth" and "Outhouse lodes", have been chiefly mined from the surface. The Outhouse lode consisted of a greisen pipe containing a central beryllium-rich zone which plunged a few degrees to the southeast. The pipe is somewhat asymmetric in cross-section consisting of a sheeted micaceous greisened granite on the footwall, quartz-topaz greisens mostly on the footwall and quartz-muscovite-fluorite greisens on the hanging wall and surrounding a central quartz-bertrandite-yellow mica greisen. The sheeted zone on the footwall of the pipe is very similar to footwall granite observed underground on the 8518-foot level. A quartz-fluorite vein which is exposed below and on the hanging wall side of the ore body is, perhaps, an indirect evidence for a north-northwest fracture zone which acted as one control of the mineralization, but has been largely obliterated in the greisen.

The Outhouse lode was mined over a distance of about 40 feet, and although the ore-bearing greisen nearly pinched out going southward, barren greisen continued farther southeast. About 20 feet south of the edge of the Outhouse ore body, another pipe was intersected on the west side of the same greisened zone. This pipe plunged S. 80° E. at about 40° and was mined between the 8533-foot level and the surface cut. The character of the ore was much different from that of the Outhouse lode. Most of the ore consisted of massive poikilitic beryl crystals in the quartz-rich greisen gangue. The ore was also somewhat unusual in containing appreciable amounts of galena near the surface, and forming on the hanging wall of an arsenopyrite zone in the lower part of the pipe. The pipe appears to connect the hanging wall of the Boomer vein with the greisen pipe of the Outhouse lode.

The Mammoth lode also contained quartz-beryl ore; it appears to be roughly pipe-like ore body elongated along a fissure which strikes NNE and dips 40^{o} SE; the pipe appears to plunge towards the Boomer vein at the far north end of the 8533-foot level.

J & S group

The J & S group consists of three mines opened by shafts, with a total of about 700 feet of drifts or crosscuts. Shafts have been numbered for purposes of discussion from west to east (plate 14). The Nos. 1 and 2 shafts explore greisens associated with the major fine-grained granite dike of the Boomer area. The No. 3 shaft is collared in Idaho Springs(?) Formation just west of the Boomer stock and intersects the stock contact underground. A few tons of beryllium ore have been produced from the J & S No. 1 mine.

The No. 1 shaft has four levels, two very short levels at about 22 and 38 feet, and longer levels at 50 and 66 feet vertically below the collar of the steeply inclined shaft (plate 14). The No. 2 shaft is essentially vertical; it has short levels at 39 and 60 feet below the collar. The No. 3 mine has an 80-foot long drift driven west-southwest from the bottom of a 60-foot vertical shaft.

Workings of the Nos. 1 and 2 shafts are driven in biotite gneiss, amphibolite, and quartz gneiss of the Idaho Springs(?) Formation, granite pegmatite, biotite-muscovite granite, and in dikes of fine-grained Pikes Peak Granite. The Idaho Springs(?) Formation has been intruded by almost concordant to sharply discordant masses of pegmatite and biotite-muscovite granite, and these rocks, in turn, are cut by the fine-grained granite dikes.

The main dike of the Boomer area is exposed on both levels of the J & S No. 2 mine, and also near the east end of the 66-foot level of the No. 1 shaft. Two other dikes are exposed in the No. 1 mine workings; one near the east face of the 66-foot level, and a second, larger dike near the shaft on the 50- and 66-foot levels.

Beryllium-bearing greisens occur in the Nos. 1 and 2 mines as replacement bodies in granite pegmatite or biotite-muscovite granite, or in thin veins and pods in the fine-grained Pikes Peak Granite. The workings of the No. 2 shaft were driven specifically to explore the granite dike since it contained thin beryl veins on the surface. The largest concentration of beryllium-bearing minerals, now largely mined, is in the No. 1 shaft. The beryllium ore was mined from a vein-like greisen followed down from the collar of the shaft to the 50-foot level. Near the collar it can be seen that the greisen replaces a thin pegmatite dike, and it is inferred that the greisen body formed mainly by replacement of pegmatite, although in the deeper workings nothing of the original character of the greisened rock can be determined. The greisen is approximately concordant to the foliation of the gneissic wall rocks, and dips 60-70° NE.; the main body of beryllium-bearing greisen occurred just above the junction of the greisen and fine-grained Pikes Peak Granite (section A-A', plate 14). The strike of the dike is nearly parallel to that of the greisen, but its dip is much flatter. A fault is found along the footwall side of the greisen, and it has been considered to be the ore control. It is not mineralized, however, and it is more likely a post-mineral fault. The fault diverges from greisen below the 50-foot level.

Other beryllium occurrences in the Nos. 1 and 2 shafts are also in or adjacent to Pikes Peak Granite dikes. Beryllium minerals are found in two zones on the 39-foot level of the No. 2 shaft; beryl is present in thin veins on the hanging wall of the dike, and a berylliferous greisen, as much as 1½ feet thick, occurs along the footwall of the dike.

The No. 3 shaft explores an apparently nearly barren portion of the Boomer stock. An irregular greisen body with only trace amounts of beryllium was intersected in the drift about 25 feet from the shaft.

Other prospects

Other prospects in the Boomer mine area include surface trenches north of the J & S Nos. 1 and 2 shafts, likewise partly on fine-grained Pikes Peak dikes, and the Blue Jay and Champell properties. Workings in the Blue Jay mine consist of a shaft about 100-feet deep, and one level with about 400-feet of workings at a depth of about 70 feet. In part the level is a drift along a fine-grained Pikes Peak Granite dike and an associated beryl-bearing vein. The vein where exposed near the shaft strikes about due N. and dips E. at about 25°.

The Champell is a vertical shaft about 100-feet deep sunk to explore small veins and greisens, some of which contain beryllium, which crop out north of the shaft. The shaft was inaccessable when the Boomer area was mapped.

Beryl veins are also exposed in the Boomer area in the long trench about half way between the Boomer and Blue Jay mines, and in a shaft south of the Blue Jay.

Suggestions for prospecting

The beryllium ores of the Boomer mine area are closely associated with greisens and with the fine-grained Pikes Peak Granite; most of the ore occurs either in the granite or in granite pegmatite or biotite-muscovite granite near Pikes Peak Granite contacts. Almost all the ore has come from the Boomer mine near the south edge of the Boomer stock, although small shoots of ore have been found and partly mined in the J & S No. 1 and Blue Jay mines apparently in association with granite dikes. At the Boomer mine, all the beryllium ore has come from the upper three mine levels or from open cuts on the surface.

Possibly favorable combinations of lithology and structure are found on the southwest and northwest sides of the Boomer stock. On the southwest side discordant masses of granitic rock (biotite-muscovite granite and granite pegmatite) are found a few feet west of the granite contact and will almost certainly be intersected at shallow depth by the stock contact. The biotite-muscovite granite and granite pegmatite bodies were emplaced along NE-striking fractures, and the combination of granite contact, older granitic rocks, and local fractures offers a possible locale for ore deposition.

Somewhat similar structural and lithologic conditions are found at the northwest edge of the stock where the main fine-grained granite dike of the Boomer area is separated from the stock by a thin, older, discordant pegmatite; it seems possible that the dike and stock will join at shallow depth, with the pegmatite truncated at the point of junction.

The shallow dip of the south contact of the Boomer stock may be a favorable feature, and it is possible that minor cupolas will be found on the southern extension of the stock. Because of the apparent coincidence of ore with the upper part of the Boomer stock such speculative possibilities are considered more likely to produce new ore bodies than is the deep exploration of the known portion of the stock.

Relatively favorable areas for subsurface prospecting in the area south of the stock are conceivably marked on the surface by concentrations of veins and dike rocks such as are found in the long trench between the Boomer and Blue Jay mines and in a marked concentration several hundred feet south of the Blue Jay mine.

Mary Lee mine area

The Mary Lee mine area is in the southern part of Section 22 about one mile east-southeast of the Boomer mine. The area is underlain by northeast trending, conformable masses of Idaho Springs(?) Formation, granitic gneiss, and quartz diorite gneiss, and a sharply discordant mass of Pikes Peak Granite. The granite extends southeasterly for about 3000 feet as a small lobe on the southwest flank of the Tarryall lobe (plates 1 and 7), and exposures in the Mary Lee mine show that it extends southeasterly for at least a short distance further in the subsurface. The granite also forms sparse, thin dikes in the older rocks.

Two facies of the Pikes Peak Granite are recognized in the area. Most of the granite in the northern part of the area belongs to the main granular facies of the Tarryall lobe. The granite in the south part of the area belongs to the fine-grained facies and is similar petrographically to the Boomer granite.

Most of the mineral deposits of the area are fissure-veins formed in high-angle fractures which strike NE. Representatives of these deposits are the Mary Lee vein and the Little John group of veins. A greisen pipe is exposed at the Happy Thought mine. With the exception of a few small veins, as those exposed in the Tennessee mine, the vein deposits lie southeast of the Pikes Peak body and trend at about right angles to the trend of the granite, or about parallel to the gneissic layering of the older rocks. The veins consist mainly of quartz in fissure-fillings in greisened rocks. Topaz, beryl, and wolframite are locally abundant and cassiterite is present in at least one of the veins. Apatite was noted in the greisen at the Little John No. 2 vein and in a greisen about 1000 feet southwest of the Little John shaft.

Mary Lee mine

The Mary Lee mine develops a fissure-vein deposit which is representative of most vein deposits of the area. The vein, which is most likely a lode zone of closely spaced fissures, can be traced with reasonable certainty for about 1400 feet. The main workings are on the eastern part of the vein and comprise two adits and an incline (plate 15); a shallow shaft, now inaccessable, was sunk near the western end of the vein (plate 7). Claims covering most of the vein were located by Bob Beal and Roy Monett in 1957; the property was sold to the Mary Lee Mining Co. in 1958.

The Mary Lee incline (plate 15) is about 140 feet long; it was driven about S. 50° W. for 120 feet thence about due south for 20 feet. Deep water prevented detailed examination of the workings beyond about 80 feet from the portal. The first 60 feet of the workings are in granitic gneiss; at 60 feet the gneiss is in faulted contact with the fine-grained Pikes Peak Granite, and the rest of the incline is in granite. The granite body apparently represents the southeasterly plunging subsurface continuation of the main Pikes Peak Granite body of the Mary Lee mine area.

The incline follows a thin quartz-beryl vein from the portal to the faulted granite contact, where the vein is cut off. Apparently the vein was not found on the footwall of the fault, although a thin quartz-feldspar vein encountered in granite at about 100 feet from the portal could be the same vein.

The lower Mary Lee adit, about 120 feet southwest of the incline, follows a complex fracture zone in granite gneiss walls. The major vein-fissure in the zone contains as much as 8 inches of crystalline beryl, now largely mined. Other subparallel fractures are marked mainly by slight reddening and greisening of the gneissic walls.

The vein zone is cut off near the portal of the adit by a fault which is almost certainly the same fault exposed along the granite contact in the incline (section A-A', plate 15). The vein of the lower adit is on the footwall of the fault and thus possibly is the faulted continuation of the quartz-beryl vein cut off in the incline. It is, however, much stronger. Furthermore, although the dip of the adit vein indicates that it should also be exposed in the incline, the granite in the incline at its projected position is not altered or broken.

Westward from the fault in the lower adit, the vein can be followed with certainty for 30 feet, and probably for at least 20 feet more, although the main vein in this latter portion may be in the south rib as shown by the queried vein (plate 15). Where well exposed the vein strikes about N. 41° E., dips about 70° NW., and contains crystalline beryl. About 30 feet west of the fault the vein-fissure has gradational contacts grading outward into hematitic greisened gneiss containing small beryl crystals. The difficulty involved in following the vein in both the incline and in the lower adit suggests that it is not actually continuous, but instead is composed of <u>en echelon</u> elements.

The upper Mary Lee adit is about 400 feet southwest of the portal of the lower adit, and the vein is exposed at several places between the adits in small prospects. The upper adit is mainly in granitic gneiss walls; it generally follows the vein, but in part the vein is probably in the southeast rib. In most places the vein is composed of quartz and topaz; locally it contains beryl and wolframite crystals as much as 2 inches across. Samples of vein filling, greisen, and equivalent unaltered rock were collected from the face of the upper adit as representative of one type of alteration suite about a nearly barren vein (fig. 21).

Happy Thought mine

The Happy Thought mine is about 2000 feet northwest of the Mary Lee mine, and apparently lies near the northern boundary of the Mary Lee mineralized area. Workings consist of a vertical shaft with one level, and an inclined shaft which connects with the vertical shaft. The vertical shaft was sunk in 1956 and 1957; the incline is much older; only the incline (fig. 26) was accessible when the property was examined.

The workings are partly in the granular facies of the Pikes Peak Granite and partly in Idaho Springs(?) Formation and granite pegmatite. A knife-edge granite contact is exposed at the collar of the incline. The contact dips westward at 40-50° and is intersected in the vertical shaft above its connection with the incline.

The incline is irregular in shape, and was driven to follow a greisen pipe. At most places the pipe is in the Pikes Peak Granite, but it locally coincides with the granite contact, and at one place is in gneiss adjacent to the contact. The pipe plunges southwesterly for about 50 feet at an average dip of about 40°, thence swings to about S. 20° E. at 35° for about 40 feet where it swings abruptly to N. 55° E., plunging at a high angle. The first

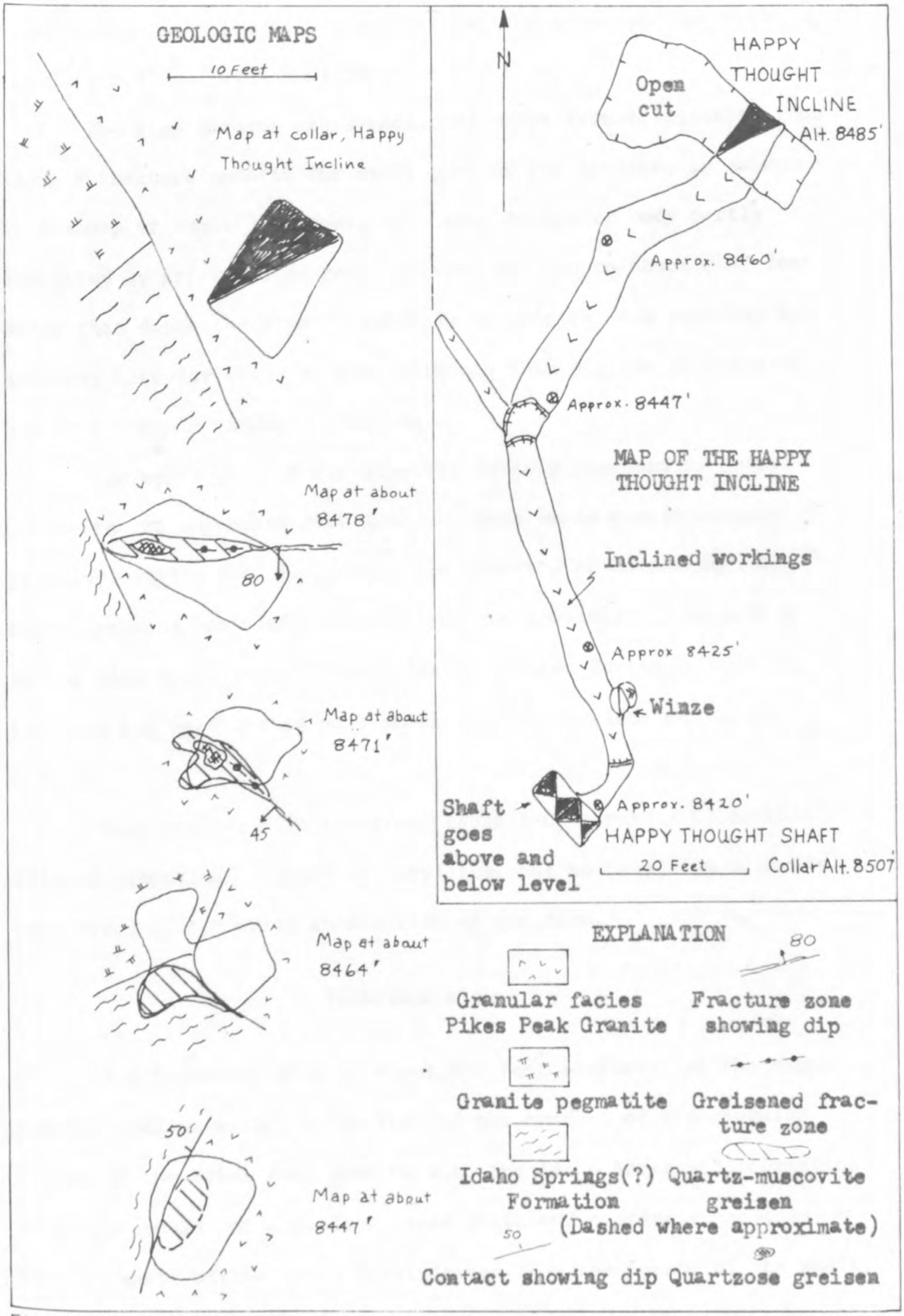


FIGURE 26. MAP OF THE HAPPY THOUGHT INCLINE AND GEOLOGIC MAPS OF GREISEN PIPE

two courses are followed by the incline; the steep northeasterly trend is followed by a shallow winze.

The pipe changes cross-sectional shape from a flattened lens along a fracture zone in the upper part of the incline, as shown by the map at about 8475 feet, to a very irregular body partly localized by fractures or rock contacts on down to about 8447 feet. Below that depth the pipe is entirely in granite, and probably had a nearly circular cross section although this portion of the pipe has been largely removed in mining.

The upper part of the pipe was largely composed of quartz-muscovite and muscovite-rich greisens with small quartzose core greisens. Below 8447 feet there are remnants of copper-stained topaz greisens containing some galena and sphalerite. According to the mine owner, Mr. Harold Moses of Manitou Springs, Colorado, the pipe has been worked on a small scale for galena and other sulfides.

Dump samples from the mine (table 1-C; Appendix C) contain slightly anomalous amounts of beryllium, but no beryllium minerals were noted in the brief examination of the mine.

Tennessee mine

The Tennessee mine is about 350 feet southeast of the Happy Thought incline within a few feet of the contact of the granular facies of the Pikes Peak Granite with the Idaho Springs(?) Formation. Workings consist of a shallow caved shaft and a steeply inclined 65-foot shaft with a short level driven from the bottom of the shaft.

Several thin quartz-beryl veins are exposed in the shaft, on the surface, and on the level at the bottom of the shaft (fig. 27); an overhand stope has been raised on a zone lying between one of the veins and the granite contact, reportedly with the recovery of some aquamarine.

Suggestions for prospecting

The occurrence of a small body of beryllium ore at the Mary Lee lower adit, scattered pods of ore at the Tennessee and little John claims, the length of some of the vein-fissures, and the geologic relations of the Pikes Peak Granite indicate that the area has some potential as a beryllium area.

The fine-grained Pikes Peak Granite which forms the southern part of the Pikes Peak body exposed in the area is similar petrographically to fine-grained granite which forms the Boomer stock and the outer zone of the China Wall pluton, both of which have associated beryllium deposits, and so it is considered favorable for prospecting. Exposure of the granite body in the Mary Lee incline suggests that the front of the lobe-like body of granite plunges southeasterly at a low-angle, and, possibly, that it underlies much of the vein area southeast of the lobe at a shallow depth. Since all known beryllium ore bodies of the Lake George area are found in or very near favorable facies of the Pikes Peak Granite, the vein-fissures along the postulated projection of the lobe appear favorable for prospecting at depth.

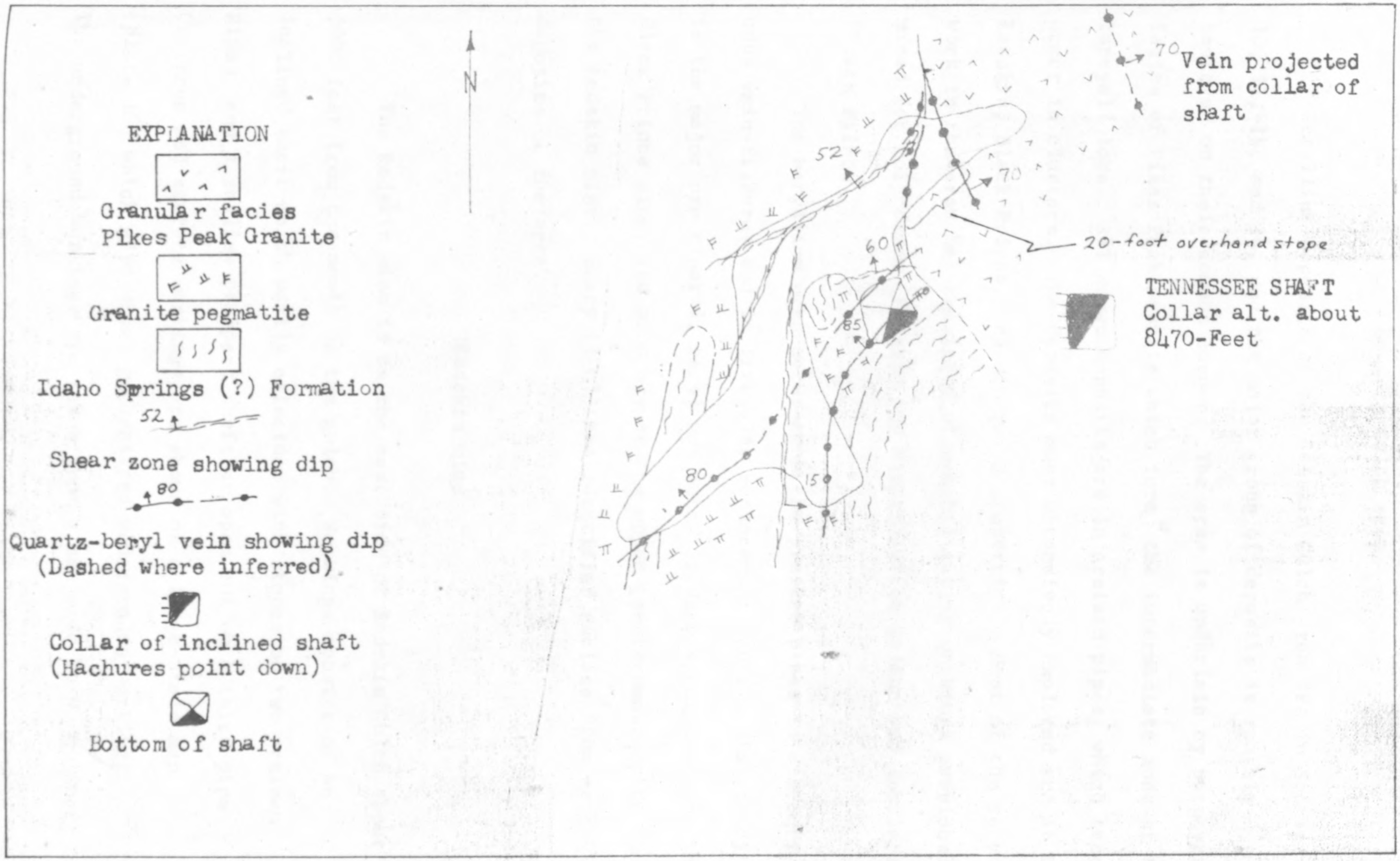


FIGURE 27.--MAP OF THE TENNESSEE MINE 20 0 20 Feet

Redskin Gulch area

Beryllium deposits of the Redskin Gulch area are in Sections 10, 11, 14, and 15, and the major group of deposits is roughly centered on their common corner. The area is underlain by porphyritic facies of Pikes Peak Granite which forms the intermediate zone of the Tarryall lobe. All known deposits are in greisen pipes, which tend to occur in clusters. The deposits most extensively explored are at the Redskin, Black Prince, and Minerva J properties. Most of the recent work in the area has consisted of rehabilitating workings previously mined for molybdenum (Redskin and Minerva J) or galena and sphalerite (Black Prince).

The beryllium ores occur within the greisen pipes in discontinuous vein-fissures and in irregular replacement bodies. Bertrandite is the major ore mineral; beryl was noted in dump specimens from the Black Prince mine, and probably at the upper (easternmost) pipe at the Redskin mine. Sharp (1961) has identified euclase from several deposits of the area.

Redskin mine

The Redskin mine is on the east side of Redskin Gulch about 3000 feet from the mouth of the gulch. Workings consist of an inclined shaft which partly coincides with stopes on two greisen pipes, and a shallow prospect shaft or open cut on a third pipe. Greisens and surface workings are shown on a large-scale map (plate 16) which also shows generalized underground workings. The underground workings are taken from a map made by W. N. Sharp.

The Redskin mine was originally prospected for molybdenum (Worcester, 1919) and it is probable that some molybdenum ore was shipped from the mine during or shortly after World War I. The mine was probably abandoned in the early 1920's and not worked again until the discovery of pitchblende at the mine by Bill Wyble in about 1954. Mr. Wyble unwatered the mine, but found only small amounts of sooty pitchblende in place. Beryllium minerals were discovered at the mine in 1959 by L. C. Moyd with a beryllium detector.

The main Redskin pipe is exposed in an open cut a few feet south of the main shaft where it plunges nearly due N at about 40°. Most of the pipe has been removed from the cut leaving only a smooth quartz-rich selvage on the footwall of the pipe, and sparse beryllium bearing greisen and barren greisen on the hanging wall of the pipe. The amount of dip of this segment of the pipe appears to coincide with a pre-greisen fracture which also partly controls the distribution of beryllium minerals within the pipe. About 30 feet horizontally from the cut, the pipe changes plunge direction to about N. 60° E. The main inclined shaft, shown in plate 16, is mostly below the pipe and approximately parallel to the direction of plunge. High-grade beryllium ore occurs as small pods localized by steeply dipping fractures within the segment of the pipe plunging about N. 60° E., but the average grade of presently known portions of the pipe is low.

A second pipe (lower pipe) was exposed about 55 feet south of the main shaft; its surface position can only be inferred from the shape of the open cut. The pipe plunges northerly, then flattens abruptly. This pipe was also intersected by the main shaft about 20 feet from the collar.

A third pipe is exposed in a shallow prospect shaft about 100 feet N. 70° E. from the main shaft. At the surface the pipe was a flattened lens lying parallel to a fracture zone; the pipe contains disseminated beryllium minerals and plunges northerly at a high angle.

Black Prince mine

The Black Prince mine is in Section 11 about 1700 feet north-northeast of the Redskin mine. Workings consist of a shaft which was recollared in 1961, a nearby caved shaft, and several open cuts. Some beryllium-bearing greisen was noted on the dumps, along with sulfide-bearing greisen.

The main pipe is exposed in the rehabilitated shaft workings. It plunges steeply northward and is partly localized by a fracture zone which strikes northeasterly (fig. 18). Several other pipes which plunge northerly at low angles are exposed in open cuts south of the main shaft (plate 17).

China Wall area

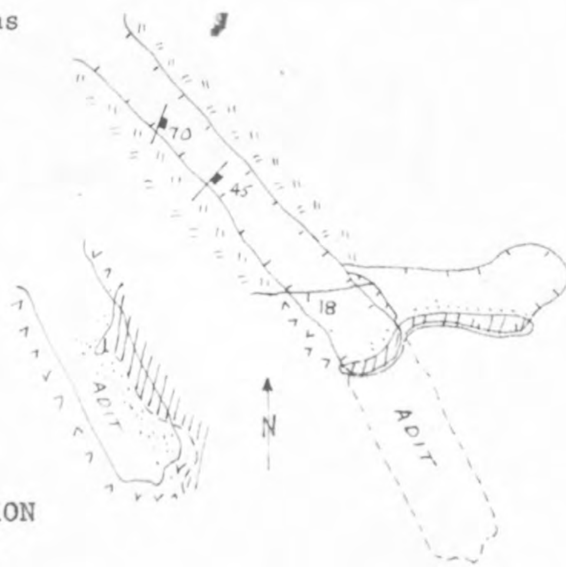
The China Wall mine area is in Sections 4 and 5 about three-quarters of a mile east of the village of Tarryall. The area is mainly underlain by fine-grained Pikes Peak Granite which forms the outer zone of the China Wall pluton. Biotite-muscovite granite forms most of the country rock west of the pluton, and also occurs as a screen between fine-grained granite and the porphyritic facies of the granite in the northern part of the mineralized area, and as numerous small inclusions in the China Wall body.

All known deposits are associated with the fine-grained Pikes Peak Granite and are found at or very near contacts of the granite with biotite-muscovite granite. With the exception of the beryllium-bearing greisen at the A & C prospect, the beryllium-bearing greisens are associated with small inclusions of the older granite. At the A & C claim, the greisen is found in a Pikes Peak dike which cuts through the large biotite-muscovite granite screen.

Small amounts of beryllium-bearing materials have been mined in the area, and Bob Beal and Roy Monett shipped a small lot of high grade beryl ore to the Custer, S. D. buying station in 1962. The ore apparently occurs in pods several feet across, and is locally associated with coarsely crystalline quartz. Topaz is apparently found in both ore-bearing and barren greisens and forms crystals as much as several inches across. Greisens including the topaz-bearing types cut across thin quartz-feldspar-topaz pegmatites.

A & C Prospect

Greisens on the A & C claim, about one-mile east-northeast of Tarryall, are opened by several open cuts or short adits. The main cut and adit was mapped in 1961. The A & C area is mostly underlain by biotite-muscovite granite which appears to be a screen lying between fine-grained and porphyritic Pikes Peak Granite; at the open cut and adit the biotite-muscovite granite is cut by a Pikes Peak dike which strikes easterly and dips to the south at about 18°. The hanging wall of the dike contains a large pod of quartzose greisen which locally contains beryl crystals. Some bertrandite also is found as pseudomorphic replacements of the beryl crystals.



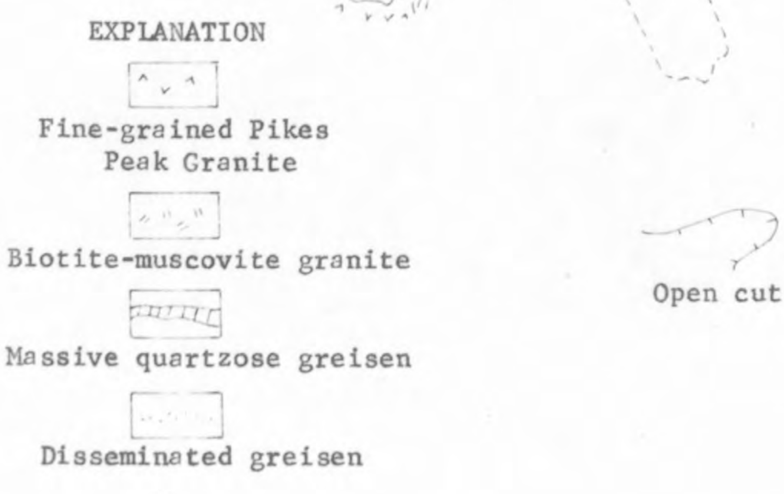


FIGURE 28. MAP OF THE A & C OPEN CUT AND ADIT

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APPENDICES

APPENDIX A

MODAL COMPOSITION OF PIKES PEAK GRANITE

Composition (volume percent) of Pikes Peak Granite was determined by microscopic point counting. In most cases the composition of the relatively fine-grained rocks belonging to the porphyritic and fine-grained facies was determined by counting 1000 points on one standard sized thin section. Composition of the coarser rocks was determined, generally, by counting a total of more than 1000 points on two standard sized thin sections.

Essentially all of the Pikes Peak Granite of the Lake George beryllium area is a two-feldspar granite composed dominantly of quartz, sodic plagioclase, potassic alkali feldspar, and biotite or muscovite. The potassic alkali feldspar is generally perthitic, and in most cases the potassic and plagioclase components could be separated during point counting. Most thin sections were stained with sodium cobaltinitrite to facilitate identification of the potassic phase of the feldspar, although it is also generally possible to distinguish potassic feldspar on the basis of faint hematitic dusting or microcline twinning. The feldspar reported as sodic plagioclase forms polysynthetically twinned subhedral to euhedral crystals which occur in aggregates or locally as single crystals mantled or included by the potassic alkali feldspar.

One possible source of error in the counting procedure used arises from the possible confusion of the perthitic plagioclase for discrete grains of sodic plagioclase. In general this is not believed to be significant, because there are slight but noticeable differences in relief of the two types of plagioclase, and also because observation at low magnifications generally gives enough perspective to separate the perthitic plagioclase from discrete plagioclase grains.

The sodic plagioclase on an average is an intermediate albite. Compositions were determined on many thin sections on the universal stage using a low-temperature plagioclase curve for P. M. sections. The range reported in the tables is based on at least five separate measurements per thin section.

Plucking of the sections during preparation probably affected some of the values reported for the micas, and for fluorite and other accessories generally closely associated with the micas.

The results of all modal analyses are presented in five tables (1-A to 5-A), and locations of samples, except for samples in the Boomer mine area in Section 21, are shown in figures 1-A to 3-A.

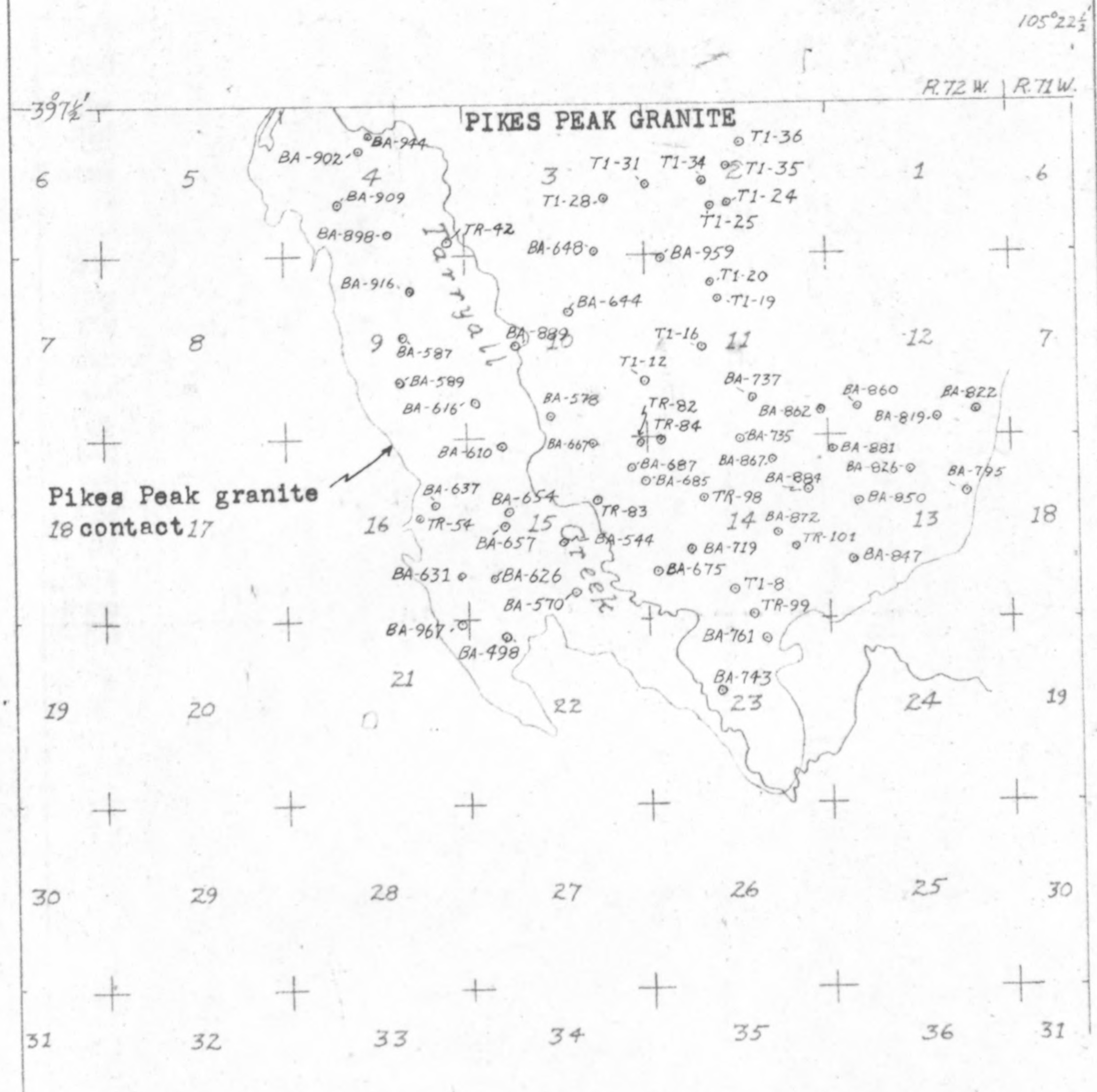

FIGURE 1-A. SAMPLE LOCATION MAP: MAIN GRANITES FROM TARRYALL LOBE,

(Table 1-A)

TABLE 1-A

MODAL COMPOSITION (VOLUME PERCENT) OF MAIN GRANITES, TARRYALL LOBE (Page 1 of 4)

Sample numbers	BA-898	BA-902	BA-909	BA-944	TR-42	BA-587	BA-916	BA-589	BA-616	BA-822	BA-819	BA-795	BA-826	BA-847	BA-850	TR-99
Quartz	29.8	24.5	22.3	31.6	16.4	36.2	28.9	41.2	23.1	39.8	27.4	31.7	25.1	27.9	40.2	28.0
Plagioclase	33.4	22.4	17.4	24.9	29.7	19.7	20.4	15.4	26.8	22.2	20.2	15.8	30.2	21.0	20.8	29.7
Potassic feldspar	32.8	48.3	55.6	40.0	47.3	41.4	45.2	40.3	46.1	32.0	50.3	48.5	41.7	45.3	36.0	34.5
K-fraction	28.2	38.8	44.5	32.5	36.5	36.2	38.2	33.8	37.4	24.8	35.2	35.5	30.9	33.7	28.5	28.0
Plag. fraction	4.6	9.5	11.1	7.5	10.8	5.2	7.0	6.5	8.7	7.2	15.1	13.0	10.8	11.6	7.5	6.5
Biotite	3.4	3.9	3.9	2.8	3.4	2.0	4.2	2.1	3.3	5.1	1.5	3.8	2.3	4.6	2.3	4.8
Muscovite	0.2	0.1	0.4	0.1	1.8	0	0.2	0.1	0.3	0.2	0.1	0	Tr.	0.2	0.1	1.7
Fluorite	0.1	0.5	0.2	0.5	1.3	0.6	1.0	0.7	0.3	0.6	0.4	0.2	0.7	0.9	0.5	1.2
Topaz	0	0.1	Tr.	0	0	Tr.	Tr.	0	0	Tr.	0	Tr.	Tr.	0	0	0
Zircon	Tr.	0.1	0.2	Tr.	0	Tr.	Tr.	Tr.	Tr.	0.1	Tr.	Tr.	Tr.	0.1	Tr.	0.1
Opaques	0.3	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0	0	Tr.	0	0	0.1	0
Kaolinite(?)	0	0	0	0	0	0	Tr.	0.1	0	0	0.1	0	0	0	0	0
Tourmaline	0	0	0	0	0	0	0	0	0	0	0	Tr.	0	0	0	0
Apatite	0	0	0	0	0	0	Tr.	0	0	0	0	0	0	Tr.	0	0
Composition of plagioclase	An_{5-13}	An_{3-8}	$<An_5$	An_{5-7}	—	An_{3-14}	—	An_{0-14}	—	An_{5-10}	—	An_{3-4}	—	An_{0-13}	—	An_{0-10}
Number of points	2005	2000	1000	2108	1502	2000	2198	2128	2000	1775	2009	2000	2000	2000	2000	2000
Number of sections	2	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2

<u>Location and remarks:</u>

BA-898: Section 4; granular facies.
BA-902: do do
BA-909: do do
BA-944: do do
TR-42: do do, slightly altered.
BA-587: Section 9; granular facies.
BA-916: do do
BA-589: Section 10; granular facies.
BA-616: do do
BA-822: Section 12; granular facies.
BA-819: do do
BA-795: Section 13; granular facies.
BA-826: do do
BA-847: Section 13; d0
BA-850: do do

TR-99: Section 14; granular facies.

TABLE 1-A

MODAL COMPOSITION (VOLUME PERCENT) OF MAIN GRANITES, TARRYALL LOBE (page 2 of 4)

Sample numbers	T1-8	BA-544	BA-570	BA-610	BA-626	BA-654	BA-657	TR-54	BA-631	BA-637	BA-967	BA-498	BA-743	BA-761
Quartz	25.5	38.3	36.6	39.5	31.8	34.2	27.8	35.4	28.5	34.3	37.8	31.6	26.9	28.6
Plagioclase	37.5	19.2	21.7	22.8	26.0	18.4	20.2	16.8	21.3	20.3	16.8	16.4	21.7	19.4
Potassic feldspar	31.3	38.6	40.2	32.3	36.0	44.7	46.0	41.6	47.1	42.6	41.1	49.0	47.4	47.0
K-fraction	28.1	29.2	30.8	23.4	28.3	35.8	37.2	31.0	34.7	33.6	29.9	38.1	34.1	33.9
Plag. fraction	3.2	9.4	9.4	8.9	7.7	8.9	8.8	10.6	12.4	9.0	11.2	10.9	13.3	13.1
Biotite	0.7	3.3	1.2	4.3	4.5	2.0	5.3	4.8	1.6	2.3	2.0	2.4	2.7	3.7
Muscovite	4.0	0.2	Tr.	0.1	0.6	0.4	0.1	0.2	0.4	0.2	1.8	Tr.	0.6	0.5
Fluorite	0.2	0.2	0.3	0.9	0.7	0.3	0.6	1.0	0.9	0.2	0.4	0.6	0.5	0.7
Topaz	0	0	0	0	Tr.	0	0	0	0	0	0	0	0	0
Zircon	0.1	0	Tr.	0.1	0.1	Tr.	0	0	0.1	Tr.	0.1	Tr.	0.1	0.1
Opaques	0	0.2	0	0	0.3	0	Tr.	0.2	0.1	0.1	0	0	0.1	0
Kaolinite(?)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tourmaline	0	0	.0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0[a]	7	0	0	0	0	0	0	0	Tr.	0	0	0	0
Composition of plagioclase	An_{0-10}	An_{0-11}	—	An_{0-7}	—	An_{0-11}	An_{0-11}	—	An_{0-11}	—	An_{1-7}	—	An_{0-7}	—
Number of points / Number of sections	2000 / 2	2000 / 2	2000 / 2	2000 / 2	2000 / 2	1660 / 2	1300 / 2	2000 / 1	2000 / 2	1800 / 2	2050 / 2	1000 / 1	2010 / 2	1800 / 2

a. 0.7 carbonate

Location and remarks:

T1-8: Section 14; granular facies: Fresh rock from dump with greisened rock; composition atypical and was not used in calculating average composition of granular facies.
BA-544: Section 15; granular facies.
BA-570: do do
BA-610: do do
BA-626: do do
BA-654: do do
BA-657: do do
TR-54: Section 16; granular facies.
BA-631: do do
BA-637: do do
BA-967: Section 21; granular facies.
BA-498: Section 22; do
BA-743: Section 23; d0
BA-761: do do

TABLE 1-A

MODAL COMPOSITION (VOLUME PERCENT) OF MAIN GRANITES, TARRYALL LOBE (Page 3 of 4)

Sample numbers	T1-24	T1-25	T1-28	BA-648	T1-12	BA-644	BA-578	BA-889	T1-16	BA-737	BA-862	BA-959	BA-860	BA-881	TR-84	TR-98
Quartz	25.8	32.9	30.3	29.0	32.5	34.7	30.0	25.5	34.5	30.4	31.0	30.1	36.3	31.2	32.5	29.7
Plagioclase	37.6	32.1	31.0	35.8	32.4	29.1	37.8	36.6	30.8	34.2	33.7	33.6	29.5	29.3	33.1	33.2
Potassic feldspar	31.3	29.3	32.7	30.8	27.4	30.6	29.2	32.0	29.6	32.0	31.5	31.8	31.5	36.0	27.9	33.6
K-fraction	30.3	28.5	31.8	28.5	24.1	28.3	25.3	30.0	—	28.7	28.0	30.2	28.3	33.4	26.6	31.4
Plag. fraction	1.0	0.8	0.9	2.3	3.3	2.3	3.9	2.0	—	3.3	3.5	1.6	3.2	2.6	1.3	2.2
Biotite	1.0	3.9	4.5	2.8	0.3	2.2	1.9	4.2	2.4	0.6	2.3	3.3	1.2	1.9	2.5	2.7
Muscovite	3.4	1.4	0.9	1.5	6.6	2.6	0.5	0.8	2.7	2.4	0.9	0.8	1.0	0.6	3.6	0.2
Fluorite	0.8	0.3	0.5	Tr.	0.7	0.8	0.5	0.9	Tr.	0.2	0.5	0.4	0.5	0.8	0.4	0.4
Topaz	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Zircon	0.1	0	Tr.	0	0.1	0	0.1	Tr.	Tr.	Tr.	Tr.	Tr.	0	0.1	Tr.	0
Opaques	Tr.	0.1	0.1	0.1	0	0	0	0	0	0.1	0.1	Tr.	0	0	0	0.2
Kaolinite(?)	0	0	0	0	0	0	Tr.	0	0	0	0	0	0	0.1	0	0
Tourmaline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Composition of plagioclase	—	An_{3-10}	—	An_{0-16}	—	An_{2-7}	—	An_{0-13}	—	An_{0-6}	—	An_{0-7}	—	An_{0-6}	An_{0-6}	An_{3-11}
Number of points	1000	1000	1000	1000	1000	1000	1000	2000	1000	1000	1000	1000	1000	1000	2000	1000
Number of sections	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1

Location and remarks:

T1-24: Section 2; porphyritic facies. Redder than normal, abundant secondary muscovite.
T1-25: do
T1-28: Section 3; porphyritic facies.
BA-648: do do
T1-12: Section 10; do
BA-644: do do
BA-578: do do
BA-889: do do
T1-16: Section 11; do
BA-737: do do
BA-862: do do
BA-959: do do
BA-860: Section 12; do
BA-881: Section 13; do
TR-84: Section 14; do
TR-98: do do

TABLE 1-A

MODAL COMPOSITION (VOLUME PERCENT) OF MAIN GRANITES, TARRYALL LOBE (Page 4 of 4)

Sample numbers	TR-101	BA-735	BA-867	BA-719	BA-872	BA-884	TR-82	TR-83	BA-667	BA-685	BA-687	T1-19	T1-20	T1-31	T1-34	T1-35	T1-36
Quartz	20.9	28.3	29.6	27.8	38.2	28.4	29.1	32.8	29.9	22.3	32.9	32.4	28.8	30.2	31.0	28.9	27.0
Plagioclase	37.4	30.4	39.4	34.2	32.9	31.0	30.2	35.3	36.0	39.8	31.6	36.9	36.6	34.2	33.6	33.1	37.4
Potassic feldspar	36.6	37.1	26.7	33.4	25.6	32.4	33.8	27.3	28.4	34.9	30.3	22.6	27.3	29.8	31.7	29.7	29.2
K-fraction	32.5	34.9	24.4	29.2	23.9	28.5	28.0	23.4	26.3	32.3	28.6	—	26.8	29.6	—	—	—
Plag. fraction	4.1	2.2	2.3	4.2	1.7	3.9	5.8	3.9	2.1	2.6	1.7	—	0.5	0.2	—	—	—
Biotite	3.2	2.1	1.6	3.1	0.6	2.9	0	3.4	2.9	0.7	3.2	0.8	4.8	4.4	2.9	0.3	4.0
Muscovite	1.1	1.7	2.2	0.8	2.5	4.5	4.0	0.6	2.3	1.8	0.7	6.7	1.8	1.0	0.8	7.0	2.2
Fluorite	0.5	0.3	0.4	0.7	0.2	0.8	0.9	0.6	0.4	0.4	0.9	0.6	0.4	0.4	Tr.	0.7	0.2
Topaz	0	0	0.1	0	0	Tr.	0	0	0:1	0	0.1	Tr.	0.1	0	0	0	0
Zircon	0.3	0	Tr.	Tr.	0	Tr.	0	Tr.	Tr.	0	0.1	0	Tr.	Tr.	0	0	Tr.
Opaques	0	0.1	0	0	0	0	2.0	Tr.	0	0.1	0.2	0	0.2	Tr.	0	0.3	Tr.
Kaolinite(?)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tourmaline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Composition of plagioclase	—	An_{0-6}	—	An_{1-11}	An_{0-17}	—	An_{3-7}	An_{1-6}	—	—	An_{1-11}	An_{0-5}	—	—	An_{0-10}	—	—
Number of points / Number of sections	1000/1	1000/1	1000/1	2000/2	1000/1	1000/1	1000/1	2000/2	1000/1	1000/1	1000/1	1000/1	1000/1	1025/1	1000/1	1000/1	1025/1

Location and remarks:

TR-101: Section 14; Porphyritic facies.
BA-735: do do
BA-867: do do
BA-719: do do
BA-872: do do
BA-884: do do
TR-82: Section 15: porphyritic facies.
TR-83: do do
BA-667: do do
BA-685: do do
BA-687: do do
T1-19: Section 11; fine-grained facies.
T1-20: do do
T1-31: Section 2: fine-grained facies.
T1-34: do do
T1-35: do do
T1-36: do do

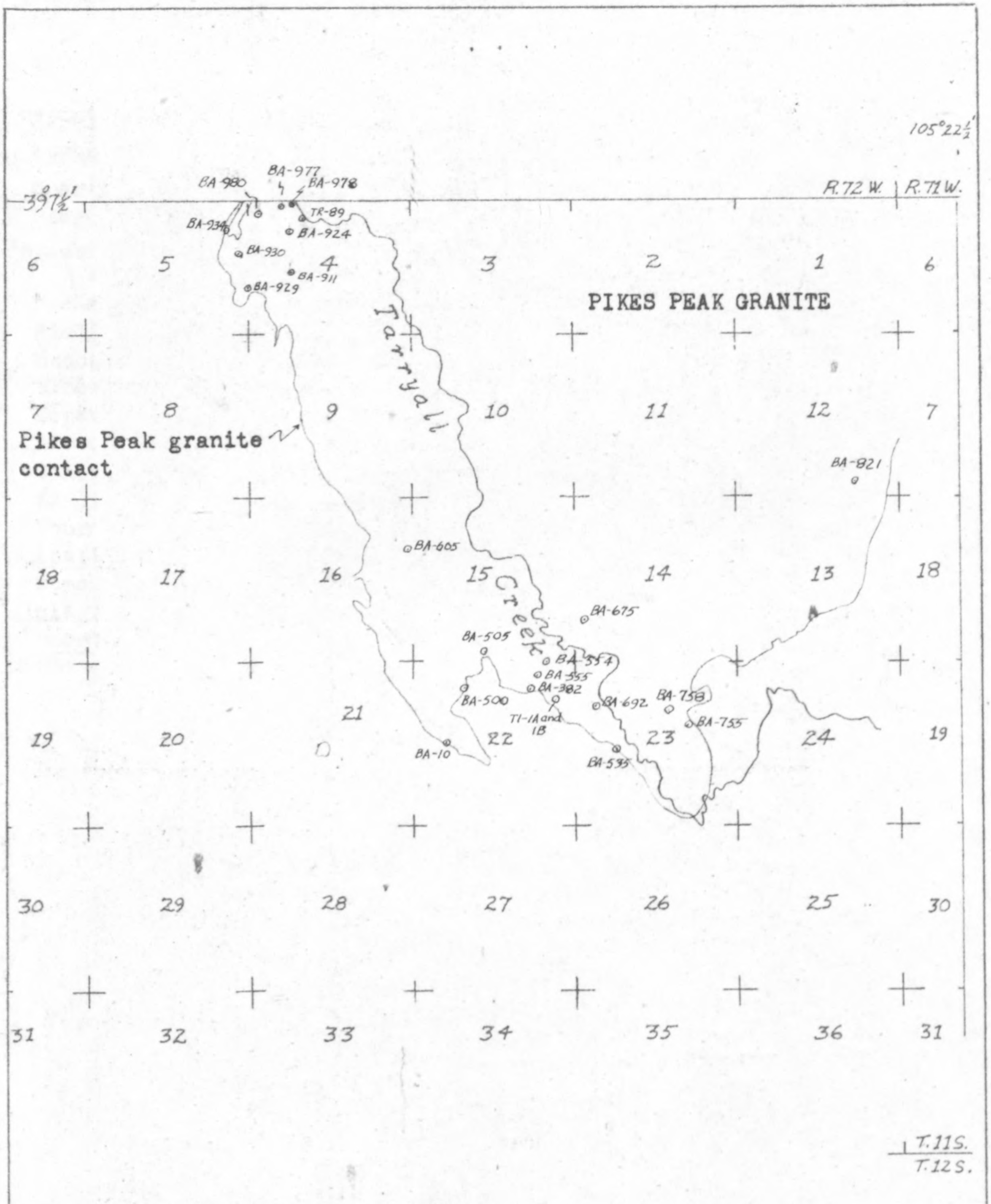

FIGURE 2A.--SAMPLE LOCATION MAP: GRANITES FROM DIKES AND BORDER FACIES, TARRYALL LOBE (TABLE 2-A), AND FROM THE CHINA WALL PLUTON (TABLE 3-A)

TABLE 2-A

MODAL COMPOSITION (VOLUME PERCENT) OF DIKE ROCKS AND BORDER FACIES, TARRYALL LOBE (Page 1 of 1)

Sample numbers	BA-505	BA-605	BA-821	BA-755	BA-758	BA-675	BA-382	BA-554	BA-555	BA-535	BA-692	T1-1A	T1-1B	BA-10	BA-500
Quartz	32.4	31.3	35.4	27.0	29.3	27.4	33.5	34.0	27.5	35.0	34.0	38.2	33.3	32.3	29.9
Plagioclase	24.0	40.2	30.0	29.3	21.4	33.0	24.9	33.1	27.3	25.0	43.3	34.8	37.5	29.4	43.6
Potassic feldspar	38.3	24.5	33.8	36.8	46.6	32.9	37.6	26.2	40.3	36.1	20.0	24.0	25.3	32.5	22.3
K-fraction	36.7	—	—	31.2	40.4	30.4	24.0	22.6	34.2	28.8	18.8	21.0	24.8	—	21.7
Plag. fraction	1.6	—	—	5.6	6.2	2.5	3.6	3.6	6.1	7.3	1.2	3.0	0.5	—	0.6
Biotite	3.4	3.0	0.8	5.3	1.5	5.9	3.2	6.1	3.8	0.2	1.7	2.1	0	0	3.9
Muscovite	1.5	0	0	0.9	0.5	0.2	0.3	0.3	0.3	3.2	0.4	0.6	3.1	5.5	0
Fluorite	0.3	0	0	0.5	0.7	0.6	0.4	0.3	0.7	0.4	0.3	0	Tr.	0.3	0.1
Topaz	0	1.0	Tr.	0	0	0	0.1	0	0	0	Tr.	0.3	0	Tr.	0.1
Zircon	0.1	0	0	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	0.1	Tr.	Tr.	0	0	0.1
Opaques	0	0	0	0.2	0	0	0	0	0.1	0	0.3	0	0.8	0	0
Kaolinite(?)	0	0	0	Tr.	0	0	0	0	0	0	0	0	0	0	0
Tourmaline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Composition of plagioclase	—	An_{0-6}	An_{5-10}	An_{0-6}	—	An_{1-8}	—	An_{0-8}	An_{0-4}	—	An_{3-6}	An_{3-6}	—	An_{0-4}	—
Number of points	1000	1000	1000	1000	1000	1000	1000	1000	1500	1000	1000	1800	1000	1000	1000
Number of sections	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1

<u>Location and remarks:</u>

BA-505: Section 15. Fine-grained dike cutting granular granite.
BA-605: Section 16. do
BA-821: Section 12. do
BA-755: Section 23. Porphyritic border zone.
BA-758: do do
BA-675: Section 14. Fine-grained dike in porphyritic granite.
BA-382: Section 22. Porphyritic border zone.
BA-554: do do
BA-555: do do
BA-535: Section 23. do
BA-692: do do
T1-1A: Section 22. do
T1-1B: do Fine-grained granite dike cutting T1-1A.
BA-10: do Fine-grained border zone.
BA-500: do do

TABLE 3-A

MODAL COMPOSITION (VOLUME PERCENT) OF GRANITES, CHINA WALL PLUTON (Page 1 of 1)

Sample numbers	BA-977	BA-980	TR-89	BA-929	BA-978	BA-911	BA-924	BA-930	BA-934
Quartz	30.0	43.6	26.9	33.2	27.4	35.1	43.8	43.2	31.6
Plagioclase	30.7	30.6	39.1	27.0	11.4	33.5	28.7	32.3	40.2
Potassic feldspar	36.3	23.1	28.1	32.9	55.7	28.1	24.2	19.2	22.0
K-fraction	31.2	21.2	26.2	27.3	40.3	25.8	22.0	19.0	21.1
Plag. fraction	5.1	1.9	1.9	5.6	15.4	2.3	2.2	0.2	0.9
Biotite	2.1	2.4	5.3	6.1	4.6	2.4	2.6	4.6	3.8
Muscovite	0	Tr.	0.4	0.1	0.2	0.4	0.4	0.7	0.7
Fluorite	0.8	0	Tr.	0.5	0.6	0	0.1	0	0.2
Topaz	0	Tr.	0.1	0	Tr.	0.5	0.2	Tr.	0.7
Zircon	Tr.	Tr.	0.1	0.2	0.2	Tr.	0	0	0.8
Opaques	0	0.3	Tr.	0	Tr.	0	0	0	0
Kaolinite(?)	0	0	0	0	Tr.	0	0	Tr.	0
Tourmaline	0.1	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0
Composition of plagioclase	—	—	An_{4-7}	—	—	An_{0-17}	—	An_{0-10}	An_{0-7}
Number of points / Number of sections	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1
Facies	GRANULAR FACIES		PORPHYRITIC FACIES			FINE-GRAINED FACIES			

TABLE 4-A

MODAL COMPOSITION (VOLUME PERCENT) OF FINE-GRAINED GRANITES FROM THE BOOMER STOCK AND ASSOCIATED DIKES (page 1 of 1)

Sample numbers	TR-1	IV-4	IV	IV-10a-4	IV-12	IV-26a	B2-7-5	B3-1	B3-2	B3-11	B5-1	J+S-9	1-1	J+S-3a	26-7a	26-7b	TR-51
Quartz	40.0	37.9	33.5	36.0	42.5	34.7	35.5	41.1	41.4	39.6	33.4	27.2	38.8	33.6	37.5	39.4	44.3
Plagioclase	27.9	26.1	27.4	30.0	25.2	43.3	35.4	37.0	36.4	36.9	35.4	27.8	38.5	28.9	45.5	41.5	45.8
Potassic feldspar	25.8	27.4	32.7	27.0	29.6	17.0	18.4	15.1	16.4	11.5	26.0	41.0	18.8	33.2	13.9	8.0	0.4
K-fraction	—	27.1	32.3	—	27.9	—	—	—	—	—	—	—	—	—	—	—	—
Plag. fraction	—	0.3	0.4	—	1.6	—	—	—	—	—	—	—	—	—	—	—	—
Biotite	0	0	0.1	0	0	0	0	0.9	0	0	0	0	0.3	0	0	0	0.4
Muscovite	6.3	8.0	5.5	6.3	2.6	4.9	10.5	5.3	5.0	9.6	4.4	3.8	3.6	4.2	3.1	11.1	8.3
Fluorite	Tr.	Tr.	0.3	0.4	Tr.	0	0.1	0.3	0.1	0.2	0.2	0.2	0	0.1	0	Tr.	0.8
Topaz	0	0	0.1	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Zircon	0	Tr.	Tr.	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
Opaques	0	0.5	0.4	0.3	0.1	0	0.1	0.4	0	0	0	0	0	0	0	0	0
Kaolinite(?)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbonates	0	0	0	0	0	0	0	0	0.7	2.2	0.5	0	0	0	0	0	0
Beryl	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Composition of plagioclase	An_{0-8}	—	An_{0-6}	An_{0-6}	An_{1-7}	—	—	—	An_{5-10}	—	An_{3-6}	—	An_{0-6}	—	An_{0-5}	—	An_{0-6}
Number of points / Number of sections	1000 / 1	1000 / 1	1000 / 1	1000 / 1	800 / 1	1500 / 1	1050 / 1	1000 / 1	1000 / 1	1000 / 1	1050 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1	1000 / 1

Remarks:

Samples TR-1 to J & S-g are pale pink fine-grained granites from the Boomer stock. TR-1 is from the Boomer dump; samples IV-4 to IV-26a are surface samples ; B2-7-5 to B5-1 were collected in the Boomer mine, and J & S-g came from underground in the J & S No. 3 mine.

Samples 1-1 to TR-51 are white to pale pink aplitic granites from dikes. TR-51 was adjacent to a quartz-beryl vein.

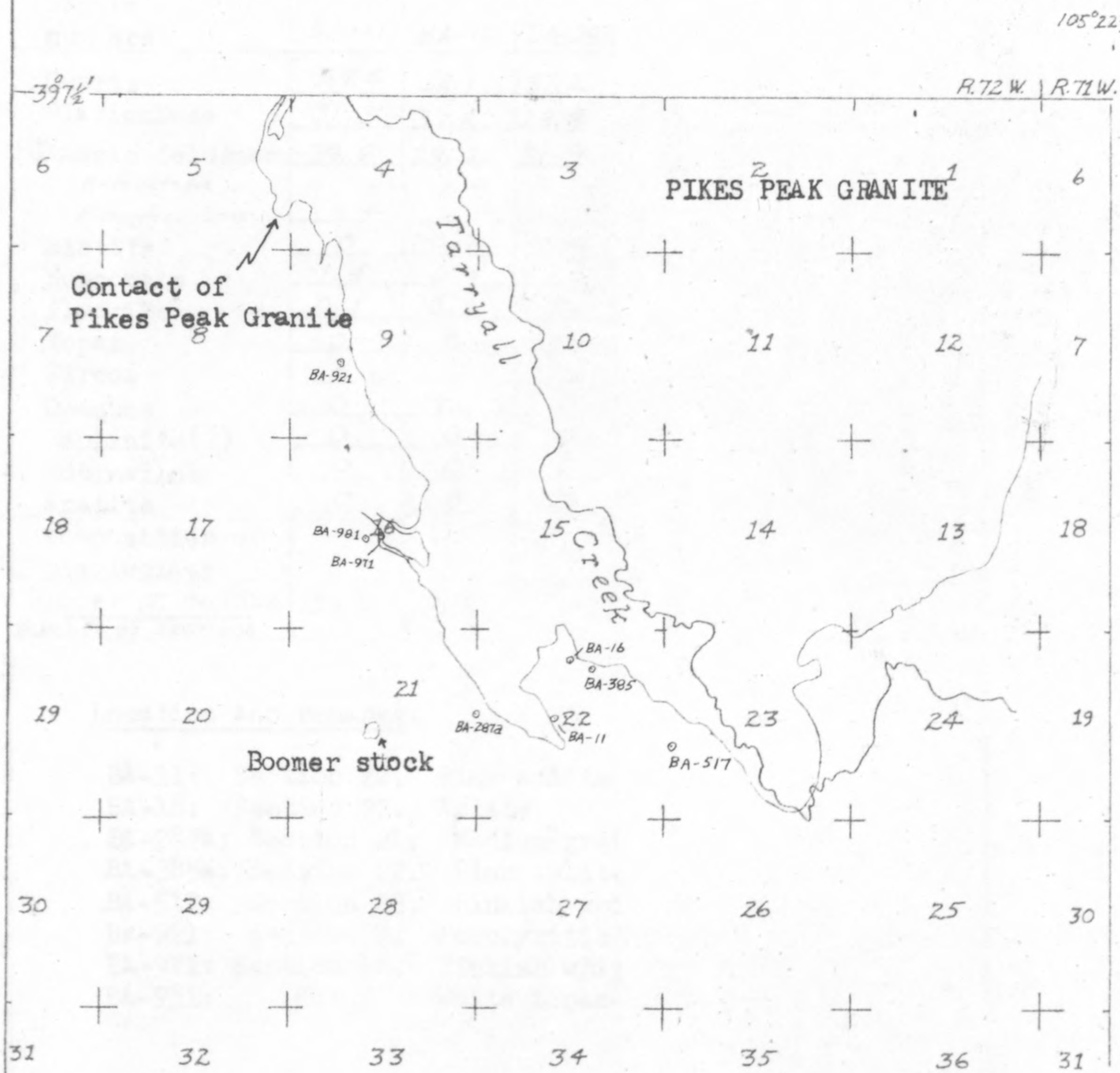

FIGURE 3-A.--SAMPLE LOCATION MAP: GRANITES FROM SATELLITIC DIKE ROCKS OUTSIDE THE BOOMER AREA (TABLE 5-A)

TABLE 5-A

MODAL COMPOSITION (VOLUME PERCENT) OF DIKE ROCKS OUTSIDE THE BOOMER AREA

Sample numbers	BA-11	BA-16	BA-287a	BA-385a	BA-517	BA-921	BA-971	BA-981			
Quartz	27.4	32.1	37.2	32.1	27.2	32.2	33.9	30.1			
Plagioclase	31.3	37.2	28.9	40.6	39.6	26.8	41.4	34.2			
Potassic feldspar	39.8	29.2	31.9	25.2	31.0	37.8	23.1	32.8			
K-fraction	—	—	—	—	—	—	—	—			
Plag. fraction	—	—	—	—	—	—	—	—			
Biotite	0	0.4	0.4	0	1.0	3.0	1.2	0.2			
Muscovite	1.4	0.9	1.6	1.9	0.3	Tr.	0.3	0.4			
Fluorite	0.1	0.2	Tr.	0.1	0.1	0	0	0			
Topaz	0	0	0	0	0.5	Tr.	0.1	2.2			
Zircon	0	Tr.	Tr.	0	0	Tr.	0	0.1			
Opaques	0	Tr.	0	0.1	0.3	0	0	0			
Kaolinite(?)	0	0	0	0	0	0.2	0	Tr.			
Tourmaline	0	0	0	0	0	0	0	0			
Apatite	0	0	0	0	0	0	0	0			
Composition of plagioclase											
Number of points	1000	1000	1500	1000	1000	1000	1000	1000			
Number of sections	1	1	1	1	1	1	1	1			

Location and remarks:

BA-11: Section 22. Pink aplite with small miarolitic cavities filled with fluorite.
BA-16: Section 22. Aplite.
BA-287a: Section 21. Medium-grained granular granite, microscopic xenomorphic texture.
BA-385a: Section 22. Pink aplite.
BA-517: Section 23. Pinkish-white aplite.
Ba-921: Section 9. Porphyritic granite, locally miarolitic.
BA-971: Section 16. Pinkish white aplitic granite.
BA-981: do White topaz-bearing aplite.

APPENDIX B

TRACE ELEMENT COMPOSITION OF PIKES PEAK GRANITE

Spectrographic analyses of Pikes Peak Granites are given in two tables. Table 1-B gives results of analyses of granular, porphyritic, and fine-grained main granites of the Tarryall lobe; table 2-B gives trace element analyses of rocks from the Boomer stock and other satellitic granite intrusions.

Elements listed are Be, Ba, Ce, Cu, Ga, La, Li, Nb, Pb, Sn, Sr, Y, Yb, and Zr. In a few samples Ag, Mo, Sc, and Zn analyses are also given. With the exception of Li, which was determined by a quantitative spectrographic method, all determinations are by the semiquantitative spectrographic method.

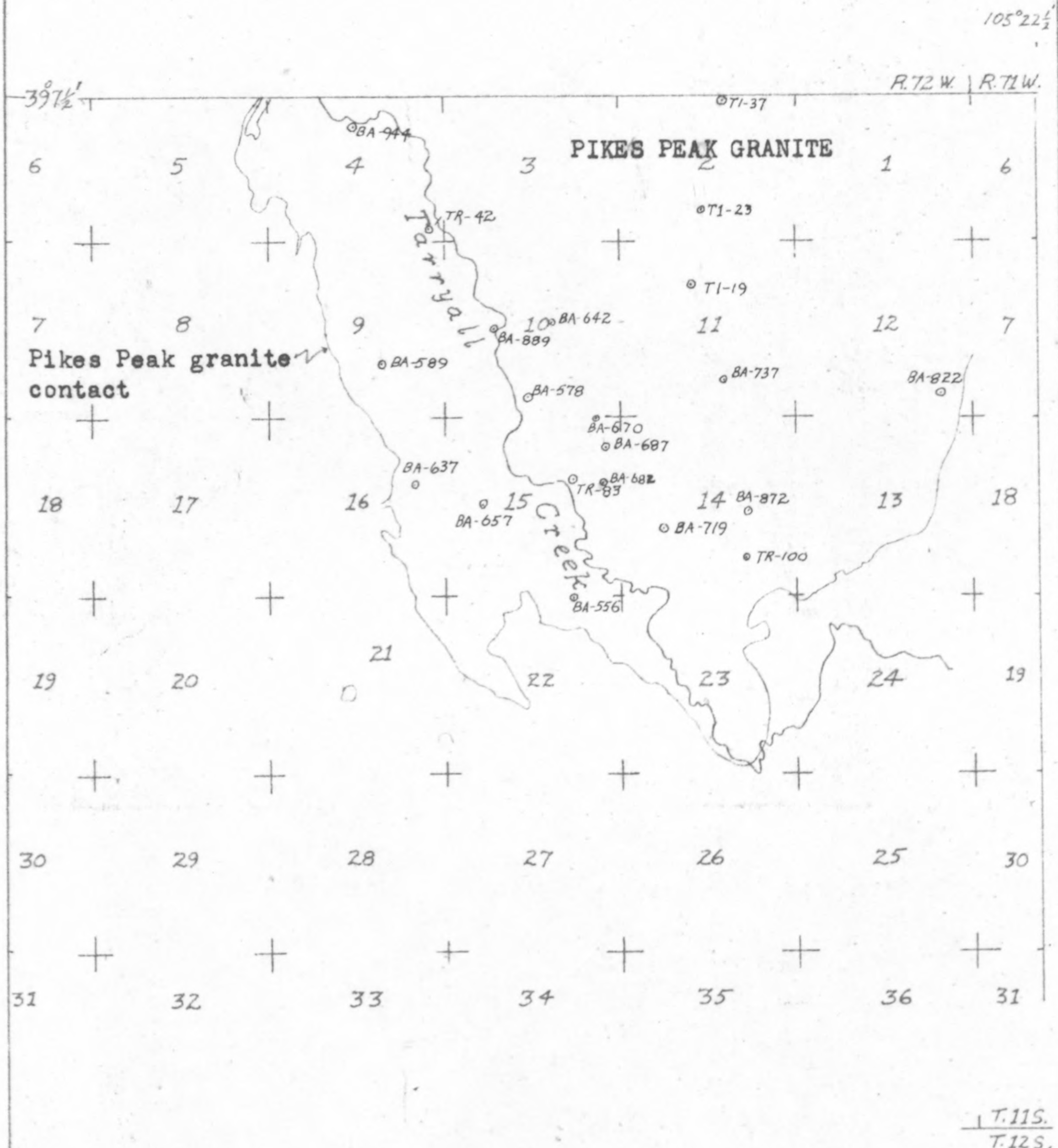

FIGURE 1-B.--SAMPLE LOCATION MAP: SPECTROGRAPHICALLY ANALYZED MAIN GRANITES, TARRYALL LOBE

TABLE I-B. TRACE ELEMENT COMPOSITION OF PIKES PEAK GRANITES. Analyses of main granites, Tarryall lobe.

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ba	Ce	Cu	Ga	La	4/ Li	Nb	Pb	Sn	Sr	Y	Yb	Zr
						Semiquantitative spectrographic analyses (percent)												
Tarryall lobe-fig. I-B	TR-42 278 774	Granular facies	0.0007			0.03	d	0.0007	0.003	0.007	0.0045	0.015	0.0015	0.003	0.003	0.007	0.0015	0.03
do	TR-100 293 642	do	.0005			.03	<.02	.0007	.003	.007	0.0061	.005	.005	.002	.003	.007	.001	.03
do	BA-589 293 643	do	.0007			.01	<.02	.0005	.005	.007	.0096	.01	.005	.0015	.001	.01	.0015	.007
do	BA-637 293 644	do	.0007			.01	<.02	.0003	.003	.01	.0080	.007	.003	.0015	.0015	.01	.0015	.03
do	BA-657 H3601	do	.0007			.01	<.02	.001	.005	.01	.0095	.015	.005	.002	.0015	.015	.002	.03
do	BA-822 H3602	do	.0005			.007	<.02	.0007	.005	.007	.011	.01	.003	.002	.001	.015	.0015	.02
do	BA-944 H3603	do	.0005			.01	.02	.0007	.003	.015	.0093	.015	.005	.002	.0015	.02	.003	.03
do	TI-23 293 645	Porphyritic facies	.0005			.02	0	.0003	.003	.005	.0061	.01	.0015	.002	.002	.007	.001	.02
do	TR-83 H3248	do	.0015			.03	N.D.	.00015	.003	.007	N.D.	.003	.003	.003	.003	.007	.0015	.015
do	BA-578 293 646	do	.0005			.015	0	.003	.003	.005	.0073	.005	.002	.002	.0015	.005	.001	.007
do	BA-642 293 647	do	.0005			.02	<.02	.0005	.003	.007	.011	.007	.003	.002	.002	.01	.0015	.03
do	BA-670 293 648	do	.0007			.015	.02	.001	.003	.015	.0071	.007	.0015	.003	.0015	.01	.0015	.02
do	BA-682 293 649	do	.0005			.015	0	.0005	.003	.005	.010	.005	.002	.003	.0015	.007	.001	.01
do	BA-687 H3604	do	.001			.05	<.02	.001	.003	.01	.014	.005	.005	.003	.003	.015	.0015	.02
do	BA-719 H3605	do	.001			.02	<.02	.0005	.003	.01	.013	.007	.003	.003	.002	.01	.0015	.015
do	BA-737 293 650	do	.0005			.015	0	.0007	.003	.005	.0095	.003	.002	.015	.0015	.007	.001	.01
do	BA-872 H3606	do	.05			.015	<.02	.001	.003	.005	.0089	.007	.003	.002	.0015	.01	.001	.015
do	BA-889 H3607	do	.0007			.03	<.02	.0003	.003	.007	.012	.01	.003	.002	.005	.015	.0015	.02
do	BA-556 293651	do	.0005			.015	0	.0005	.005	0	.0093	.015	.0015	.0015	.0015	.01	.0015	.015
do	TI-19 293 652	Fine-grained facies	.0005			.02	0	.001	.003	0	.013	.01	.003	.002	.0015	.007	.001	.015
do	TI-37 293 653	do	.0005			.05	0	.0005	.003	.005	.0062	.005	.003	.002	.005	.007	.001	.01
Estimated abundance of elements in low calcium granitic rocks (Turekian and Wedepohl, 1961)				.0003		.0840	.0092	.0010	.0017	.0055	.0040	.0021	.0019	.0003	.0100	.0040	.0004	.0175

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis 4/ Quantitative spectrographic analysis

TABLE 2-B.-- TRACE ELEMENT COMPOSITION OF PIKES PEAK GRANITES, Boomer stock and other locales.

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ba	Ce	Cu	Ga	La	Li	Nb	Pb	Sn	Sr	Y	Yb	Zr					
						Semiquantitative spectrographic analyses (percent)																	
Boomer stock, surface	IV 278 809	Pink, fine-grained aplitic granite	.0003			.007	0	.007	.003	0		.003	.03	.0015	.0007	.003	.0007	.007	Ag .0003			Zn .03	
do	IV-4 G-2952	do	.0003			.007	0	.003	.003	0	-	.003	.015	.0015	.0015	.003	.0015	.015				Zn .03	
do	IV-29 287 991	do	.0003			.007	0	.007	.003	0	-	.003	.015	.0015	.0015	.003	.0007	.007	Ag .00015				
Boomer stock, surface Adjacent to greisen	IV-108-4 G-2954	do	.0007			.007	0	.007	.003	0	-	.003	.07	.0015	.0015	.007	.0015	.007	Ag .0003	Mo .007		Zn .007	
Boomer stock, 8518-foot level, adj. to greisen	82-7-4 H3245	do	.0007			.007	0	.003	.003	0	<.005	.003	.15	.0015	.0015	.007	.0015	.007	Ag .00015	Mo .0015	Sc .0007	Zn .3	
do	82-7-5 H3246	do	.0007			.007	0	.007	.003	0	<.005	.007	.07	.0015	.0015	.007	.0015	.015	Ag .00007	Mo .0015	Sc .0007	Zn .07	
Dike at NE edge, Boomer stock	II-26A 278 810	Pink, fine-grained aplitic granite	.0007			.015	0	.0015	.003	0		.003	.007	.0015	.003	.003	.0007	.007					
Dike 500-feet S. of J+S No. 1	1-1 G-2955	Pink, very fine-grained aplite	.0003			.007	0	.0003	.003	0		.003	.007	.0007	.0015	.003	.0015	.007					
Dike 200-feet-N of J+S No. 1	26-7A 278 808	White, very fine-grained aplite	.0007			.007	0	.0007	.003	0		.003	.007	.0015	.003	.003	.0015	.007					
SE 1/4, SECTION 15 Cuts granular facies	BA-569A 293 654	Pink aplite	.0003			.002	0	.0005	.005	0	-	.003	.005	0	<.001	.003	.0007	.005					
NE 1/4, SECTION 16 Cuts granular facies	BA-605 293 657	Almost white aplite	.0007			.0007	0	.0005	.005	0	-	.007	.005	.002	<.001	.003	.0007	.005					
SE 1/4, SECTION 12 Cuts granular facies	BA-821 H3608	do	.0005			.002	<.02	.0005	.003	.007		.005	.003	0	<.001	.002	.0007	.007					
SW 1/4 SECTION 4 China Wall Platon	BA-927 293 658	White, fine-grained granite	.0003			.002	0	.0007	.003	0		.003	.005	.001	<.001	.01	.0015	.007					
SECTION 5 do	BA-930 293 659	Light pink fine-grained granite	.0003			.0015	0	.0005	.003	0		.003	.003	.001	<.001	.003	.0005	.007					
do do	BA-934 H3609	do	.0003			.003	0	.0007	.005	.005		.007	.003	.002	.0015	.01	.002	.007					
SW 1/4, SECTION 22 Border facies, Mary Lee mine area	BA-10 278 793	Fine-grained pink granite	.0007			.003	d	.007	.003	0		.015	.007	.003	.0007	.015	.003	.007	Ag .00015	Mo .0007			
NW 1/4, SECTION 22, Dike in Idaho Springs (?) Formation	BA-11 278 794	Pink, miarolitic aplite, fluorite in vugs	.0007			.015	0	.0015	.007	0		.007	.007	0	.003	.003	.0007	.003					
NW 1/4 NE 1/4 SECTION 22 Dike in Idaho Springs (?) Fmn.	BA16 278 796	Pink aplite	.0007			.007	0	.003	.003	.003		.007	.015	.0015	.003	.003	.0007	.007					
NE 1/4 SECTION 22 Dike in granitic gneiss	BA-385A 288 012	do	.0007			.007	0	.0007	.003	.003		.003	.003	.0015	.0007	.007	.0015	.007					
Estimated abundance of elements in low calcium granitic rocks (Turekian and Wedepohl, 1961)				.0003		.0840	.0092	.0010	.0017	.0055	.0040	.0021	.0019	.0003	.0100	.0040	.0004	.0175					

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis

APPENDIX C

TRACE ELEMENT COMPOSITION OF ORES AND GREISENS

Results of semiquantitative spectrographic analyses are presented in two tables, 1-C and 2-C. The results in table 1-C are of altered granite, barren greisen, and ore-bearing greisens from the larger mines and prospects of the area; by far the greatest number of samples are from the Boomer and Redskin mines. Table 2-C presents results from smaller prospects; locations of the sampled localities are shown in plate 7. Most of the samples reported are greisens, but there are a few analyses of altered calc-silicate gneisses with small amounts of beryllium, and also a few analyses of the fluorite fissure-vein deposits which generally contain very little beryllium.

Elements listed on both tables are Be, Ag, B, Ba, Bi, Ce, Cu, Ga, Ge, La, Li, Mo, Nb, Pb, Sc, Sn, W, Y, and Zn, all of which are at least locally enriched in the greisens. Other elements could have been listed; for example, Sr and Yb are generally present in greisens of the area, but both are somewhat less abundant than geochemically similar elements Ba and Y. Li is only recorded for a few samples; it was reported in almost all semiquantitative spectrographic analyses, but comparisons between the semiquantitative analyses and a few quantitative determinations indicate that most of the semiquantitative analyses are anomalously high and so only the quantitative values are given. Some elements such as Cr, Ni, and V are present in many of the greisens in amounts generally less than 100 ppm; they are not recorded because they are not significantly enriched nor have they generally been considered as characteristic greisen minerals. Some elements such as B and Ge were included on the table even though they are not found in many of the greisens, because they have been found as enriched elements in some other greisens, and because Ge is at least locally enriched in greisens from the Lake George area.

TABLE 1-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS. Larger mines and prospects (Page 1 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag (Semiquantitative spectrographic analyses (percent))	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
Boomer mine "Outhouse lode", fig. 24	IV-10a-2 G-2953	Sheeted greisened granite, footwall of ore body	.007			.0015	.0015	.03	.0007	.015	.07	.007	0	.007		.03	.007	1.5	.003	.007	0	.007	.15
do	IV-10a-1 278 803	Quartz-topaz greisen	.0003			.0015	0	.003	0	0	.15	.003	.015	.003	4/ .024	.0007	.007	.07	.0015	.003	d	.015	.07
do	IV-10a-9 H-3610	Gray, quartz-muscovite greisen	.001			0	0	.003	0	0	.0015	.007	0	0		0	.007	.02	.003	.01	0	.003	0
about the same as -10a-9	S59-Bo-122g 288 289	do	.015			d	.003	.003	0	0	.0007	.007	0	0		0	.007	.003	.007	.03	0	.007	.007
fig. 24	IV-10a-y H3611	Yellow, quartz-bertrandite-muscovite greisen	5.0			.00015	.003	.002	0	0	.001	.005	.003	0		0	.0015	.01	.007	.003	0	.002	0
about the same as -10a-y	S59-Bo-122y 288 290	do	3.0			d	.003	.003	0	0	.0007	.007	.003	0		0	.003	.007	.007	.007	0	.003	.015
Composite sample of ore zone	IV-10a-3 278 804	do	1.5	.88	.79	.0015	0	.007	0	0	.15	.003	<.005	0	4/ .023	.0007	.015	.7	.003	.007	d	.003	.07
fig. 24	IV-10a-4 G-2954	granite adjacent to IV-10a-2	.0007			.0003	0	.007	0	0	.007	.003	0	0		.007	.003	.07	.0007	.0015	0	.007	.007
South end of "Outhouse lode" open cut	S60-Bo-155 288 291	Quartz-topaz greisen	.00015			.0015	0	.0015	0	0	.007	.003	.007	0		.0007	.015	.03	.003	.003	.7	.007	0
Upper end of greisen pipe, Sec. E-E', plate 13	C2-D 293 626	Galena-bearing greisen	1.5	2.1		.015	0	.02	.0015	0	.03	.005	0	0		.005	.002	>10	.005	.005	0	.003	.3
Boomer mine, 8565-foot level, plate 13	B0-1 289 731	Topaz-quartz-wolframite greisen	.0015	.0022		.00015	0	.003	0	0	.015	0	.007	0		0	.15	.3	.03	.03	>10	.015	.03
do	B0-2 289 732	Quartz-beryl vein	3.0	1.6		0	.003	.007	0	.03	.015	.0015	0	.015		0	.003	.07	.007	.0015	.03	.07	.03
Boomer mine, 8533-foot level, plate 13	B1-13 289 733	Beryl-quartz-muscovite greisen, footwall of B1-14	3.	2.0		.003	.003	.003	0	d	.07	.007	0	.007		.007	.007	3.0	.007	.007	0	.015	.3
do	B1-14 289 734	Beryl vein	3.	3.1		.0003	.003	.003	.0015	0	.07	.007	0	0		0	.003	.07	.015	.007	.03	.0015	.03
do	B1-15 278 780	Muscovite greisen on hanging wall of -14	1.5	.56	.57	.0007	0	.03	0	0	.15	.007	0	.003		.003	.007	.3	.003	.007	0	.03	.3
do	B1-16 278 781	Greisened pegmatite; 7.0-foot chip	.07	.07	.07	.0015	0	.015	0	.07	.07	.007	<.005	.015		.0015	.007	.7	.0015	.015	.015	.03	.15
do, also fig. 22	B1-18 281 310	Bertrandite-rich vein	3.	6.20		0	.003	.003	0	0	.015	.003	.003	0	.003	0	.003	.03	.007	.0015	0	.015	.07
do, do	B1-19 281 311	Beryl vein	3.	4.43		0	d	.0015	0	0	.007	.003	d	0	.007	0	d	.007	.007	.0015	0	.003	0
do, do	B1-20 281 312	Muscovite greisen between B1-18 and -19	.007	.0035		0	d	.007	0	0	.015	.007	0	0	.03	0	.003	.07	.003	.007	0	.007	.07
do, do	B1-21 281 313	Beryl-bearing greisen, hanging wall, B1-19	3.	4.24		0	d	.003	0	0	.007	.003	d	0	.015	0	.003	.015	.015	.003	0	.003	0
do, do	B1-22 281 314	Barren quartz-mica greisen, footwall, B1-18	.007			0	0	.003	0	0	.003	.003	0	0	.015	0	.003	.015	.0015	.007	0	.003	.015
do	B1-26-1 288 149	Muscovite-rich greisen	.0015	.0015		0	.003	.007	0	0	.003	.007	0	0		.0007	.003	.03	.0015	.03	0	.015	.03
do	B1-26-2 288 150	Quartz greisen, hanging wall, -26-1	.0015	.0012		.0007	.003	.003	d	0	.0015	.003	0	0		.0015	.003	.03	.0007	.003	0	.003	d
do	B1-27 288 151	Quartz-muscovite-fluorite vein	.015	.032		.00015	.003	.003	d	d	.03	.003	0	.007		.0007	.007	.15	.0015	.003	0	.015	.07
do	B1-28 288 152	Cryptocrystalline quartz vein	.0007	.0014		.0003	.003	.003	0	0	.015	.003	0	0		0	.003	.07	.0007	.0015	0	.015	.07

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis 4/ Quantitative spectrographic analysis

TABLE 1-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS. (Page 2 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
Boomer mine, 8533-foot level, plate 13	B1-31 293 624	greisen	.02	.029		.0001	0	.003	0	0	.015	.005	.005	0		0	.005	.1	.002	.007	0	.02	.05
do	B1-32 293 625	quartz-beryl greisen	5.	4.9		.0005	0	.003	0	.015	.03	.005	.005	.01		.002	.007	.7	.007	.003	0	.03	.15
Boomer mine, 8518-foot level, plate 13	B2-4 278 782	Boomer vein, sparse sulfides	.15			.015	0	.007	.007	0	1.5	.0007	.007	0	4/ .031	.015	.003	3.	.0007	.007	d	.03	.7
do	B2-5 278 783	Boomer vein	.07			.0015	0	.003	.0015	0	.15	.0007	.007	0	4/ .12	.003	.003	.7	.0007	.0015	d	.03	.7
do, also fig. 20	B2-7-1 H 3242	quartz-muscovite greisen, hanging wall of -7-2	.0007			.00007	.0015	.003	0	0	.007	.003	0	0	4/ .009	0	.007	.03	.0007	.003	0	.015	.07
do, do	B2-7-2 H 3243	Boomer vein-fissure Muscovite-fluorite vein	.0015			d	.003	.015	0	0	.03	.007	0	0	4/ .051	.003	.003	.15	.0015	.015	0	.03	.15
do, do	B2-7-3 H 3244	quartz-muscovite greisen, footwall of -7-2	.0007			.0007	.0015	.007	.0007	0	.007	.003	0	0	4/ .018	.0007	.003	.15	.0007	.007	0	.007	.07
Boomer mine, 8486-foot level, plate 13	B3-3 288 023		.0003			.003	.003	.007	.003	0	.015	.003	0	0		.003	.003	.15	.0007	.003	0	.007	.07
do (Samples B3-5 to -10 are from one greisen)	B3-5 278 786	greisened granite	.0003			.0015	0	.003	.003	0	.007	.003	0	.003	.015	.03	.007	.15	.0007	.007	0	.015	.15
do	B3-6 278 784	quartzose greisen	.0007			0	0	.003	0	0	.007	.0015	.003	0	.03	.0007	.007	.03	.0007	.015	0	.015	.03
do	B3-7 278 785	Muscovite greisen 3.0-foot chip	.0007			0	.003	.007	0	0	.003	.007	<.005	0	.07	0	.007	.03	.0015	.03	0	.015	.03
do	B3-9 278 787	quartz-muscovite greisen	.0007			0	0	.007	0	0	.003	.003	.007	0	.15	.0015	.007	.07	.0015	.015	.015	.007	.03
do	B3-10 278 788	Fluorite-rich greisen	.0015			0	0	.015	0	<.05	.007	.003	0	0	.07	.03	.007	.15	.0015	.015	0	.03	.07
Boomer mine, 8486-foot level, plate 13	B3-12 278 789	Muscovite greisen 2.5±-foot chip	.0007			0	.003	.007	0	0	.0015	.007	0	0	.07	0	.007	.03	.0015	.03	.015	.003	d
do	B3-13 278 790	granite, disseminated sulfides	.0003			.007	0	.03	.0015	0	3.	.0007	.015	.003	.03	.0007	.003	.3	.0007	.007	0	.03	.15
do	B3-14 278 791	quartz-muscovite greisen 3.0-foot chip	.0007			.0007	0	.003	.0015	0	.07	.007	0	0	.03	.0015	.015	.15	.0015	.015	.015	.007	1.5
J+S No. 1 shaft plate 14	J+S-1-1 289 719	Beryllium-bearing greisen	3.	1.7		0	.003	.015	0	d	.003	.007	.0015	.007		0	.007	.15	.007	.015	0	.007	.07
do	J+S-1-2 289 720	do	.15	.18		d	.003	.015	.0015	d	.003	.003	0	.007		.0015	.003	.07	.0015	.015	0	d	.03
J+S No. 2 shaft plate 14	J+S-3-1 288 155	Altered pegmatite on hanging wall of dike 0.5' chip	.0003			.0003	0	.07	0	0	.015	.0015	0	0		0	.003	.15	.0015	0	0	.003	.03
do	J+S-3-2 288 156	greisen in footwall of dike, 1.5-foot chip	.15	.21		.0003	0	.007	.0015	0	.03	.007	0	.003		0	.007	.15	.003	.015	0	.015	.03
Blue Jay mine	S59-BJ-2 288 326	Vein	.003			d	0	.007	.0015	0	.03	.0007	.0015	0		.003	.003	.015	.0007	.0015	.015	.0015	0
do	S59-BJ-3 288 327	do	.0007			0	0	.015	0	0	.0007	.003	.0015	0		0	.003	003	.0015	.003	.007	.0015	<.02
Champell; Surface greisen N of shaft	Champell 278 779	greisen	.15			0	0	.03	0	.03	.03	.007	.007	.015	.15	.0007	.015	.007	.0015	.015	.03	.03	0

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis 4/ Quantitative spectrographic analysis

TABLE 1-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS (Page 3 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
Redskin mine Lower pipe	S60-RS-A 288 294	greisen	.7			.00015	.007	.015	.0015	0	.0015	.003	0	.003		0	.003	.015	.0015	.007	0	.007	.007
do Main pipe	S60-RS-B 288 295	do	1.5			.0007	.003	.015	.0015	.015	.015	.003	0	.015		.15	.007	.03	.003	.03	0	.003	.007
do Main pipe	S60-RS-C 288 296	do	.7			d	.003	.015	0	0	.0015	.003	0	0		.0007	.003	.007	.0015	.007	0	.003	.007
do Main pipe	RS-M1 288 297	do	.0015			d	.003	.07	0	0	.007	.007	0	0		.0007	.003	.003	.007	.03	d	.003	.007
do Main pipe	RS-M2 288 298	do	.003			.0007	.0015	.07	.0007	.015	.0015	.007	0	.007		.0007	.003	.03	.003	.03	0	.015	.007
do Main pipe	RS-M2a 288 299	Altered granite	.003			.0015	.0015	.03	.0015	.015	.07	.003	0	.007		.003	.003	.3	.0007	.007	0	.015	.015
do Main pipe	RS-M3 288 301	greisen	.07			.015	0	.015	.015	0	.07	.0007	0	.003		.0007	.0015	7.	.0007	.007	0	.003	.015
do Main pipe	RS-M3b 288 302	do	.0007			.0015	0	.015	.0007	.015	.003	.0007	0	.007		.007	.007	.3	.0007	.003	0	.007	.007
do Adjacent to lower pipe	RS-M9b 288 304	do	.15			0	.003	.03	0	.015	.0015	.0015	0	.007		0	.003	.007	0	.0015	0	.015	0
do Adjacent to lower pipe	RS-M11 288 305	do	.0015			0	.0015	.07	0	.015	.0007	.007	0	.007		.0007	.003	.003	.007	.03	0	.007	.007
do Shear zone on hanging wall, main pipe	RS-M62 288 306	Vein	.03			.0003	0	.007	.007	.015	.03	.0015	0	.007		.0007	.03	.03	.0007	.003	.03	.015	.007
do Main pipe	RS-M91a 288 307	greisen	.0015			.015	.0015	.07	.015	.015	.07	.007	0	.007		.007	.003	.3	.003	.015	.015	.007	.007
do Main pipe	RS-M91b 288 308	Quartz vein in greisen	.07			.0007	.0015	.03	0	0	.007	.003	0	0		0	.003	.015	.0015	.007	d	.0015	0
do Main pipe, about 110-feet from shaft	RS-M91c 288 309	Bertrandite-molybdenite greisen	7.			.0007	.003	.03	.003	.015	.015	.007	.003	.007		1.5	0	.03	.003	.015	0	.003	.007
do do	RS-M91d 288 312	Bertrandite-bearing greisen 0.7% U	7.			.0015	.003	.007	.003	.07	.15	.003	.003	.03		.15	.003	.07	.007	.007	0	.03	0
do Open cut, main pipe	RS-M-S1 288 310	Bertrandite-bearing greisen	7.			.003	.007	.015	.0015	.015	.07	.003	.007	.007		.15	.003	.3	.007	.007	.007	.003	.007
Upper pipe do	RS-B-1 288 311	Beryl(?)-bearing greisen	.3			.0003	.003	.03	0	.015	.015	.003	.007	.007		.015	.003	.07	.003	.015	0	.03	.015
Black Prince mine Open cut	S59-BPr-143a 288 322	Greisen	.0007			.0003	.003	.015	0	.015	.0007	.0015	0	.007		0	.003	.003	.0007	.003	0	.007	.015
do Main shaft	S59-BPr-143b 288 323	Chalcopyrite-bearing greisen	.003			.015	.0015	.03	.03	0	1.5	.007	0	.007		0	.007	1.5	.003	.015	.15	.007	.03
do Main shaft	S59-BPr-143c 288 324	Greisen	.0007			.0015	.0015	.015	.007	0	.7	.003	0	.007		0	.0015	.3	.0007	.007	0	.007	.015
Minerva J	S60-J-M1 288 313	Altered granite	.003			0	.0015	.03	0	.015	.0007	.003	0	.007		0	.003	.003	.0015	.007	0	.003	0
do	S60-J-M2 288 314	Bertrandite(?)-muscovite-rich greisen	.03			.015	0	.003	.3	0	.07	.003	0	0		.0007	.007	.15	0	.003	0	.007	.03
do	S60-J-M3 288 315	Greisen	.03			d	.0015	.015	.0015	0	.0015	.003	0	0		.003	.007	.007	.0015	.007	0	.003	.007
Minerva K	S60-Jo-1 288 316	Fluorite-rich greisen	.03			d	.003	.03	.0015	.03	.0015	.003	0	.03		.0015	.007	.015	.0015	.003	0	.015	0
do	S60-Jo-2 288 317	Muscovite greisen	.0007			0	.003	.015	0	.015	.0003	.0015	0	.015		0	.003	.0015	.0007	.003	0	.007	0

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis

TABLE I-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS (Page 4 of 4)

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
Mary Lee mine Incline, plate	ML-2 288 153	Sheer zone, granite contact 7.0-foot chip	.0015	.0018		0	0	.03	0	0	.003	.003	0	.003		0	.003	.007	.0007	.0015	0	.007	.03
do	ML-3 288 154	Altered granite	.0003			0	0	.007	0	d	.0015	.007	0	.007		0	.015	.007	.0007	.003	0	.007	.03
Mary Lee mine upper adit, plate	ML-4-2 H-3238	greisen on wall of ML-4-3	.0007			.00007	0	.007	0	0	.015	.003	0	.003		0	.003	.07	.0015	.007	0	.007	.03
do	ML-4-3 H-3239	Quartz-topaz vein	.0015			.0003	0	.003	.0015	0	.07	.00015	.003	0		.007	.0007	.15	0	.0007	0	.003	.03
do	ML-4-4 H-3240	greisen on wall of ML-4-3	.0007			.00015	0	.007	0	0	.07	.003	0	.007		.0015	.003	.15	.0015	.007	0	.007	.07
Happy Thought mine, dump sample, Incline	HT-1 289 735	Quartz-muscovite-fluorite greisen	.007	.008		0	.003	.007	0	d	.015	.007	0	.007	4/ .14	.0007	.0015	.03	.0015	.015	0	.015	.07
do	HT-2 289 736	Topaz-quartz greisen	.003	.005		.0003	d	.003	.0015	0	.07	.003	.003	0	4/ .051	.0015	.003	.3	.0015	.007	.03	.007	d
do	HT-3 289 737	Fine-grained greisen	.0015	.001		.0003	.003	.007	.0015	0	.03	.015	0	0	4/ .11	.0015	.0015	.07	.0015	.015	0	.015	.07
Happy Thought mine, Surface west of shaft	BA-167 288 002	Quartz-muscovite vein	.0015	.001		0	.003	.03	0	0	.0003	.0007	0	0		0	0	0	.0007	.003	0	.003	0

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis 4/ Quantitative spectrographic analysis

TABLE 2-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS. Samples from smaller mines and prospects (Page 1 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
1-1 (Plate 7)	TI-127A 304 812	Greisened granite	.002			0	0	.03	0	0	.0007	.007	0	.005		0	.01	.001	.0015	.01	0	.01	0
do	TI-127B 304 813	Granite cut by quartz-fluorite veins	.0005			0	0	.03	0	0	.00015	.003	0	.005		0	.005	.003	0	.002	0	.01	0
2-1	TI-170A 304 814	Gray, quartz-muscovite greisen	.001			0	0	.05	0	.02	.0005	.005	0	.01		0	.005	.0015	0	.007	0	.01	0
do	TI-170B 304 815	Yellow, quartz-muscovite greisen	.001			0	.003	.1	0	0	.0003	.007	0	.007		0	.005	.0015	.001	.01	0	.01	.03
3-1	BA-1006 304 816	Greisened granite	.0015			0	0	.07	0	0	0	.01	0	0		.0005	.015	.01	.003	.1	0	.007	.03
3-2	BA-1019 304 817	Gray quartzose greisen	.0007			0	0	.007	0	.05	.003	.0007	0	.015		0	.005	.001	0	.0015	0	.007	0
3-3	TI-29A 293 628	Micaceous greisen, dump	.015			0	0	.05	.003	0	.002	.007	0	.007		.002	.007	.015	.003	.02	0	.015	.03
do	TI-29B 293 629	Quartzose greisen, dump	.05			.0001	0	.005	.0005	0	.0015	.002	0	0		.0007	.0015	.005	0	.002	0	.003	0
do	TI-29C 293 630	Hematitic fault gouge	.0015			.0001	0	.02	0	.05	.0015	.005	0	.03		0	.01	.02	.0007	.005	0	.02	0
do	TI-29D 293 631	Soft micaceous greisen in pipe	.0015			0	0	.05	0	.15	.0015	.007	0	.07		0	.005	.005	.0015	.03	0	.015	0
4-1 (see 9-2) Hope claim	S60-8 288 277	Quartz-muscovite greisen	.0007			0	.003	.015	0	.03	.0015	.007	0	.007		0	.003	.007	.0015	.015	0	.007	<.02
5-1 Lower Hazel Marie Surface samples, taken before mining	S60-70B 288 336B	do	0.7			d	.003	.0015	.003	0	.003	.003	.003	.003		.007	.003	.03	.007	.0015	0	.015	0
do	S60-70 288-287	Greisen	.0015			d	.003	.003	.0015	0	.0007	.015	0	.003		0	.003	.007	.003	.015	0	.015	.007
do	TR-66A 287 982	Altered granite	.0007			0	0	.007	0	0	.0015	.007	0	0		0	.003	.0015	.0007	.015	0	.0015	0
do	TR-66B 287 983	Micaceous greisen	.0007			0	.003	.007	0	0	.0007	.007	0	0		0	.003	.003	.003	.015	0	.003	0
do	TR-66C 287 984	Quartz-fluorite-muscovite greisen	.007			0	0	.007	0	0	.0003	.003	0	0		0	.0015	0	.0007	.007	0	.015	0
do	TR-66D 287 985	Hematitic greisen	.0015			.00015	0	.015	0	.03	.007	.007	.003	.007		0	.015	.15	.007	.015	0	.03	.03
5-2 Upper Hazel Marie Surface sample	S60-36 288 280	do	.0007			0	.0015	.015	0	0	.0007	.003	0	.003		0	.0015	.015	.0007	.007	0	.003	0
5-3	BA-937 293 641	Vuggy, quartzose greisen	.0005			0	0	.007	0	0	.0007	.003	0	0		0	.0015	.007	0	.005	0	.003	0
9-1	BA-583 293 635	Fluorite vein	.0003			.0003	0	.0015	0	<.05	.002	0	0	0		0	0	.015	0	0	0	.007	0
9-2 Hope claim	S60-23 288 336A	Quartz-beryl vein	.07			0	.003	.015	0	0	.0007	.003	0	.003		0	.003	d	.0015	.003	0	.003	0
10-1 Minerva O	S60-O-1 288 325	Micaceous greisen	.0015			0	.003	.07	0	0	.0015	.007	0	.007		0	.003	.003	.003	.015	0	.007	0
10-2 Minerva N	S60-N-1 288 318	Greisen	.015			.00015	.0015	.015	0	.015	.03	.0015	0	.007		0	.003	.007	.0007	.003	0	.007	.007
do	S60-N-2 288 319	Quartz-bertrandite-muscovite greisen	7.0			0	.03	.003	0	0	.0007	.003	.003	0		0	.0015	.003	.0007	.007	0	.003	.007

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis

TABLE 2-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS (Page 2 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
10-2 Minerva N	S60-Nb-1 288 320	Greisen	.003			0	.0015	.015	0	.015	.0003	.003	.007	.007		0	.003	0	.0015	.007	0	.015	<.02
do	S60-Nb-2 288 321	Fine-grained greisen cut by quartz-euclase	0.7			0	.003	.003	.0007	0	.0015	.0015	.0015	0		0	.0015	.0015	.0007	.0015	0	.007	.007
11-1 Minerva I	S60-I-1 288 292	Greisen	.0015			.03	0	.07	.07	0	.15	.007	0	.003		.0003	.003	>10	.003	.015	0	.007	.015
11-2	T1-17 293 627	Fluorite vein	.003			0	0	.0015	0	<.05	.0005	0	0	0		0	0	.05	0	0	0	.1	0
14-1	S60-38 288-281	Muscovite greisen	.0007			0	.003	.07	0	.015	.0003	.007	0	.007		.0003	.003	.003	.003	.015	0	.007	.007
	T1-7 288 021	Quartz-muscovite greisen	.0007			.00015	0	.03	0	d	.015	.007	0	.007		.003	.003	.015	.0015	.015	0	.015	.03
14-2	S60-40 288 283	do	.0007			d	.003	.03	0	0	.003	.007	.003	.003		0	.0015	.007	.0015	.015	0	.015	.015
	T1-5 288 020	do	.0007			.0003	0	.3	0	0	.07	.007	.003	.003		.0015	.007	.015	.0015	.015	0	.015	.07
14-3	T1-8 288 022	do	.0007			.0003	0	.03	0	d	.0007	.007	0	.007		0	.003	.003	.003	.007	0	.015	d
14-4	BA-691 293 636	Greisen	.002			0	0	.05	0	.1	.0015	.005	0	.07		0	.007	.002	.001	.005	0	.007	0
14-5 Minerva D + E	S60-D-1 288 293	do	.007			.0007	0	.07	0	.015	.007	.007	0	.007		.003	.003	.07	.007	.015	0	.007	<.02
15-1	BA-569B	Greisened aplite dike																					
15-2	S60-33b 288 279	Gray, quartz-muscovite greisen	.0003			d	.003	.007	0	0	.007	.003	.007	.003		0	.003	.3	.0007	.007	0	.03	.015
15-3	BA-545B 293 633	do	.003			0	0	.007	0	0	.0015	.005	0	0		0	.007	.007	.0007	.015	0	.007	0
	S60-33 288 278	Yellow, quartz-muscovite greisen	.0007			d	.007	.007	0	.03	.0007	.003	.003	.007		0	.0015	.03	.0007	.015	0	.015	0
	BA-545A 293 632	do	.0007			.0002	.002	.007	0	0	.003	.005	0	0		.007	.007	.03	0	.005	0	.01	0
	BA-545C 293 634	Quartz-topaz greisen	.0007			.0015	.005	.01	0	0	.005	.003	.005	0		0	.003	1.0	.0007	.007	0	.02	0
15-4 Jacob Kolle	S60-35 288 269	Fluorite vein	.00015			.0003	0	.003	0	-	.07	.0003	0	0		.007	0	1.5	0	0	0	.03	<.02
15-5	S60-10 288 267	do	0			0	0	.0007	.0007	-	.0003	0	0	0		0	0	.003	0	0	0	.03	<.02
15-6	S60-9 288 266	do	.00015			.00007	0	.007	0	-	.0003	.00015	0	.003		0	0	.03	0	0	0	.03	<.02
16-1	S60-69 288 273	Greisened biotite-muscovite granite	0			d	0	.07	0	0	.0007	.0007	0	0		0	.0007	.007	0	0	0	.0007	<.02
16-2	S60-59A 288 271	do	.007			0	0	.15	0	0	.0003	.0015	0	.003		0	0	.007	.0007	.003	0	.003	<.02
16-3	S60-59 288 276	Altered calc-silicate gneiss	.007			0	.0015	.07	0	.015	.0003	.0015	0	.007		0	0	0	.0015	.007	0	.0015	0
16-4	S60-21a 288 274	do	.0015			d	.0015	.003	.003	-	.0003	.0007	0	.003		0	0	.015	.003	.015	0	.0007	.03
	S60-21g 288 270	Greisened biotite-muscovite granite	.015			d	0	.15	0	0	.0007	.0015	0	0		0	0	.007	.0007	.003	0	.0015	<.02

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis

TABLE 2-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS (Page 3 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
17-1	S60-27 288 275	Altered calc-silicate gneiss	.015			d	.0015	.007	.015	-	.0007	.0015	0	.007		0	0	.007	.0015	.07	d	.003	.015
21-1	BA-532 289 728	greisen	.0015	.0013		0	.003	.03	0	0	.0003	.003	0	0		0	.0015	0	.0015	.015	0	.0015	0
21-2	BA-25 278 799	greisened aplite	.003			0	0	.015	0	d	.003	.003	0	.007		0	.003	.003	0	.007	0	.003	0
21-3	BA-525 289-727	greisened aplite and coarse quartz-muscovite greisen	.003	.0020		0	0	.015	0	0	.003	.003	0	0		0	.003	.0015	.0015	.007	0	.003	0
21-4	BA-24 278 798	quartz-pyrite vein	.0007			.0007	0	.03	.0015	0	.7	.0007	0	.003		.0007	.0015	.07	0	.007	0	.003	.07
21-5	I-8A 278 802	greisened pegmatite	.003			0	0	.07	0	0	.0015	.003	0	0		0	0	.0015	0	.015	0	.003	0
21-6	I-20 278 805	greisened aplite	.007			0	0	.015	0	d	.0015	.007	0	.007		0	.003	.003	.0007	.015	0	.003	0
21-7	BA-19 278 797	Limonitic gossan	.0003			0	0	.015	0	0	.7	0	0	0		.007	0	.003	0	.003	0	.0015	0
21-8	BA-301 288 007	Thin greisen vein in pegmatite	.0007			0	0	.03	0	0	.0007	.0015	0	0		0	0	0	.0007	.007	0	0	0
21-9	BA-152 289 725	greisen	.003			0	0	.07	0	.07	.0007	.007	0	.03		0	0	.007	.0015	.03	0	.0015	0
21-10	BA-239 288 004	do	.0007	.0008		0	0	.07	0	0	.0007	.0015	0	0		0	0	0	.0007	.015	0	0	0
21-11	BA-240 288 005	do	.0007			0	0	.07	0	0	.007	.003	0	0		0	0	.003	0	.015	0	.0015	0
21-12	BA-138 288 001	do	.0007			0	0	.015	0	0	.0007	.003	0	0		0	.003	.003	.0015	.015	0	.0015	0
22-1	BA-385B 288 013	do	.0015			0	0	.007	0	0	.0015	.0015	0	.003		.0007	.0015	.007	.0015	.007	0	.003	0
22-2	BA-190 288 003	quartz vein, greisened walls	.0003			0	0	.003	0	0	.015	.0015	0	0		0	.0015	0	.0007	.15	0	0	0
22-3 Shaft on Mary Lee vein	BA-62 287 994	quartz-topaz vein, greisened walls	.0003			.0007	0	.015	.003	0	.015	.0015	0	0		0	0	.15	.0007	.003	0	.0015	.03
22-4	BA-470A 288 015	Beryl-bearing greisen	.015	.014		0	0	.003	0	0	.015	.0015	.0015	.003		.0007	0	.15	.0007	.007	0	.003	0
do	BA-470B 288 016	Same vein, 1.0-foot chip across vein	.0007			.0003	0	.007	0	.03	.03	.003	0	.015		.003	0	.3	.0007	.007	0	.015	d
22-5	BA-473 288 017	greisen	.0007			0	0	.03	.03	0	.003	.0007	0	.003		0	.0015	.0015	.0007	.007	0	.007	0
22-6	BA-351A 288 010	Muscovite-rich greisen	.0015			0	0	.03	0	d	.0007	.003	0	.007		0	0	0	.0015	.03	0	.003	0
do	BA-351B 288 011	Quartzose greisen	.003			0	0	.03	0	0	.0007	.003	0	.007		0	.0015	0	.0015	.03	0	.003	d
22-7 Little John group	BA-352 289 726	1½-inch quartz-beryl vein	1.5	1.1		0	0	.007	0	d	.003	.0015	0	.007		.0015	0	.03	.003	.007	0	.003	0
22-8	BA-408 288 014	Hematitic quartz-muscovite-fluorite greisen	.0007	.001		0	0	.03	0	0	.0007	.0015	0	0		0	0	0	.0007	.015	0	.0015	.007
22-9 Little John 1 shaft	BA-399 288 336	greisen	.0007			.0007	0	.03	.003	0	.015	.0015	0	0		.0015	.0015	.07	.0007	.015	.15	.003	0
22-10	BA-336 288 008	greisen	.0015			0	0	.03	.0015	0	.0015	.003	0	0		0	.0015	.0015	.0015	.03	0	.007	0

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis

TABLE 2-C. TRACE ELEMENT COMPOSITION OF ORES AND GREISENS. (Page 4 of 4).

SAMPLE LOCATIONS	FIELD AND LABORATORY NUMBERS	DESCRIPTIONS	1/ Be %	2/ Be %	3/ Be %	Ag	B	Ba	Bi	Ce	Cu	Ga	Ge	La	Li	Mo	Nb	Pb	Sc	Sn	W	Y	Zn
						Semiquantitative spectrographic analyses (percent)																	
23-1	BA-772A 293 638	Fluorite vein	.0003			.001	0	5.0	0	<.05	.015	0	0	0		.007	0	>10	0	0	0	.015	.05
do	BA-772B 293 639	greisen	.001			0	0	.07	0	.07	.001	.005	0	.03		0	.005	.02	.0015	.007	0	.01	0
23-2 Silverdollar vein	S60-17 288 268	Fluorite vein	.00015			.00015	0	.007	.0015	-	.015	0	0	0		.15	0	3.0	0	0	0	.03	<.02
23-3	BA-763 293 637	greisen associated with quartz-beryl vein and pegmatite	.001			.0001	0	.05	.001	.015	.0015	.005	0	.01		.0015	.007	.007	0	.007	0	.007	0
23-4	BA-536 289 729	greisen	.003	.0025		0	.003	.015	0	0	.003	.003	0	0		0	.015	.007	.0015	.007	0	.007	0
27-1	BA-356 288 009	1-inch quartz vein, greisened walls	.0003			0	0	.03	0	0	.0015	.0015	0	.003		0	.0015	0	.0007	.03	0	.0015	0
28-1	BA-250 288 006	greisen	.0007			0	0	.03	0	0	.0015	.003	0	0		0	.0015	.0015	.0015	.03	0	.003	0
28-2	BA-37D 289 724	greisened graphic granite	.0007			0	0	.07	0	0	.0007	.0007	0	0		0	0	.0015	.0007	.015	0	0	0
28-3	BA-244B 288 334	greisen	.0007			0	0	.03	0	0	.0015	.0015	0	0		.0007	.0015	.007	.0007	.015	.007	.0015	0
do	BA-244C 288 335	greisen, 1-foot vein	.0007			0	0	.03	0	0	.0015	.003	0	0		.0007	.0015	.0015	.0015	.015	.015	.0015	0
28-4	BA-50 287 993	greisen	.0007			0	0	.015	0	0	.0015	.003	0	.003		0	.0015	0	.0007	.015	0	.0015	0
28-5 do	BA-108C 287 999	Vein, greisened walls	.0007			0	0	.07	0	0	.015	.003	0	.003		0	.0015	0	.0007	.03	0	.003	0
	BA-108D 288 000	Massive pyritic greisen	.0007			0	0	.07	0	0	.07	.0015	0	.003		0	.0015	.007	.0007	.03	0	0	0
28-6 do	BA-104A 287 995	greisen, hard, micaceous	.0007			0	.003	.07	-	0	.003	.0015	0	0		0	0	.003	.0007	.03	0	0	0
	BA-104B 287 996	quartz-musovite-fluorite greisen	.0003			0	0	.015	-	0	.0007	0	0	0		0	0	0	0	.015	0	.003	0

1/ Semiquantitative spectrographic analysis 2/ Morin-fluorescent analysis 3/ Activation analysis


EXPLANATION
Porphyritic facies