Occurrence of Nonpegmatite Beryllium in the United States

GEOLOGICAL SURVEY PROFESSIONAL PAPER 318

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By LAWRENCE A. WARNER, WILLIAM T. HOLSER, VERL R. WILMARTH
and EUGENE N. CAMERON

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THE OCCURRENCE OF NONPEGMATITE BERYLLIUM IN THE UNITED STATES

By LAWRENCE A. WARNER, WILLIAM T. HOLSER, VERL R. WILMARTH, and EUGENE N. CAMERON

ABSTRACT

The demand for beryllium in industry increased rapidly during and after World War II, establishing a trend that is likely to continue. Production of beryl from pegmatites, the only present source of beryllium, has lagged far behind annual consumption in the United States, and even with heavy imports, an adequate domestic supply has not been assured. This condition has directed attention to nonpegmatite deposits. During the period 1948–50 the U. S. Geological Survey conducted a program of field, laboratory, and library research to determine the occurrence and distribution of beryllium in nonpegmatite rocks and mineral deposits, and to appraise the extent to which these might furnish beryllium ore. Although no deposits of present commercial value were found, the investigation has set criteria that will be of value in future prospecting.

The average beryllia content of the lithosphere is about 0.001 percent. Beryllium is thus more abundant than certain other metals, such as arsenic, gold, silver, tungsten, and molybdenum. Unlike these elements, however, beryllium does not readily form sulfides and oxygen salts, which constitute the bulk of metalliferous ores. Because of its small ionic radius, resulting low coordination number, and strongly electro-positive character, crystal structures that will permit high concentrations of beryllium in minerals are comparatively rare. It forms only a few stable minerals of its own, such as beryl, helvite, chrysoberyl, and phenakite. In other silicates, including the common rock minerals, it may replace elements such as silicon and aluminum to a slight extent. Under special conditions, as when it fills normally empty lattice positions in idocrase, it may be present in appreciable quantity.

As an accessory constituent in rock minerals, beryllium is somewhat more common in granitic and feldspathoidal rocks than in other igneous rocks. Its principal occurrence is in beryl in granitic pegmatites. Other than in pegmatites, beryllium minerals are found chiefly in quartz-tungsten veins and pyrometasomatic deposits. Small amounts also occur in other types of veins, particularly quartz-gold and manganese veins. In most of these occurrences beryllium is found with fluorite; in pyrometasomatic deposits it sometimes occurs with fluorine-rich beryllian idocrase.

Many sedimentary rocks contain small quantities of beryllium, particularly those formed by residual concentration, as the metal hydrolyzes in a manner similar to aluminum. For the most part, however, beryllium tends to be dissipated by processes of weathering and sedimentation. Under simple metamorphic conditions, beryllium is not easily mobilized, and therefore it is not concentrated in metamorphic rocks other than pyrometasomatic deposits.

Pyrometasomatic deposits and feldspathoidal rocks were sampled at many localities in the United States. Only a small proportion of the pyrometasomatic deposits contained detectable quantities of beryllium; the richest are the deposits at Iron Mountain, N. Mex. In the feldspathoidal rocks beryllium was found only as an accessory constituent in rock minerals.

Some of the vein deposits investigated have promise as possible sources, but sampling was not sufficiently detailed to furnish a basis for calculating reserves. In places the beryllium content compares favorably with that of beryl pegmatites. Mining of these deposits will depend on an increase in price of beryllium, improved beneficiation methods, and utilization of coproducts and byproducts.

INTRODUCTION

NATURE AND PURPOSE OF REPORT

Technological developments during the past decade have greatly increased the demand for many minor metals. Beryllium, because of its peculiar properties, has come to assume great strategic importance. Special alloys containing beryllium are in wide demand in modern industry and their use is restricted chiefly by the short supply and relatively high cost of beryllium metal.

Beryl-bearing pegmatites, so far as known in mid-1956, constitute the only commercial source of beryllium. Because high-grade domestic reserves are small, the United States has been forced to import most of the beryl it uses. Recently attention has been focused on rocks other than pegmatite as potential sources of beryllium. During the past century many beryllium-bearing minerals have been reported from a variety of rocks and mineral deposits. Only a few of these minerals are common and many are exceedingly rare. However, beryllium is evidently much more widely distributed in the rocks of the earth than had been assumed previously, a discovery that suggests the possibility of locating new sources of supply.

A program of field, laboratory, and library research to formulate workable criteria that might be used in the search for beryllium ore in nonpegmatite rocks was begun in 1948 by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. It had as its objectives (1) to obtain information on the distribution, grade,

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and size of domestic deposits of beryllium in nonpegmatite rocks, (2) to determine the types of rocks and mineral deposits most likely to contain beryllium, and (3) to suggest favorable areas for prospecting. The results of these investigations are set forth in this report.

During the early stages of the fieldwork, all types of rocks and mineral deposits were regarded as potential sources of beryllium, and materials of wide variety were sampled and tested spectrographically. Special attention was given to those types that were thought to be most promising on the basis of earlier investigations. Much of the material regarded as beryllium bearing in this report is too low in grade to be commercial by present standards. However, the consistent presence of beryllium in certain types of deposits, even though in very small amounts, seems to mark these for further study, and its consistent absence in certain other types of material seems to exclude these.

RECOVERY, PROPERTIES, AND USES OF BERYLLIUM

Beryllium was discovered in 1798 in beryl by L. N. Vanquelin, and in 1828 Wöhler and Bussey succeeded in isolating the metal (Parsons, 1909, p. 77). Processes for the preparation of beryllium, except on a laboratory scale, were not developed until late in the 1920's. Since then the price of the metal has decreased from $200 to an average of less than $100 per pound. Beryllium metal is produced by the Beryllium Corporation of America at Reading, Pa., the Brush Beryllium Company of Cleveland, Ohio, and the Clifton Products Company of Painesville, Ohio. Details of beryllium metallurgy are given by Kroll (1945) and Kawecki (1946).

Beryllium is a metallic element belonging to the alkaline-earth family, which constitutes group 2 of the periodic table of Mendeleeff. It has many properties in common with other members of this group, which includes magnesium, calcium, strontium, barium, and radium. It also closely resembles aluminum in chemical behavior.

Pure beryllium is rather brittle but can be hammered, forged, rolled, and polished. It may be alloyed with many other elements, of which copper and aluminum are the two most commonly used. Its hardness, depending on the amount of impurities, ranges from 6 to 7 on the Mohs scale. It is one of the lightest metals, the specific gravity being 1.85, as compared to 1.75 for magnesium and 2.7 for aluminum. Other valuable properties of the metal are a high modulus of elasticity, a low electrical conductivity as compared with common metals, and a high resistance to heat and corrosion. Beryllium has the lowest atomic weight of any element that is crystalline at normal temperatures and, therefore, absorbs few X-rays; this makes it useful as windows on X-ray tubes. Because beryllium also has a low absorption cross section for neutrons, it is comparable to deuterium and graphite as a moderator and reflector in atomic piles (Smyth, 1945, p. 62).

Besides slowing neutrons without absorbing them, beryllium produces neutrons more easily than any other element, when excited with gamma or other radiation (Russell and others, 1948). The reaction is as follows:

$$Be^9+\gamma>1.65 \text{ mev} \longrightarrow Be^8+n;$$

$$Be^8 \xrightarrow{10^{-13} \text{ sec}} 2\ He^2.$$

It is used as a neutron source in laboratories and in neutron logging of wells.

Beryllium imparts to its alloys lightness, hardness, strength, and resistance to heat and corrosion. When alloyed with aluminum, magnesium, and zinc, it forms a protective coating of beryllium oxide on the surface of the metal. Beryllium-aluminum alloys have promise in high strength-high temperature applications where lightness is important (Raynor, 1946). Beryllium-copper, one of the most useful alloys of beryllium (Yarham, 1945; Williams, 1946), combines high electrical conductivity with high strength and is used extensively in current-carrying springs, in telephone equipment, and in pressure gages, as well as in bushings, cams, and sleeves. A beryllium-copper alloy with nonsparking qualities is used in the explosive and petroleum industries where dangerous dust or vapor conditions exist. A beryllium-copper-cobalt alloy that combines high electrical conductivity with heat resistance has recently become important in the manufacture of electrical equipment.

Because beryllium oxide melts at 2,570°C and is resistant to corrosion, it has been used to some extent in crucibles and electric furnace parts. Beryllium nitrate added to thorium nitrate solution is used in the manufacture of gas mantles, to strengthen the oxide skeleton. Beryllium stearate is used in printing inks, beryllium nitride in making C^{13}, and other beryllium salts are used in pharmaceutical preparations. If beryl is substituted for feldspar in the manufacture of porcelain, the product has high electrical resistance and low thermal expansion, properties that are necessary in airplane spark plugs. Emerald and aquamarine, transparent varieties of beryl, are highly valued as gem stones.

PRODUCTION OF BERYLLIUM ORE

In mid-1956 the only known commercial source of beryllium is beryl, mined from granite pegmatites and recovered by hand sorting. In 1951 the world production of beryl concentrates totaled about 50,000 tons. Nearly all of this amount was produced between 1930 and 1951 and more than two-thirds from 1940 to 1951. Foreign production is chiefly in Brazil and Argentina, though India and Australia have at times contributed substantial amounts. In the United States, the Black Hills region of South Dakota is the main producing area. Beryl has been mined also in New England, Colorado, Virginia, North Carolina, Arizona, and New Mexico.

The status of the United States with respect to beryl supply is summarized diagrammatically in figure 1. Domestic production and imports of beryl in relation to world supply are shown for the period 1936–51. The dependence of the United States upon foreign sources is clearly indicated. Since 1940 the United States has produced and imported, on the average, somewhat more beryl than it has consumed, but current trends indicate that this surplus may be reduced in the future unless domestic production is increased.

Known reserves of coarse beryl ore are small, and any marked increase in supply must come from deposits of a milling type. The U. S. Bureau of Mines has experimented with methods of beneficiating low-grade beryl ore and results are encouraging (Lamb, 1947; Sneddon and Gibbs, 1947; Kennedy and O'Meara, 1948). Fatty-acid reagents are used in a flotation process to separate beryl from other minerals. High recovery has been obtained from ores containing more than 0.35 percent BeO, and fair recovery from ores containing less than that amount, some as little as 0.08 percent. Helvite responds to similar treatment. Feldspar, mica, and other minerals may be recovered as coproducts.

Quantitative spectrographic analyses for beryllium were made under contract to the U. S. Geological Sur-

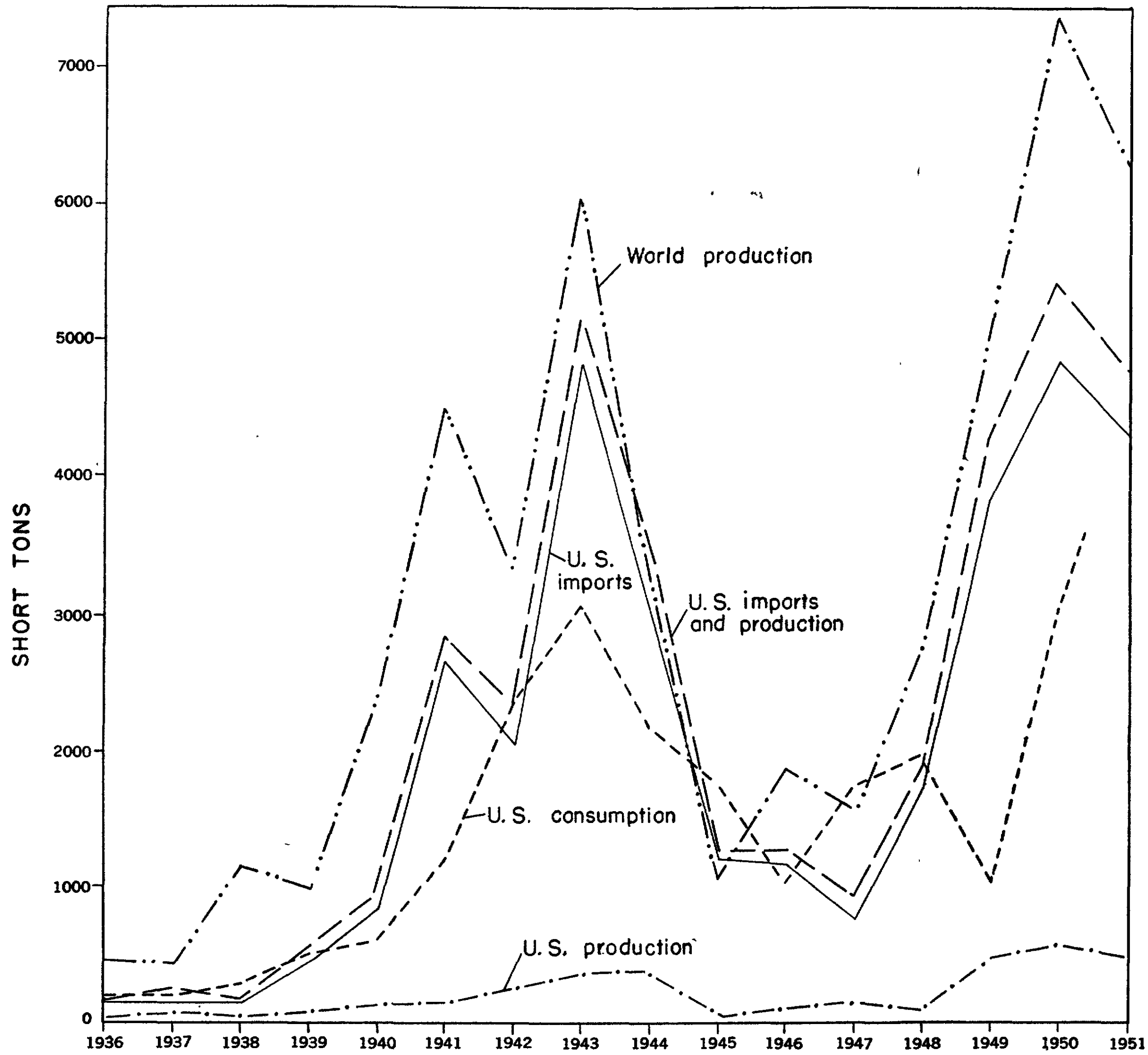

FIGURE 1.—Production, imports, and consumption of beryl in the United States, and total world production.

vey by the Saratoga Laboratories, Inc., and the Strock Laboratories, Inc., of Saratoga Springs, N. Y., and by the National Spectrographic Laboratories of Cleveland, Ohio; check samples were also analyzed by the Geological Survey. All semiquantitative spectrographic and chemical analyses were made in the laboratories of the Geological Survey.

ACKNOWLEDGMENTS

Without exception we found owners and operators of mining properties cooperative in making available samples and geological information. The officials of the American Smelting and Refining Co., Tucson, Ariz., the Coronado Copper and Zinc Co., Johnson, Ariz., and the New Jersey Zinc Co., Franklin, N. J., made available some of their own analyses for beryllium and other elements. L. H. Bauer of the New Jersey Zinc Company, James Gilluly of the U. S. Geological Survey, D. M. Henderson of the University of Illinois, F. A. Hildebrand of the University of Chicago, V. C. Kelley of the University of New Mexico, R. G. Knickerbocker of the U. S. Bureau of Mines, E. S. Larsen, Jr., of Harvard University, M. D. Lyons of Beryl Ores Co., J. H. C. Martens of the New Jersey Bureau of Mineral Research, and officials of Climax Molybdenum Co., the Anaconda Copper Mining Co., and the Utah Copper Co. generously supplied samples and specimens from localities that we were unable to visit in the field. Messrs. D. M. Henderson, C. T. Griswold of Albuquerque, N. Mex., and D. S. Tedford of Columbus, N. Mex., were particularly helpful in supplying unpublished results of their geologic mapping.

We are grateful to the University of Colorado, Cornell University, the University of Wisconsin, and the New Mexico Bureau of Mines and Mineral Resources for the facilities lent us.

FIELD INVESTIGATIONS

PREVIOUS WORK

Most information about the occurrence of beryllium in rocks has come from geochemical studies of trace elements. The pioneer work on the geochemistry of beryllium was that of Goldschmidt and Peters (1932), who concluded from their spectrographic studies of many rocks that the beryllium content of granites and syenites tends to be noticeably greater than that of olivine-bearing and other mafic rocks, and that beryllium is found commonly in the contact metamorphic products of calcium-rich sedimentary rocks, notably in such minerals as idocrase and axinite. They noted the apparent similarity of beryllium to aluminum in the processes of weathering and sedimentation, and their later studies indicated the presence of small amounts of beryllium in English and German coals (1933). Earlier, Washington (1931) had pointed out the possibility that beryllium had been overlooked in many chemical analyses of rocks, particularly nepheline syenites. Other studies were made by Tolmacev and Filippov (1934), Zilbermintz and Rusanov (1936), Szelenyi (1937), Oftedal (1939), Sahama (1945a), and Rankama (1946).

In the United States Sandell and Goldich (1943) studied the minor elements in igneous rocks, including the beryllium content of nine samples of granitic rocks. During World War II the U. S. Geological Survey collected a large number of samples from mines and mills throughout the country, most of which were analyzed spectrographically for beryllium and other rare elements (Kaiser and others, 1954).

References to the occurrence of beryllium-bearing minerals are numerous in geological literature. Beryl and phenakite have been reported from quartz veins at many localities throughout the world, and helvite has been noted in several manganiferous veins and in contact metamorphic deposits. Some idocrase and allanite have been found to contain beryllium, and minor amounts have been reported in garnets, micas, and many other minerals. Before the present work, the only nonpegmatite beryllium deposits in the United States that had been studied in detail were those at Iron Mountain, N. Mex. (Jahns, 1944a, 1944b; Glass and others, 1944), where minerals of the helvite group occur rather abundantly in unusual tactite deposits.

Information concerning the occurrence of beryllium was summarized by Fleischer and Cameron (1946), who suggested that in addition to pegmatites, potential sources of beryllium include contact-metamorphic zones, alkalic intrusive rocks, coals, and bauxite deposits.

PRESENT WORK

SCOPE OF INVESTIGATIONS

With the aid of clues to the occurrence of beryllium suggested by earlier investigations, a field program was planned which would enable investigation of as many favorable areas as possible. Time did not permit sampling of all the localities that were considered, but those sampled are sufficiently numerous and widespread to be considered representative. Fieldwork was done during August-November 1948 and June-September 1949. A total of 23 man-months was spent in actual field work in connection with this program.

In August 1948, alkalic intrusive rocks of Tertiary age in western Texas and southern New Mexico were investigated by Holser and Wilmarth. During September, October, and November, 1948, fieldwork was continued in Colorado, Wyoming, Arkansas, and the Tri-State lead-zinc region by Warner and Wilmarth. In the winter of 1948–49 samples collected in 1948 were analyzed for beryllium and studied mineralogically. The results were used to plan fieldwork for 1949.

The program was expanded in 1949 in order to investigate areas in Nevada, California, Utah, Montana, and Arizona, as well as to continue activities in areas previously studied, and three parties consisting of two men each were actively engaged in fieldwork. Holser and W. I. Finch returned to western Texas for detailed mapping of two alkalic intrusive bodies, and investigated many localities in Arizona and New Mexico, spending 2 months in the field. Work in Colorado and Wyoming was carried on during July and August by Wilmarth and P. L. Cloke. Cameron and J. H. Macleod spent 6 weeks investigating a number of mining districts in Nevada, California, and Utah. The fieldwork was concluded by Warner and Wilmarth who investigated several mining districts in central Montana and near Salt Lake City, Utah, in September 1949. Several localities in New England were visited by Holser in May 1950. During the winter of 1949–50 analytical and mineralogical work was continued, and compilation of results begun.

FIELD METHODS

In planning the field program, a choice had to be made between sampling a few localities in great detail or a larger number of areas somewhat superficially; the latter alternative was chosen. This imposed many difficulties in obtaining representative samples. Some of the deposits selected for sampling are large and extremely variable. Literally hundreds of samples might be needed at each deposit to obtain a reliable estimate of the beryllium content. Many of the localities visited are so isolated that only a few samples could be removed conveniently. In deposits consisting of alternating layers of many types of material, a composite sample of the whole would be of little value in determining the beryllium-bearing type; yet sampling each layer individually requires much time and care. It is doubtful that beryllium-bearing minerals are evenly distributed through the containing rock masses. A sample taken at a point where the concentration of such minerals is relatively high might indicate a potential ore body, whereas one taken a short distance away might contain no beryllium even though the differences between the two materials might not be distinguishable in the field. Both would give an erroneous impression of the average contents. For these reasons, many of the samples that were analyzed probably were not truly representative, and future sampling in the same localities may give significantly different results.

Three general methods of sampling were employed. Grab sampling, which consists of gathering pieces of material at random, was used at large mine dumps and mill tailings ponds. Channel sampling, which consists of cutting continuous strips of rock along preferred lines, was done mainly in mine openings. Because of the time consumed in this method, it was employed in relatively few places. Chip sampling, in which chips are taken along preferred lines, was used in sampling large exposures.

In active mining districts, samples of the mill products were obtained wherever possible, as well as samples of ore and waste rock from the operating mines. At abandoned mines, an attempt was made to obtain representative samples of the different types of material observed on the dumps. An effort was made in sampling rock types to include all significant varieties noted in the field. Many hand specimens of rocks and minerals were collected for laboratory study in event the bulk samples proved to contain beryllium.

The field program was designed to obtain information concerning the beryllium content of a variety of rocks and mineral deposits throughout the United States in the shortest possible time. The amount of time that could be devoted to detailed geologic mapping was therefore small. For the most part, when geologic maps were not available for areas where samples were obtained, sketch maps were made showing the more pronounced geologic and cultural features. Topography and geology of areas at Wind Mountain in the Cornudas Mountains, Otero County, N. Mex., and Cave Peak in the Sierra Diablo, Culberson County, Tex., were mapped in detail by planetable.

DETERMINATION OF BERYLLIUM

SPECTROGRAPHIC ANALYSIS

The spectrographic method appears to be the most reliable for quantitative determination of small amounts of beryllium in rocks and minerals. A general discussion of the method is given by Peer (1943), and the application of the method to ore samples has been investigated by Marks and Jones (1948). The lower limit of accurate spectrographic determinations is in the range 0.005 to 0.0001 percent BeO. The equipment required is expensive and complicated, and trained technicians are needed to interpret the results. Spectrographic analyses of samples collected in the present investigation were made in part by the Geological Survey laboratories, and in part by the National Spectrographic Laboratories, Cleveland, Ohio, and Strock Laboratories, Inc., Saratoga Springs, N. Y.

GRAVIMETRIC AND VOLUMETRIC ANALYSIS

Beryllium as a trace constituent in rocks and minerals cannot be determined quantitatively by gravimetric or volumetric methods of analysis, as the lower limit for BeO of these methods is approximately 0.01 percent. Beryllium will generally be precipitated with aluminum unless special precautions are taken, and in many analyses it has been calculated with that metal. The problem of separating beryllium and aluminum has been a challenge to analytical chemists for many years, as is indicated by the extensive literature on the subject. Special techniques must be employed also in the removal of iron, lest some beryllium be lost in the process. Any quantitative separation of beryllium should be verified by spectrographic analysis of residues.

A gravimetric method for determining beryllium in rocks and minerals containing a few hundreds of 1 percent of the metal was developed by Stevens and Carron (1946). The new method separates beryllium from aluminum by a sodium carbonate fusion of their phosphates and leaching with water. Various methods for removal of iron were studied, and the cupferron method was found to be most satisfactory.

COLORIMETRIC AND FLUORIMETRIC ANALYSIS

Colorimetric analysis is based on the reactions of certain elements with dye reagents to produce colored or fluorescent compounds in solution. Many of the reactions are very sensitive and thus applicable to analysis for beryllium. A comprehensive treatment of the subject is given by Sandell (1944). Several metals, including zinc, lithium, the rare earths, thorium, and calcium, react with certain of the reagents commonly employed in colorimetric tests for beryllium. Other elements such as iron, magnesium, manganese, and aluminum form flocculent hydroxides that cloud the solution and absorb beryllium and the color reagent. Procedures for dealing with interfering ions differ according to the method of analysis employed, but in general they may either be eliminated from the solution or rendered harmless by adding appropriate reagents. Special methods for removal of iron from the test solution have been described by Hillebrand and Lundell (1929, p. 110–111) and Sandell (1949, p. 93).

The two types of color reagent that have been most used in beryllium determination are morin and the anthraquinones. Of the latter, quinizarin (1-4-dihydroxyanthraquinone) and quinalizarin (1-2-5-8-tetrahydroxyanthraquinone) are the most popular. Quinizarin-2-sulfonic acid (1-4-dihydroxyanthraquinone-2-sulfonic acid) has also been used (Cucci and others, 1949). Quantitative methods for each of the reagents have been rather carefully worked out. Comparative characteristics of the methods are shown in table 1 and detailed procedures are given in the publications cited.

TABLE 1.—*Comparison of quinalizarin, quinizarin, and morin methods for determination of beryllium in rocks and minerals*

	Quinalizarin	*Quinizarin*	*Morin*
Visual reaction	Blue lake	Red fluorescent solution	Yellow-green fluorescent solution.
Light conditions	Daylight	Ultraviolet (3,650 A)	Ultraviolet or sunlight.
pH condition	−0.5N NaOH	−0.3N NaOH (pH 11.5)	0.01 to 0.1N NaOH.
Sensitivity [1]	0.5 ppm Be	0.05 ppm Be	0.001 ppm Be.
Interfering ions	Zn, Mg, Zr, Th, rare earths	Li	Li, Ca, Zn, Sc.
Remarks	Least sensitive, best at high pH	Most specific, color stable, tested on all ores.	Most sensitive, least specific, worst at high pH, color fades, tested on all rocks.
References	Sandell, 1944, p. 153–154; Feigl, 1939, p. 119–121; Fischer, 1928.	Rienacker, 1932; White and Lowe, 1941; Fletcher, White, and Sheftel, 1946; Zermatten, 1933; Fletcher and White, 1946; Underwood and others, 1947.[2]	Sandell, 1944, p. 152–153; 1940a, 1940b, 1949.

[1] Stated in terms of minimum parts per million Be in test solution.
[2] Underwood, A. L., Neuman, W. F., and Carlson, A. B., 1947, Determination of small amounts of beryllium by fluorescence measurement: U. S. Atomic Energy Comm., MDDC 941, 17 p.

The morin reaction is the most sensitive of the three tests and, unlike other fluorescent methods, the fluorescence may be observed in daylight. A disadvantage is the large number of interfering ions that must be eliminated. Though apparently suitable for rocks, this method may have application in testing ores. Quinizarin gives a less sensitive fluorescent test than morin and requires the use of an ultraviolet lamp. Its chief advantage is that few ions interfere with the test, and therefore it is probably of greater use in testing of ores and all types of rocks than are other reagents. The quinalizarin test, like most other colorimetric methods, is of much lower sensitivity than fluorimetric reactions. However, only simple laboratory equipment is required in the procedure and most interfering ions may be eliminated without difficulty.

Several other reagents have been found to give color reactions with beryllium but have not been adapted for trace analysis of rocks and minerals (Kolthoff, 1928; Feigl, 1939, p. 121; Kulcsar, 1943; Aldridge and Liddell, 1948; Underwood and Neuman, 1949; Kassel and Neuman, 1950). Most of the reagents used in colorimetric and fluorimetric analysis for beryllium may also be used in making qualitative spot tests. Reasonable precautions must be observed, even in qualitative work, in ridding the test solutions of ions which may interfere with the results, and quantitative determinations may be carried out with slightly more effort.

MINERALOGIC METHODS

Beryllium in rocks may be determined by finding the amounts of beryllium minerals present and their beryllium contents. Commonly the BeO content of the mineral or minerals is determined by one of the methods discussed above, though optical determinations are possible for some species. For accurate results the average of several determinations must be taken. Mineral percentages by volume are determined by petrographic methods. Techniques employed with the more common beryllium minerals are discussed below.

BERYL

Beryl crystals, if large, generally may be recognized by their crystal form, hardness, and color; some beryl, however, is white and easily confused with quartz or feldspar. Beryl in small crystals or fragments in a ground sample may be recognized microscopically, but identification is not always certain, for quartz and apatite have similar optical properties and crystal form. Once beryl has been recognized, its proportion in the rock may be found by one of the ordinary methods of volume, area, line, point, or grain counting, subject to the statistical restrictions of the method employed (Krumbein and Pettijohn, 1938, p. 465–489). Because the specific gravity of beryl is about that of its usual gangue, quartz, its volume proportion is approximately equal to its weight proportion.

The beryllia content of beryl ranges from 10 to 14 percent, varying inversely with the alkali content. The alkali content of the beryl may be determined by measuring the ordinary refractive index by the immersion method and referring to an empirical curve (Winchell, 1951, p. 464). In pegmatites the beryllium content of beryl may vary within a single pegmatite, or even within a single unit (Cameron and others, 1949, p. 69). No such variation has yet been discovered in veins, but relatively few analyses of vein beryl are available.

Mineralogical calculation of beryllium in beryl deposits has so far been applied only to pegmatites (Hanley and others, 1950, p. 12).

HELVITE GROUP

In some districts, such as the Victorio Mountains and Carpenter districts, New Mexico, the Silverton district, Colorado, the Butte district, Montana, and the Rockport area, Massachusetts, minerals of the helvite group commonly may be recognized by their crystal form and color. In the Iron Mountain district, New Mexico, and at places in some of the other districts just mentioned, helvite is easily confused with garnet of the same shade of yellow or red. Some danalite and garnet in the Iron Mountain district were so intimately intergrown that identification was especially difficult (Jahns, 1944a, p. 57–58). A stain test developed by Gruner (1944) has proved useful if helvite is admixed with garnet.

The proportion of helvite is determined by methods similar to those used for beryl. If the gangue is garnet, the volume proportions nearly equal the weight proportions. The theoretical BeO content of helvite ranges only from 12.5 to 13.5 percent (Glass and others, 1944, p. 182). In the absence of a chemical analysis, a value of 12.8 $\pm$0.9 percent BeO may be assumed. More than one mineral of the helvite group may be found in the same deposit,[1] and this possibility must be considered in evaluating the beryllium content.

Mineralogical calculation of beryllium has been applied by Glass (Jahns, 1944a, p. 63, 77) to the Iron Mountain helvite deposit.

OTHER MINERALS

Other beryllium minerals have not been found in sufficient quantity to make their quantitative determination important. Beryllium-bearing minerals such as idocrase, garnet, axinite, aegirite, and nepheline have a content of beryllium that ranges from more than 3 percent BeO to below the limit of detection. Correlation between physical properties and beryllium content is uncertain for these minerals, and no data have been gathered on their probable ranges of beryllium content within a given deposit or rock type.

The two minerals of highest extraneous beryllium content are allanite and idocrase, both of which contain such a diversity of elements that correlation of physical properties with beryllium content is extremely difficult. Gädeke (1938) has achieved some success in correlating the optical properties of idocrase with its highly variable composition. However, some half-dozen types of isomorphous substitution were found to have a marked effect on the optical properties, and a reliable criterion for determining the presence of beryllium seems improbable. If either idocrase or al-

[1] Iron Mountain, N. Mex. (Jahns, 1944a, p. 56–58); Bartlett, N. H. (Glass and others, 1944, p. 185); and Cornwall, England (Miers and Prior, 1892, p. 11).

lanite occurs in a deposit containing helvite or beryl, it may be expected to be beryllium-bearing. In each of the three helvite deposits where idocrase has been found and analyzed, it contained at least 0.2 percent BeO. In such deposits a mineral count of beryl or helvite will give a BeO content below the true value.

A mineral count of all the recognizable beryllium minerals may miss a substantial quantity of beryllium occurring in fine-grained or unknown species. This was the experience of Glass and Lemke with the Iron Mountain, N. Mex., tactite (Jahns, 1944a, p. 77–78), and of Holser with the Victorio Mountains, N. Mex., tactite during the present investigation. However, the beryllium content determined from beryl or helvite counts could be of more economic significance than that given by chemical or spectrographic methods if the trace quantities of beryllium in the minerals associated with the beryl or helvite were not recoverable.

RADIOMETRIC METHODS

Beryllium is an efficient producer of neutrons when excited by high-energy gamma radiation. It shares this property with H^2 and several other atoms, but the energy threshold for the beryllium reaction happens to be lower than for any other element. The reaction was experimentally applied to the mechanical sorting of beryl (Gaudin and others, 1950), and the data obtained in these experiments allow a preliminary calculation of the sensitivity of the reaction for the assay of beryllium in rocks.

The gamma-ray sources used in the published experiments were a Van de Graaf generator and radium (Gaudin and others, 1950, p. 496). The recently available artificially radioactive antimony may be more desirable for field determination of beryllium, despite its short half-life. It decays according to the following equation:

$$Sb^{124} \xrightarrow{60\text{ days}} Te^{124} + \beta^{-}_{2.4}\text{ Mev} + \gamma_{1.7}\text{ Mev}$$

The gamma radiation is of sufficient energy to excite beryllium, giving 2.10^5 neutrons per curie per gram of beryllium at 1 cm. (Russell and others, 1948). Sb^{124} possesses an advantage over Ra^{226} in the analysis of natural materials, because it gives only a very small number of neutrons from H^2. The neutrons may be slowed in a moderator, such as paraffin, and detected by standard procedures. Preliminary calculations, including allowance for efficiency and background, indicate a limit of detection of 0.00X (percent BeO times curies of Sb^{124}).

This method has some promise for semiportable field equipment, as it would be highly specific, independent of the state of beryllium, fast, and simple. However, there are several disadvantages. Initial expense would be moderate but operating expense would include the maintenance of a supply of Sb^{124}, which has a rather short half-life. Safety and waste-disposal of the source required to detect small amounts of BeO would be problems.

MINERALOGY OF BERYLLIUM

CRYSTAL CHEMISTRY OF BERYLLIUM MINERALS

Most beryllium minerals are silicates, many of which are structurally complex. The commonly associated elements are aluminum and the metals of the alkali and alkaline-earth groups, together with fluorine, water, and the hydroxyl ion. With few exceptions, iron and magnesium are rare constituents. Other mineral groups, including oxides, carbonates, phosphates, and borates, are sparsely represented, but sulfides, halides, and related compounds are notably lacking. The tendency for beryllium to affiliate itself with the silicates and oxygen salts in preference to the sulfides and halides is best explained by the marked difference in crystal chemistry of these compounds. Full treatment of this subject is beyond the scope of this report. However, the principles involved are thought to have an important bearing upon the nature and occurrence of beryllium minerals and thus to merit the following brief discussion.

Beryllium has a relatively small ionic radius, is strongly electropositive, and is found only in tetrahedral coordination in crystal structures. As a result of these properties, it favors combination with anions that are not easily polarized, forming crystal bonds of the ionic or semi-ionic type. Stable combinations of beryllium with sulfur, which is readily polarized, are not to be expected. Similarly, chlorine, bromine, and iodine form structures which, except for the alkali chlorides, tend to approximate the sulfide type and are not likely to contain beryllium. Fluorine vigorously resists polarization but, because of its large ionic size does not favor tetrahedral coordination with beryllium. The most stable combination of beryllium is with oxygen, which is not readily polarized and, which, though comparable in size to fluorine, will permit bonds of semi-ionic type involving some electron sharing. Such bonds result in relatively close packing of four oxygen ions around the small beryllium ion and permit the required spacing of beryllium ions in the structure. The oxide, bromellite, though rare, is thus a stable mineral compound.

The silicate minerals are most favorable for beryllium occurrence. The complex structural arrangement and chemical composition of these minerals give greater opportunity for meeting the four-fold coordination requirement of beryllium. Even here many combinations which fit the ordinary laws of valency are structurally incompatible. Whereas beryllium is known only in tetrahedral coordination in oxyminerals, aluminum, iron, magnesium, and other elements are capable of either four-fold or six-fold coordination. Such elements therefore have a considerable advantage over beryllium in meeting structural requirements in silicate minerals. Even if beryllium were present in concentration equal to that of these elements, a condition which is rare in nature, it would be at a loss in competing with them for positions in crystal lattices.

Though oxysalts of beryllium occur as minerals, they are not common. In the oxyradicals, oxygen atoms are closely grouped around small atoms such as carbon, nitrogen, and phosphorus; and bonds within the radicals are mainly covalent. Because the bonds between beryllium and oxygen are mainly ionic, the beryllate radical is unstable in nature and not found in minerals. Bonds between beryllium ions and the large oxyradicals are of a weak ionic type and the resulting beryllium nitrate, carbonate, and phosphate also have poor stability under natural conditions.

In the presence of water, especially at low temperatures, hydrogen has considerable influence on the relations of beryllium and oxygen. The hydroxyl ion is deformed by the charge of the beryllium ion and, according to the theory developed by Wickman (1944), the resulting deformation may allow formation of hydroxyl bonds and precipitation of beryllium hydroxide. This is thought to be of considerable importance in the occurrence of beryllium in sedimentary rocks.

Many minerals contain beryllium in solid solution, though rarely in significant amounts. That ionic size, rather than valency, is the controlling factor in isomorphous substitution is now commonly accepted. Thus beryllium may replace ions or atoms of comparable size in crystal structures but is not likely to replace those of substantially different ionic radius. Because of the discrepancy in ionic size, the substitution of beryllium for most of the more common metals is not to be expected in appreciable amount. The best possibilities for substitution are with ions such as Cr^{6+}, P^{5+}, S^{6+}, and Si^{4+}, which are of about the same size as Be^{2+}. Not only are these ions, except that of silicon, comparatively rare, but all have valences ranging from four to six, whereas the valence of beryllium is only two. Other ions of some of these elements have lower valences, but their radii are considerably larger than that of the beryllium ion. Although difference in valence does not prohibit substitution, the ions of higher charge will in general be somewhat more stable in the structure than beryllium (Goldschmidt, 1934, p. 385); also the interchange of ions is subject to the condition that the positive and negative charges must balance.

Excess charges may be balanced by adding ions to the structure. Such complex substitutions are well known in amphiboles, micas, and clay minerals. As an example, Rankama and Sahama (1950, p. 126) theorize that the small content of lanthanum sometimes present in potassium feldspar is a result of the substitution of La^{3+} for K^{+} simultaneously with Be^{2+} for Si^{4+}. Not only must the combined charges of the substituting ions bring about electrical neutrality in the structure but their sizes and coordination numbers must be such that they will fit into the spaces provided by the ions replaced. The difficulty of finding proper combinations is immeasurably increased when the disparity of valences is greater, so despite the greater difference in ionic size, Be^{2+} is more likely to substitute for Si^{4+} than for S^{6+}, Cr^{6+}, or P^{5+}.

Presumably beryllium ions or atoms may fill interstices of proper size in certain crystal lattices without actually substituting for other ions. In this connection the small ionic radius for beryllium would seem a distinct advantage. However, the difficulties inherent in isomorphous substitution would not be entirely obviated in this process, and it is doubtful that significant amounts of beryllium could be thus accommodated except in minerals where vacant oxygen tetrahedra exist, as in idocrase.

On the whole, isomorphism does not promise to provide minerals of even moderately high beryllium content except under special conditions. Undoubtedly it is a means by which much beryllium is dissipated among silicate minerals as a trace constituent.

Throughout the foregoing discussion the matter of ion concentration, or availability, has been largely neglected. As pointed out by Osborn (1950), the concentration of a given element in a particular geologic environment has much to do with the amount of that element contained in the minerals that form. In the early stages of basaltic magma crystallization the concentration of beryllium is low, and it is not a serious competitor to the more common cations which are more readily incorporated into the structures of the ferromagnesian silicates and plagioclase. It thus tends to be concentrated in the late magmatic residue where opportunities for the formation of minerals in which beryllium is a necessary constituent reach their maximum. Silicate minerals that form during the late magmatic and early hydrothermal stages of igneous activity probably remove most of the beryllium. Sulfur, the oxyradicals, and to some extent the halogens tend to be concentrated in later hydrothermal fluids and combine with metals to form the common ore and gangue minerals. Not only are the structures of these minerals unfavorable to beryllium occurrence, but the concentration of beryllium in the ore fluid probably is low, most of it having gone into previously formed minerals. Paucity of beryllium in ore deposits that formed at moderate or low temperature is, therefore, to be expected.

Theoretical considerations thus indicate that, because of the peculiar structural and chemical properties of beryllium, minerals in which beryllium is a necessary constituent are few. These minerals are most likely to occur in rocks believed to have formed during the transition from magmatic to hydrothermal activity. The number of potential beryllium ore minerals is, therefore, not large and their geologic environments are restricted. These principles, though not without exception, are in accord with, and tend to substantiate, conclusions previously drawn from field observations.

BERYLLIUM AS AN ESSENTIAL CONSTITUENT IN MINERALS

Minerals in which beryllium is an essential constituent are described in table 2. Although the list is an imposing one, many of these minerals are rare, and some are found in only one or two localities. Knowledge of physical and chemical conditions in nature, is not adequate to explain these rare occurrences. Beryl, helvite, bertrandite, chrysoberyl, and phenakite are not only the most common minerals of beryllium, but actually account for nearly all mineralogical occurrences as well as all probable ores of beryllium. All can occur in deposits other than pegmatites.

The chrysoberyl ($BeAl_2O_4$) structure is similar to that of fayalite and has been described by Bragg and Brown (1926). Although the possibility of isomorphic variation in the aluminum or beryllium content is suggested by artificial melt studies (Geller and others, 1946, p. 289), the only variation found in natural chrysoberyl has been the substitution of small amounts of ferric iron for aluminum, and ferrous iron for beryllium (Palache and others, 1944, v. 1, p. 719). Chrysoberyl occurs in some pegmatites and in at least one it constitutes beryllium ore (Hanley and others, 1950, p. 103). It is found also in aluminous schists commonly associated with pegmatites, as in the Ural Mountains (Fersman, 1929, p. 94) and in New York (Palache and others, 1944, v. 1, p. 721). None was found during the present investigation.

TABLE 2.—*Minerals in which beryllium is an essential constituent*

[Key to abbreviations: isom.—isometric; tetr.—tetragonal; hex.—hexagonal; trig.—trigonal; orth.—orthorhombic; mono.—monoclinic; H—hardness Moh scale; G—specific gravity; F—fusibility; Cl—cleavage form; N—index of refraction; N_o—index of refraction for the ordinary ray; N_e—index of refraction for the extraordinary ray; N_y—index of refraction for the intermediate ray; B—birefringence; 2V—optic axial angle]

Mineral	*Chemical composition*	*Percent* BeO	*Description*	*Occurrence*
Aminoffite	$Ca_8Be_3Al(OH)_3Si_8O_{28}\cdot 4H_2O$	6. 2	Tetr., pyramidal; vitreous; colorless; H, 5.5; G, 2.9; N_o, 1.64; N_e, 1.637; B, 0.010.	Pyrometasomatic with magnetite; very rare.
Barylite	$BaBe_2Si_2O_7$	15. 4–15. 8	Orth., platy; greasy; white; insoluble; Cl, 001, 100; H, 6–7; G, 4.0; F, 7; N_y, 1.68–1.70; B, 0.013; (+)2V, 65° to (−)2V, 65°.	Pyrometasomatic, New Jersey; very rare.
Bavenite	$Ca_4BeAl_2Si_9O_{26}.H_2O$	3. 0– 7. 7	Orth., fibrous, prismatic; white; H, 5.5; G, 2.7; N_y, 1.58–1.59; B, 0.004–0.0007; (−)2V, 47°.	Granitic pegmatite, Italy; very rare.
Bertrandite	$Be_4Si_2O_7(OH)_2$	39. 6–42. 6	Orth., tabular, prismatic; vitreous; colorless, yellow; insoluble; Cl, 001, 110, 100; H, 6; G, 2.6; F, 7; N_y, 1.61; B, 0.023; (+)2V, 74°.	Granitic pegmatite and feldspathic veins; widely distributed in small amounts.
Beryl	$Be_3Al_2(SiO_3)_6$	10. 0–14. 0	Hex., prismatic (vert. striae), vitreous; green (rarely white, pink, yellow); insoluble; Cl, 001 (poor); H, 7.5–8; G, 2.6–2.8; N_o, 1.57–1.60; N_e, 1.56–1.59; B, 0.004–0.008.	Granitic pegmatite, high temperature veins; widely distributed. Alters to kaolinite.
Beryllonite	$NaBePO_4$	19. 8	Orth., short prismatic; vitreous; colorless, white, yellow; soluble; Cl, 001, 100; H, 5.5–6; G, 2.8; F, 5; N_y, 1.56; B, 0.01; (−)2V, 67°.	Granitic pegmatite, Maine; rare.
Bityite	$Ca_4(Li,Be)_4Al_8$—$[(Si,Al)_4O_{10}]_3(OH)_{20}$.	2. 3– 8. 1	Pseudohex., minute plates; white; insoluble; Cl, 001; H, 5.5; G, 3.0; F, easy; N_y, 1.63; B, 0.02; (−)2V, small.	Granitic pegmatite, Madagascar; rare.
Bromellite	BeO	100. 0	Hex., prismatic; white; insoluble; Cl, 1010; H, 9; G, 3.0; N_o, 1.72; N_e, 1.73.	Pyrometasomatic, Sweden; very rare.
Chkalovite	$NaBeSi_2O_6$	12. 7	Orth., colorless; H, 6; G, 2.7; soluble; Cl; N_y, 1.55; (+) 2V, 78°.	Syenitic pegmatite, U.S.S.R; very rare.
Chrysoberyl	$BeAl_2O_4$	16. 9–19. 7	Orth., tabular, twinned crystals; vitreous; green, yellow, brown, red; Cl, 110; H, 8–9; G; 3.7; F, 7; N_y, 1.75; B, 0.009; 2V, variable.	Granitic pegmatite, schist, placers; uncommon.

TABLE 2.—*Minerals in which beryllium is an essential constituent*—Continued

Key to abbreviations: isom.—isometric; tetr.—tetragonal; hex.—hexagonal; trig.—trigonal; orth.—orthorhombic; mono.—monoclinic; H—hardness Moh scale; G—specific gravity; F—fusibility; Cl—cleavage form; N—index of refraction; N_o—index of refraction for the ordinary ray; N_e—index of refraction for the extraordinary ray; N_y—index of refraction for the intermediate ray; B—birefringence; 2V—optic axial angle]

Mineral	*Chemical composition*	*Percent* BeO	*Description*	*Occurrence*
Epididymite	$HNaBeSi_3O_8$	10. 6	Orth., basal plates; vitreous; white; nearly insoluble; Cl, 001 and 010; H, 5.5; G, 2.6; F, 3; N_y, 1.54; B, 0.002; (+) 2V, 23°.	Syenitic pegmatite, Greenland; rare.
Euclase	$BeAlSiO_4(OH)$	16. 9	Mono., prismatic; vitreous; colorless, green, blue, white; insoluble; Cl, 010; H, 7.5; G, 3.0–4.0; F, 5.5; N_y, 1.655; B, 0.02; (+) 2V, 50°.	Granitic pegmatite, chlorite schists, placers; rare.
Eudidymite	$HNaBeSi_3O_8$	10. 6–11. 1	Mono., basal plates; vitreous; white; nearly insoluble; Cl, 001; H, 6; G, 2.5; F, 3; N_y, 1.55; B, 0.006; (+) 2V, 30°.	Zircon syenitic pegmatite, Norway; rare.
Gadolinite	$Be_2Y_2FeSi_2O_{10}$	5. 5–13. 2	Mono., prismatic; vitreous; black, greenish, brown; gels HCl; Cl, none; H, 7; G, 4.0–4.6; N_y, 1.78; B, 0.01; (+), 2V, 85°.	Granitic pegmatite, generally with fluorite; uncommon.
Hambergite	$Be_2(OH)BO_3$	36. 7	Orth., prismatic; vitreous; gray-white; insoluble except in HF; Cl, 010 and 100; H, 7.5; G, 2.3; F, 7; N_y, 1.59; B, 0.074; (+) 2V, 87°.	Granitic and syenitic pegmatites, Norway and Madagascar; very rare.
Harstigite	$(Ca,Mn)_7Be_4(Si_2O_7)_3(OH,F)_4$	11. 2	Orth., short prismatic; vitreous; colorless; soluble in HCl after ignition; Cl, none; H, 5.5; G, 3; N_y, 1.68; B, 0.005; (+) 2V, 52°.	Pyrometasomatic, Sweden; very rare.
HELVITE GROUP				
Helvite	$Mn_4Be_3Si_3O_{12}.S$	10. 5–15. 0	Isom., tetrahedrons, spherical masses; vitreous to resinous; yellow, red, brown; gels in HCl; Cl, 111 (poor); H, 6; G, 3.2–3.4; F, 3; N, 1.73–1.75.	Pyrometasomatic deposits; rhodonite veins, granitic and syenitic pegmatites; uncommon.
Danalite	$Fe_4Be_3Si_3O_{12}.S$	12. 7–13. 8	Isom., octahedrons, massive; red, brown; H, 6; G, 3.3–3.5; F, 3; N, 1.75–1.77.	Granitic pegmatite, pyrometasomatic deposits; rare.
Genthelvite	$Zn_4Be_3Si_3O_{12}.S$	12. 6	Isom., rose red, brown; H, 6; G, 3.6; N, 1.75.	Pegmatite, Colorado; very rare.
Herderite	$CaBePO_4(OH,F)$	15. 0–15. 8	Mono., prismatic; vitreous; yellowish to greenish; soluble in acid; Cl, 110 (poor); H, 5; G, 3.0; F, difficult; N_y, 1.61; B, 0.029; (−) 2V, 74°.	Pegmatites, Maine; very rare.
Kolbeckite(?)	Hydrous Be, Ca, Al, Si phosphate, poorly defined.	8. 7	Mono., short prisms; blue to gray; Cl, 010; H, 3.5–4.0; G, 2.4.	Quartz-wolframite vein, Germany; very rare.
Leucophanite	$(Ca,Na)_2Be\ Si_2(O,OH,F)_7$	10. 0–12. 4	Orth., basal plates, massive, columnar; vitreous; white, green, yellow; insoluble; Cl, 001, 010; H, 4; G, 3; F, 6; N_y, 1.59; B, 0.027; (−) 2V, 39°.	Syenite pegmatite, Norway; very rare.
Meliphanite	$(Ca, Na)_2Be(Si, Al)_2(O, F)_7$	9. 8–14. 0	Tetr., obtuse pyramidal or platy; vitreous; yellow to reddish; insoluble; Cl, 001; H, 5–5.5; G, 3; fuses with intumescence; N_o, 1.61; N_e, 1.59.	Syenite pegmatites, Norway; very rare.
Milarite	$K_2Ca_4Be_4Al_2Si_{24}O_{60}.H_2O$	5. 0	Hex., prismatic; vitreous; pale green, colorless; insoluble; no cleavage; H, 5.5–6; G, 2.6; F, 3; N_o, N_e, 1.53; B, 0.001–0.003.	Granite, Switzerland; very rare.
Phenakite	Be_2SiO_4	44. 0–45. 6	Trig., rhombohedral or prismatic; vitreous; colorless, yellow, rose, brown; insoluble; Cl, 1120; H, 7.5–8; G, 3.0; F, 7; N_o, 1.654; N_e, 1.670.	Granitic pegmatites, high temperature veins; rare.
Rhodizite	$(Na, K)_2Li_4Al_4Be_3B_{10}O_{27}(?)$	9. 0–15. 1	Isom., dodecahedrons; translucent; white or yellow; insoluble; Cl, 111 (poor); H, 8; G, 3.4; F, 7; N, 1.69.	Pegmatite, U.S.S.R., Madagascar; very rare.
Swedenborgite	$NaBe_4SbO_7$	35. 3	Hex., short prismatic; colorless; yellow; insoluble; Cl, 0001; H, 8; G, 4.3; N_o, 1.77, N_e, 1.77; B, 0.002.	Pyrometasomatic deposit, Sweden; very rare.
Tengerite	Hydrous Y, Ca, Be carbonate	9. 8	Fibrous, powdery; dull; white; soluble with effervescence; G, 3.1; N_y, 1.57–1.63; B, 0.02–0.03; (−) 2V, large.	Granitic pegmatite as alteration product of gadolinite, Texas; very rare.
Trimerite	$Be_3Mn_2Ca(SiO_4)_3$	17. 1	Mono., tubular prisms; pink; soluble in HCl; Cl, 0001; H, 6–7; G, 3.5; F, 6; N_y, 1.72; B, 0.01; (−) 2V, 83°.	Pyrometasomatic, Sweden; very rare.

The phenakite (Be_2SiO_4) structure according to Bragg and Zachariasen (1930) consists of linked tetrahedra with silicon and beryllium at their centers. The structure is similar to that of willemite and a small amount of willemite is needed as a seeding agent in producing synthetic phenakite (Morgan and Hummel, 1949, p. 252). Phenakite occurs in small quantities in pegmatites, but rarely is found in those containing chrysoberyl. It is an associate of beryl in a few granites containing segregations of aplite and occurs rarely in beryl-bearing quartz veins. None was discovered in the current investigation, but it has previously been described from veins at Irish Creek, Va. (Koschmann and others, 1942, p. 281–282) and Mount Antero, Colo. (Switzer, 1939, p. 789).

Beryl ($Be_3Al_2(SiO_3)_6$) is uncommon among silicates as an example of a sixfold ring structure of four-coordinated silica groups (Bragg and West, 1926). The groups are tied together by beryllium in four-coordination and aluminum in six-coordination.

Beryl is variable in composition, ranging from 10 to 14 percent BeO (the formula content is 14 percent). Alkalies and alkaline earths, principally sodium, constitute as much as 4 percent of many beryls, and constitutional water may amount to 2.7 percent. The decrease of beryllium content might be structurally correlated with either the addition of an alkali atom to the empty position in the center of each silicate ring, or with the substitution of hydroxyl for oxygen in part of the ring itself. Both systems have been found in other silicates; [2] sufficient analyses are not yet available to determine which is more important.

Theoretically, the type and amount of substitution in beryl should be closely related to the mode of occurrence. Beryl formed as a late magmatic product should contain less beryllium than that formed earlier, because of increase in alkali content of the magma as differentiation progresses. The abundance of water in the preforming fluid should result in a further reduction of beryllium in vein beryl. Accordingly, the alkali content of beryl might be expected to increase during pegmatization and, in general, the beryllium content of beryl should be higher in igneous rocks than in vein deposits. The few analysis of nonpegmatite beryl show, however, that the average BeO content does not appear to be appreciably different from that of beryl in pegmatites. The optical data on nonpegmatite beryl indicates that the index is higher, and therefore the beryllium content probably lower in tungsten-bearing veins than in molybdenum- and tin-bearing veins (Adams, 1953, p. 117).

[2] Na in amphibole: Warren (1929, p. 42); OH in garnet: McConnell (1942, p. 458–460).

Beryl is the most common beryllium mineral in beryllium-bearing veins. The vein occurrences are tabulated and discussed by Holser (1953, p. 604) and by Adams (1953, p. 114–117). Beryl also occurs less commonly as an accessory mineral in granitic rocks and in schists, generally associated with pegmatites. The known occurrences in nonpegmatite rocks of the United States are discussed in this report.

Helvite and its isomorph ($(Mn, Fe, Zn)_4Be_3Si_3O_{12}S$) have a three-dimensional framework of oxygen tetrahedra similar to that of sodalite. Beryllium occupies the position normally given to aluminum in such structures, and this allows the presence of the divalent metals in place of sodium (Barth, 1926, p. 40).

The chemical composition and physical properties of the helvite group are summarized by Glass, Jahns, and Stevens (1944), who list many helvite localities. In addition to the pegmatite occurrences at Amelia, Va., Cheyenne Canyon, Colo., Rockport, Mass., Langesundfiord, Norway, Miass, U. S. S. R., and Mount Francisco, western Australia, helvite has been found in pegmatites at Rincon, Calif. (Murdoch and Webb, 1948, p. 170), Walrus Island, Northwest Territory, Canada (Hoffman, 1901, p. 15), and Ipe', Minas Gerais, Brazil (written communication, E. R. Swoboda). In common with phenakite and beryl, minerals of the helvite group are found rarely in small rather fine-grained segregations in granite (Fischer, 1942). Most helvite occurs in veins and pyrometasomatic deposits. Occurrences in the United States are described in detail in this report.

BERYLLIUM AS AN ACCESSORY CONSTITUENT IN MINERALS

The minerals that are known to contain beryllium as an accessory constituent are listed in table 3, together with some of their physical properties and their modes of occurrences. The range of beryllium content reported for these minerals is also indicated, although the accuracy of most of the figures is difficult or impossible of evaluation. Aside from the usual analytical difficulties, most reports in the literature give no information about what precautions were observed against inclusions of other beryllium minerals. Indeed, even with detailed microscopic examination of the sample, one cannot be certain of its nature, as only a few minute grains would be necessary to give the small amounts of beryllium detected by spectrographic analysis.

The recovery of beryllium by known hydrometallurgical or similar methods from most minerals in which beryllium is dispersed as an isomorphous constituent is not possible, but some recovery may be possible from very low grade material containing inclu-

TABLE 3.—*Minerals in which beryllium may be an accessory constituent*

[Key to abbreviations: isom.—isometric; tetr.—tetragonal; hex.—hexagonal; trig.—trigonal; orth.—orthorhombic; mono.—monoclinic; tric.—triclinic; H—hardness Moh scale; G—specific gravity; F—fusibility; Cl—cleavage form; N—index of refraction; N_o—index of refraction for the ordinary ray; N_e—index of refraction for the extraordinary ray; N_y—index of refraction for the intermediate ray; B—birefringence; 2V—optic axial angle]

Mineral	*Chemical composition*	*Approximate maximum percent* BeO	*Description*	*Occurrence*
Amphibole group:				
Arfvedsonite	$Na_3(Fe,Mg)_4FeSi_8O_{22}(OH)_2$	0.0X	Mono., prismatic; vitreous; black to deep green; insoluble; Cl—110; H—6; G—3.5; F—2; Ny—1.69; B—0.015; (−)2V—variable.	Alkalic igneous rocks; uncommon.
Glaucophane	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$	.001	Mono., prismatic; vitreous; blue; insoluble; Cl—110; H—6; G—3.0–3.1; N_y—1.63; B—.019; (−) 2V—small.	Schists; uncommon.
Hornblende	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	.006	Mono., prismatic; vitreous; green to black; Cl—110; H—5.6; G—2.9–3.4; N_y—1.61–1.71; B—0.02–0.03; (−)2V—large.	Igneous and metamorphic rocks; very common.
Apatite	$Ca_{10}(F,Cl,OH)_2(PO_4 \cdot AsO_4)_6$	.01	Hex., prismatic; vitreous; green, white; soluble; H—5; G—3.2; Cl—0001 imperfect; N_o—1.60–1.77; N_e—1.58–1.77; B—0.002–0.01.	Widely distributed igneous rocks, pegmatites and sedimentary and metamorphic rocks; common.
Axinite	$H(Fe,Mn)Ca_2Al_2BSi_4O_{16}$	.1	Tric., wedge-shaped; vitreous; brown, blue, gray; insoluble; Cl—$\bar{1}$12, 010, 1$\bar{3}$0; H—7; G—3.3; F—2; N_y—1.68–1.69; B—0.01; (−)2V—70°–90°.	Pyrometasomatic and high-temperature veins; uncommon.
Cassiterite	SnO_2	tr	Tetr., short prismatic or pyramidal; adamantine; brown or black; Cl—110; H—6–7; G—6.8–7.1; N_o—1.99; N_e—2.09.	High-temperature veins and pegmatites, placers; common.
Chevkinite	$(Ca,Fe)(Ce,Y,Di)_2(Si,Ti)_3O_{10}$	1.9	Mono., vitreous; red-brown, black; gels with HCl; Cl—none; H—5; G—4.3–4.6; F—4; N_y—1.88–1.97; B—low, may be amorphous and isotropic.	Granitic pegmatite; rare.
Chlorite	$(Mg,Fe,Al)_{5-6}(Si,Al)_4O_{10}(OH)_8$	tr	Mono., lamellar; pearly; green; Cl—001; H—1–2; G—2.6–2.8; N_y—1.58; B—0.003–0.007; (+)2V—small.	Schists and hydrothermally altered rocks; common.
Clay minerals:				
Illite series	$K_5(Al,Mg)_2(Si,Al)_4O_{10}(OH)_2 \cdot nH_2O$.	.008	Mono., minute lamellae; white; H—2; G—2.6; N_y—1.57.	Soils; very common.
Kaolinite group.	$Al_2Si_2O_5(OH)_4$	.005	Tric., minute pseudohexagonal plates, vermicular groups common; white; H—2; G—2.6; F—7; N_y—1.56; B—0.006; (−)2V—20°–55°.	Hydrothermally altered rocks, soils; common.
Montmorillonite series.	$Al_{1.7}(Na,Mg)_3Si_4O_{10}(OH)_2 \cdot nH_2O$.	.01	Mono., minute lamellae; Cl—001; H—1.5; G—2.5–2.6; F—5 with swelling; N_y—1.50–1.60; B—0.025; (−)2V—variable.	Altered tuff, hydrothermally altered rocks, soils; common.
Clinohumite	$Mg_7[Mg(F,OH)]_2$	1.7	Mono., complex crystals; vitreous; yellow, red; gels in HCl; Cl—001; H—6; G—3.2; F—7; N_y—1.65; B—0.03; (+)2V—large.	Pyrometasomatic; rare.
Epidote group:				
Epidote	$Ca_2 \cdot (Al,Fe,Mn)O_2 \cdot Al(AlSi_3)O_9$	tr	Mono., prismatic or acicular; vitreous; green to black; partially decomposed by HCl; Cl—001; H—6–7; G—3.3–3.5; F—3 (swells); N_y—1.72–1.82; B—0.006–0.07; 2V—large.	Pyrometasomatic, metamorphosed limestones; common.
Allanite	$(Ca,Ce)_2O \cdot Fe_2OH \cdot Al \cdot (Al,Si_3)O_9$	5.5	Mono., tabular or acicular; submetallic; brown to black; gels in HCl; no distinct cleavage; H—6; G—4; F—2.5 (swells); N_y—1.65–1.78; B—variable; (−)2V—large.	Accessory in acidic igneous rocks, gneiss, schist, magnetite iron ores; uncommon. All beryllium material from granitic pegmatite; rare.
Eudialite	$(Na,Ca)_6ZrSi_6O_{18}OH$	.005	Hex., rhombohedral; pink; gels in HCl; Cl—001; H—5; G—2.8–3.1; F—2.5; uniaxial + or −; N_o, N_e—1.59–1.64; B—0.00–0.01.	Nepheline syenite pegmatite; rare.
Euxenite	$(Y,Ca,Ce,U,Th)(Cb,Ta,Ti)_2O_6$	.05	Orth., massive; brilliant; brownish black; insoluble; Cl—none; H—6.5; G—4.8; F—7; isotropic (from alteration); N—2.06–2.26.	Pegmatite; rare.

TABLE 3.—*Minerals in which beryllium may be an accessory constituent*—Continued

[Key to abbreviations: isom.—isometric; tetr.—tetragonal; hex.—hexagonal; trig.—trigonal; orth.—orthorhombic; mono.—monoclinic; tric.—triclinic; H—hardness Moh scale; G—specific gravity; F—fusibility; Cl—cleavage form; N—index of refraction; No—index of refraction for the ordinary ray; N_e—index of refraction for the extraordinary ray; N_y—index of refraction for the intermediate ray; B—birefringence; 2V—optic axial angle]

Mineral	*Chemical composition*	*Approximate maximum percent* BeO	*Description*	*Occurrence*
Feldspar group:				
Microcline (microperthite).	$KAlSi_3O_8$	0.04	Tric., short prismatic crystals; vitreous; white; Cl—001, 010; H—6; G—2.55; F—5; N_y—1.52; B—0.007; (−) 2V—large.	Granitic rocks, pegmatite, metamorphic rocks; very common.
Plagioclase	$NaAlSi_3O_8$	.01	Tric., tabular or prismatic; vitreous; white; Cl—001, 010; H—6; G—2.6–2.76; F—5; N_y—1.53–1.58; B—0.01; 2V—large.	Igneous rocks and pegmatite, metamorphic rocks very common. All beryllian material is albite from pegmatite.
Fergusonite	$(Y,Er,Ce,Fe)(Cb,Te,Ti)O_4$	.74	Tetr., prismatic or pyramidal; submetallic; brown; soluble in H_2SO_4; Cl—111; H—6; G—5.8; F—7; isotropic (from alteration); N—2.06–2.19.	Pegmatite; rare.
Fluorite	CaF_2	.000X	Isom., cubic; vitreous; white, purple; soluble in H_2SO_4; Cl—111; H—4; G—3.2; F—3; N—1.43.	Accessory in igneous rocks and pegmatites; widespread in veins and pyrometasomatic deposits; common.
Garnet (grossularite-andradite).	$Ca_3(Al,Fe)_2Si_3O_{12}$	.2	Isom., dodecahedronal; vitreous; red, brown, yellow, green; Cl—none; H—6.7; G—3.1–3.4; F—3; N—1.74–1.79.	Pyrometasomatic; common.
Gersdorffite	$NiAsS$	tr	Isom., massive, metallic, silver-white; Cl—none; H—5.5; G—5.6–6.2.	Sulfide veins; rare.
Homilite	$Ca_2FeO_2Si_2B_2O_8$	3.0	Mono., basal plates; black; H—5; G—3.36; F—2; gels in HCl; N_y—1.73; B—0.023; (+) 2V—80°.	Syenitic pegmatites, Norway; very rare; beryllian variety highly altered.
Hyalotekite	$(Pb,Ba,Ca)_9B_2(SiO_3)_{12}$	.75	Orth. (?); vitreous; white; insoluble in HCl; Cl—2 at 90°; H—5; G—3.8; F—3; N_y—1.96; B—0.003; (+) 2V—small.	Pyrometasomatic deposits, Sweden; very rare.
Idocrase (vesuvianite).	$Ca_{19}(Al,Mg)_{13}Si_{18}(O,OH,F)_{76}$	4.0	Tetr., prismatic; vitreous; brown, green, blue; decomposed by HCl; Cl—110 (poor); H—6.5; G—3.4; F—3; N—1.71–1.174; N_e—1.70–1.73; B—0.001–0.006 (may be biaxial, small 2V).	Pyrometasomatic deposits; common.
Maucherite	Ni_3As_2	tr	Tetr., square tabular crystals; metallic; reddish white; Cl—none; H—5; G—7.8; F—easy.	Sulfide veins; rare.
Mica group:				
Biotite	$K(Mg,Fe)_3(AlSi_3)O_{10}(OH)_2$	.0X	Mono., tabular; pearly; black; decomposed by H_2SO_4; Cl—001; H—2.5–3; G—2.8–3.4; F—5; N_y—1.56–1.69; B—0.040–0.060; (−) 2V—small.	Igneous and metamorphic rocks very common. (Beryllium-bearing samples obtained from granite, pegmatite, and related rocks.)
Lepidolite	$KLi_2AlSi_4O_{10}(OH)_2$	.0X	Mono., tabular; pearly; violet, yellow; attacked by acids; Cl—001; H—2.4–4.0; G—2.8–3.3; F—1.5–2.5; N_y—1.55; B—0.02; (−) 2V—42°.	Granitic pegmatites and tin veins; common.
Muscovite	$KAl_2(AlSi_3)O_{10}(OH)_2$	.0X	Mono., tabular; pearly; colorless, brown; insoluble in acids; Cl—001; H—2.5–3; G—2.7–3; F—6; N_y—1.58; B—0.036; (−) 2V—47°.	Granite, gneiss, schist, pegmatite, hypothermal veins; very common.
Microlite	$(Na,Ca)_2Ta_2O_6(O,OH,F)$	2.97(?)	Isom., octahedral; vitreous, brown, black; decomposed by H_2SO_4; H—5.5; G—5.5; F—7; N—1.93.	Granitic pegmatite; very rare.
Nepheline	$NaAlSiO_4$	.0X	Hex., tabular, prismatic; vitreous to greasy; colorless; Cl—1010; H—5.5–6; G—2.6; F—4; N_o—1.54–1.55; N_e—1.53–1.54; B—0.003–0.005.	Sodic syenites; common.
Niccolite	$NiAs$	tr	Hex., massive; metallic; pale red; Cl—none; H—5; G—7.3–7.7.	Sulfide veins; common.
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	.0008	Mono., lamellar; pearly; white; Cl—001; H—1; G—2.8; F—6; N_y—1.59; B—0.048.	Metamorphic rocks; uncommon.

TABLE 3.—*Minerals in which beryllium may be an accessory constituent*—Continued

Key to abbreviations: isom.—isometric; tetr.—tetragonal; hex.—hexagonal; trig.—trigonal; orth.—orthorhombic; mono.—monoclinic; tric.—triclinic; H—hardness Mch scale; G—specific gravity; F—fusibility; Cl—cleavage form; N—index of refraction; N_o—index of refraction for the ordinary ray; N_e—index of refraction for the extraordinary ray; N_y—index of refraction for the intermediate ray; B—birefringence; 2V—optic axial angle]

Mineral	*Chemical composition*	*Approximate maximum percent* BeO	*Description*	*Occurrence*
Pyroxene group:				
Aegirite	$(Na,Ca)(Mg,Fe)Si_2O_6$	0.1	Mono., long prism, vitreous; green; slightly soluble; Cl—110; H—6; G—3.5; F—2; N_y—1.77–1.82; B—0.05; (−)2V—large.	Syenitic rocks and related deposits; common.
Diopside	$Ca(Mg,Fe,Mn,Zn)Si_2O_6$	.01	Mono., prismatic; vitreous; green; Cl—110; H—5–6; G—3.2–3.3; F—5; N_y—1.67; B—0.03; (+)2V—58°.	Pyrometasomatic, metamorphic, and igneous rocks; very common.
Rhodonite	$Mn_2Si_2O_6$	.002	Tric., basal plates; vitreous; pink; Cl—100, 010, 001; H—5.5–6.5; G—3.7; F—4; N_y—1.68–1.74; B—.01–.02; (+)2V—large.	Ore deposits of manganese, iron, copper, generally with rhodochrosite.
Samarskite	$(Y,Er,Ce,U,Ca,Fe,Pb,Th)(Cb,Ta,Ti,Sn)_2O_6$	.3	Orth., prismatic, tabular, massive; vitreous; black or brown; insoluble; Cl—010; H—5–6; G—5.6–5.8; F—5; isotropic (from alteration); N—2.10–2.25; also strongly biref. (Unaltered)	Granite pegmatite; rare.
Steenstrupine	$(Ca,Na,Ce)_5(OH)Si_3O_{12}(?)$	1.9	Hex., rhombohedral; dull; brown; H—4; G—3.3; uniaxial negative.	Syenitic pegmatite; very rare.
Stilbite	$NaCa_5(Al_{11}Si_{29})O_{80}.3O\ H_2O$	.7	Mono., tabular; pearly; white; decomposed by HCl; Cl—010; H—4; G—2.1–2.2; F—2; N_y—1.49; B—.011; (−)2V—30°–50°.	Cavities in basalt; common. Beryllian variety (foresite) in pegmatite; very rare.
Thorite	$ThSiO_4$	.1	Tetr., prisms with pyramids; vitreous; brown; insoluble; Cl—110; H—5; G—5.2–5.4; F—6; N_0—1.8, commonly isotropic from alteration, with N—1.7.	Pegmatite and syenite; rare.
Tilleyite	$Ca_5(CO_3)_2Si_2O_7$	tr	Mono., colorless; Cl—100, 101 (?); G—2.84; N_y—1.63; B—0.04; (+) 2V—large.	Metamorphosed limestone, California; rare.
Tourmaline	$Na(Mg,Fe,Li)_9B_3Si_6O_{27}(OH)_4$	.0X	Trig., prismatic; vitreous; black, brown, green, red; insoluble; Cl—poor; H—7; G—2.9–3.2; F—4–6; N_0—1.64–1.67; N_e—1.62–1.64; B—0.02–0.03.	Widely distributed in metamorphic rocks, pegmatites, and high temperature veins; common.
Triphyllite	$Li(Fe''Mn'')PO_4$	.01	Orth., prismatic; vitreous; greenish gray; soluble; Cl—001; 010, 110; H—5; G—3.4–3.6; F—1.5–2; N_y—1.67–1.70; B—0.004–0.010; 2V—variable.	Granitic pegmatites; common.
Uraninite	UO_2	.01	Isom., octahedral, massive; submetallic; black; soluble in HNO_3; H—5.5; G—9; F—7.	Veins and granitic pegmatites; rare.
Variscite	$(Al,Fe)PO_4.2H_2O$	.01	Orth., pyramidal or prismatic; green; soluble; Cl—010; H—4; G—2.5–2.9; F—7; N_y—1.56–1.59; B—0.02–0.03; 2V—variable.	Sedimentary rocks.
Wavellite	$(Al(OH)_3(PO_4)_2.5H_2O$	1.	Orth., fibrous; pearly; white, green; soluble in H_2SO_4 and in NaOH; Cl—110, 011, 010; H—4; G—2.3; F—7; N_y—1.53; B—0.02–0.03; (+)2V—72°.	Secondary mineral in bedded ores; rare.
Willemite	Zn_2SiO_4	.005	Hex., prismatic; resinous; white, green, red; soluble; Cl—0001, 1120; H—5.5; G—3.9–4.1; F—4; N_0—1.70, N_e—1.72.	Zinc deposits; uncommon.
Yttrotantalite	$(Fe,Y,U,Ca)(Cb,Ta,Zr)O_4$	.58	Orth., prismatic; submetallic; black; insoluble; H—5; G—5.5–5.9; F—7; isotropic from alteration, N—2.15.	Granitic pegmatite; rare.
Zircon	$ZrSiO_4$	14(?)	Tetr., prismatic; adamantine; brown; Cl—110 imperfect; H—7.5; G—4.7; N_0—1.94, N_e—1.98; B—0.04–0.06.	Accessory mineral in igneous rocks, especially in granite, syenite and diorite; common. Beryllian variety (alvite) in granitic pegmatites; very rare.

sions of beryllium minerals. The possibilities of the occurrence of beryllium in various minerals as a guest element, and the importance of these minerals as possible sources of beryllium are discussed below.

SULFIDES

Beryllium is not likely to be precipated in sulfide lattices. However, it has been detected spectrographically in gersdorffite, niccolite, and maucherite (Hawley, Lewis, and Wark, 1951, p. 154). The manner of occurrence of the beryllium is not known. Helvite and other beryllium-bearing minerals occur in sulfide deposits, and minute inclusions of these minerals in the sulfides are a possibility.

OXIDES

In the Franklin district, New Jersey, beryllium was reportedly discovered in franklinite concentrates in 1944 (L. H. Bauer, written communication). Spectrographic analyses of carefully selected samples of franklinite taken at the Franklin and Sterling mills during the present investigation showed less than 0.0004 percent BeO, the lower limit of sensitivity.

Traces of beryllium have been detected in cassiterite from pegmatites and hydrothermal veins (Borovick and Gotman, 1939; Larionov and Tolmacev, 1937).

The beryllium content of uraninite and other radioactive oxides was determined by Oftedal (1939) who found that most uraninite contains less than 0.01 percent beryllium. Most of the uraninite samples from the Colorado Plateau contain from 0.0001 to 0.0005 percent beryllium, however the uraninite from the Red Bluff area, Gila County, Ariz., contains as much as 0.005 percent beryllium (Thomas W. Stern, oral communication). The distribution of beryllium in the uraninite structure is not known.

Bauxites containing as much as 0.018 percent beryllium and beryllium hydroxides readily form under similar conditions of surface temperatures and hydrogen-ion concentrations. It is not known whether the small proportion of beryllium in the bauxite can be accommodated in the lattice of the finely crystalline, hydrous aluminum minerals or whether it forms discrete crystals of its own. An even more likely possibility is adsorption of the beryllium hydroxide to the surface of aluminum minerals. Detailed study of beryllium-rich bauxite might solve this problem.

In general, the occurrence of beryllium in oxide minerals is unlikely because of structural difficulties and none may be regarded as a potential source of beryllium.

HALIDES

Fluorite samples from several veins contain as much as 0.00X percent BeO by spectrographic analysis, although none of the samples analyzed were from known beryllium mineral localities. The fact that fluorine does not favor tetrahedral coordination with beryllium suggests that beryllium in fluorite will be of small amount and restricted occurrence. However, the geological occurrence of beryllium may be related to the presence of fluorine, as fluorite is a common constituent in many beryllium-bearing tactites, veins, and pegmatites.

CARBONATES

Although rhodochrosite from Kapnik, Hungary, and calcite from Franklin, N. J., are reported to contain traces of beryllium (Goldschmidt and Peters, 1932, p. 368), the difficulty of accommodation of beryllium in the lattice suggests that the maximum amount is extremely small. At Franklin, N. J., a district from which several beryllium minerals are known, only 1 of 10 samples of dolomitic marble contained more than the detectable minimum of 0.0005 percent BeO (L. H. Bauer, written communication).

PHOSPHATES

The substitution of beryllium for phosphorus is a possibility on the basis of comparable ionic size but adjustment of valence is difficult. Although Nockolds and Mitchell (1948) and Goldschmidt and Peters (1932, p. 367) did not find beryllium in apatite from igneous rock, Schroeder (1931) found beryllium only in apatite, among all the rock minerals which he spectrographed qualitatively. Apatite from beryl-bearing pegmatite in the Newry and Rumford area, Maine, contained 0.002 percent BeO. In the present investigation one specimen of arsenian apatite (svabite) from Franklin, N. J., was found to contain 0.001 percent BeO; in three others it was absent. The principal mineral of phosphate rock is a member of the apatite family, but phosphate rock in the United States contains no more beryllium than the shale with which it occurs. Apparently apatite group minerals can contain only traces of beryllium. Wavellite, however, has been found to contain as much as 0.1 percent BeO (Preuss and Gliszczynski, 1951).

NEOSILICATES

In minerals of the garnet group a large number of trace elements have been detected, particularly the rare-earth metals, which enter by means of the substitution $Y^{3+}Al^{3+}$ for $Mn^{2+}Si^{4+}$ (Jaffe, 1951, p. 133). Beryllium has been detected in only a few varieties of garnet; typical examples are given in table 4. All known varieties of garnet containing appreciable beryllium are members of the grossularite-andradite series and are from pyrometatasomatic deposits. Helvite or other beryllium minerals occur in three of these deposits (Iron Mountain, N. Mex., Wykertown, N. J., Victorio Mountains, N. Mex.) and within a few miles of a fourth (Aarvold, Norway: Goldschmidt, 1911, p. 30); beryllium occurs in idocrase at all four. Samples from many of the garnet-rich pyrometasomatic deposits in the western United States were analyzed for beryllium in the present investigation; of these more than 90 percent did not contain a detectable amount of BeO (0.0004 percent); the maximum content was only 0.002 percent BeO. Many of these samples were nearly pure garnet. Beryllium was not detected in spessartite from beryl- and helvite-bearing pegamatites (Glass, 1935, p. 765). Apparently, no more than traces of beryllium can be expected in garnets except in helvite-bearing pyrometasomatic deposits.

TABLE 4.—*Garnet analyzed for beryllia*

Composition	*Locality*	*Percent* BeO	*Reference*
Grossularite	Iron Mountain, N. Mex.	0. 08–0. 19	Glass and others, 1944, p. 173.
Andradite ($And_{57}Gr_{36}Py_3Al_3Sp_1$).	Wykertown, N. J.	0. 0X–0. 00X	Milton and Davidson, 1950, p. 504.
Grossularite	Victorio Mountains, N. Mex.	0. 007	Holser, 1953, p. 603.
Manganian grossularite.	Aarvold, Norway.	0. 00X	Goldschmidt and Peters, 1932, p. 369.
Spessartite	Mill Creek, Mont.	<0. 000X	(1)
Grossularite	Franklin, N. J.	<0. 0004	(1)

1 Spectrographic analysis by A. A. Chodos.

Spectrographic lines of beryllium were reported in willemite concentrate from Franklin, N. J. (L. H. Bauer, written communication). In the present work, willemite was carefully picked from composite samples of average willemite concentrates. The material from Franklin, which is characteristically green, contained 0.004 percent BeO; material from Sterling Hill, which is characteristically pale red, contained 0.005 percent BeO. No beryllium was detected spectrographically in willemite from Northern Rhodesia (L. H. Bauer, written communication).

The structure of willemite is nearly identical to that of phenakite, zinc being in rare tetrahedral coordination with oxygen (Bragg and Zachariasen, 1930). A small quantity of beryllium substitutes for zinc in this peculiar structure, despite the difference in ionic sizes. At the lower temperature at which supergene willemite forms by alteration of sphalerite (Pough, 1941, p. 98), the presence of beryllium in the solutions seems unlikely. Beryllium in willemite is apparently confined to that of high-temperature origin, as at Franklin, N. J.

Idocrase contains beryllium more consistently than any other silicate in which beryllium is not an essential constituent, and of all such minerals that occur outside of pegmatites it contains the largest amount of beryllium (see table 5).

TABLE 5.—*Analyses of idocrase for beryllia*

Locality	BeO (*percent*)	*Reported by—*
Franklin, N. J.	3.95	C. S. Hurlbut, written communication, 1951.
Iron Mountain, N. Mex.	1.09	Glass and others, 1944.
Turnback Lake, North West Territory, Canada.	1.07	Meen, 1939.
Victorio Mountains, N. Mex.	.2	Holser, 1953.
Graubunden, Switzerland.	.09	Zilbermintz and Roschkova, 1933.[1]
Mill Creek area, Montana.	.0X	(2).
Aarvold, Norway	.0X	Goldschmidt and Peters, 1932.
Breitenbrunn, Germany	.0X	Do.
Julia mine, U. S. S. R. (?).	<.01	Zilbermintz and Roschkova, 1933.
Johnson, Ariz.	.005	(2).
Woodstock, Me.	Present	(3).
Amherst, N. H.	tr.	(3).
Carro de los Muertos, Chihuahua, Mexico.	Small tr.	(3).
Guffey, Colo.	None	(3).
Ternares mine, Durango, Mexico.	None	(3).

1 The several complete analyses of material from this locality are of an intergrown mixture of idocrase and diopside.
2 Spectrographic analysis by A. A. Chodos.
3 Spectrographic analysis by George Steiger.

The structure of idocrase is similar to that of garnet and has been described by Warren and Modell (1931) and Machatschki (1930). A study of the distribution of beryllium in idocrase has shown that perhaps a third of beryllium in idocrase replaces silicon in tetrahedra, and the rest enters normally unoccupied tetrahedral positions. Valence is balanced by loss of aluminum and some loss of calcium from the structure. Beryllian idocrase is consistently high in fluorine content, but there is no correlation with B, Ti, Zn, Mn, Cu, Na, K, or other minor constituents.

With few exceptions idocrase is found only in allochemical metamorphic rocks (those which have received additions of material while being changed by heat and pressure). Within this general category, however, two general types of occurrence are common. In one, as exemplified by some of the occurrences in Switzerland and the Ural Mountains, idocrase is found at the contact of mafic intrusive rocks (usually serpentinized) and limestone. A number of samples of this type of occurrence are among those of table 5 in which no beryllium was detected. The second type of occurrence is in limestone near the contact of granitic rocks and is probably more common. All examples of idocrase containing 0.1 or more percent of BeO are from the second type of occurrence (table 5). Several of these occurrences are from localities at which helvite or other beryllium minerals have also been found, and at all such places fluorite is an associate of the idocrase.

RING AND CHAIN SILICATES

Tourmaline from pegmatites has been reported to contain as much as 0.0X percent BeO (Goldschmidt and Peters, 1932), but even that from beryl pegmatites commonly contains much less.[3] Tourmaline from hypothermal veins has not been analyzed separately, but tourmaline-quartz vein material from the Lordsburg district, New Mexico, contained less than 0.0004 percent BeO (table 14).

Beryllium occurs in soda-rich pyroxenes and amphiboles more commonly than in the normal members of these groups. Goldschmidt and Peters (1932, p. 366) reported 0.1 percent BeO in aegirite, and 0.X percent in arfvedsonite and barkevikite. One sample of aegirite from Wind Mountain, N. Mex., contained only 0.000X percent BeO. The foregoing are all from pegmatitic facies of nepheline syenite intrusive rocks, but zincian-manganoan diopside from Franklin, N. J., was found also to contain 0.01 and diopside-hedenbergite from Mill Creek, Mont., contained 0.00X percent BeO.

Goldschmidt and Peters (1932, p. 367) list two amphiboles of metasomatic origin containing 0.00X percent BeO and one enstatite in which beryllium was not detected. An augite which contained less than 0.001 percent BeO was from basalt, and a pyroxene in which beryllium was not detected was from eclogite. Nockolds and Mitchell (1948) analyzed the hornblendes and pyroxenes from a series of Scottish igneous rocks ranging nearly continuously in composition from dunite through granodiorite. One hornblende sample contained a questionable 0.003 percent BeO, which was the limit of sensitivity, and the rest showed no BeO. Bray (1942b, p. 794) did not detect any beryllium in five samples of hornblende from granodiorite. In synthetic fluo-amphiboles, beryllium has been substituted for silicon to the extent of 12 percent of the tetrahedral groups (about 3 percent BeO) in both lime- and soda-rich varieties (Comeforo, Hatch, and Eitel, 1950). The presence of beryllium in pyroxenes and amphiboles is probably due largely to beryllium concentration during differentiation of sodium-rich magmas, from which these minerals are late to crystallize.

Rhodonite is associated with beryllium minerals at several places, including Franklin, N. J., Butte, Mont., and the Sunnyside mine, near Eureka, Colo. An analysis of rhodonite from Franklin, shows 0.002 percent of BeO. Samples of vein material in which rhodonite is the principal gangue were taken from the Butte district during the present study. The BeO content in these samples ranged from 0.0005 to 0.007, and in most of the samples helvite was observed. Samples from the Sunnyside mine showed little helvite and contained an average of less than 0.001 percent of BeO. One sample from Bill Young mine contained 0.0016 percent BeO; no helvite was identified. Beryllium was not detected in samples of other rhodonite veins at localities in the San Juan region, Colorado, from which no beryllium minerals have been reported.

Manganese-bearing members of the epidote group have been reported to contain traces of beryllium (Glass and others, 1944, p. 177). The ordinary pistacite variety has not been analyzed separately for beryllium, but a large number of epidote-rich tactites analyzed in the present investigation contain a maximum of 0.0008 percent BeO (table 15), but in 75 percent of them BeO was below the limit of detection. Allanite, which is structurally and chemically related to the epidote group, is reported to contain as much as 5.52 percent BeO (Dana, 1892, p. 526). All allanites containing more than 0.5 percent BeO were highly altered and all were from pegmatites. Beryllium was not detected in the unaltered allanite of hydrothermal origin at Wykertown, N. H. (Milton and Davidson, 1950, p. 504).

SHEET SILICATES

Complex substitutions of various ions in sheet silicates are common, and opportunities for the occurrence of beryllium are numerous. Micas from pegmatites have been found to contain a maximum of 0.0X percent BeO (Goldschmidt and Peters, 1932, p. 366), but no beryllium was found in micas from a series of igneous rocks (Nockolds and Mitchell, 1948, p. 564–565). Fluorine-phlogopite has been synthesized as much as one-fourth of the silicon being replaced by beryllium (that is, $K_2Mg_6BeSi_7O_{20}F_4$=about 3 percent BeO) (Eitel, Hatch, and Humphrey, 1950). This is an example of replacement of $Al^{+3}Al^{+3}$ by $Be^{2+}Si^{4+}$ in tetrahedral coordination, a process which may be important in other alumino-silicates. Another replacement observed was AlAl by $BaBe_2$. Such replacements in synthetic fluorine-muscovite are more restricted. Data on natural micas do not yet indicate any preference of beryllium

[3] Average of 0.006 percent BeO in blue, green and pink tourmaline from the Newry and Rumford area, Maine; analyses by J. D. Fletcher.

for those of a particular mode of occurrence or of a particular composition.

A large number of representative samples of clay minerals were analyzed spectographically for beryllium by Wheeler and Burkhardt (1950). All of the montmorillonites that originated through surface or submarine alteration of tuffaceous rocks were found to contain beryllium, the maximum content being 0.01 percent BeO. Beryllium was found in nearly all of the kaolinite-group samples that were of hydrothermal origin (maximum 0.008 percent BeO), but could not be detected in most of those of residual origin. Illite formed by soil alteration contained a maximum of 0.008 percent BeO. None was detected in attapulgite. None of these clays appear directly related to bauxite deposits formed by alteration of syenitic igneous rocks. Szelenyi (1937) reported that some clays contain about the same amount of beryllium as the associated bauxite (0.005 to 0.01 percent BeO), although others contain less. In addition to the mechanisms proposed above for other silicates, a new interpretation of the montmorillonite structure (McConnell, 1950) suggests the further possibility of replacing Si_4O_{10} by $BeSi_3H_2O_{10}$ in the tetrahedra.

Chlorite (Glass and others, 1944, p. 177), pyrophyllite (Wheeler and Burkhardt, 1950, p. 80), and apophyllite (Goldschmidt and Peters, 1932, p. 367) have been reported to contain small amounts of beryllium.

FRAMEWORK SILICATES

Beryllium is found in small quantities in feldspars (table 6).

Although the maximum beryllium content recorded for albite is higher than that for the potassium feldspars, a few determinations show the averages not to be significantly different. The alkali feldspars as a group contrast markedly with calcic plagioclase, in which beryllium has not been detected. Nockolds and Mitchell (1948) tested 11 potsassium feldspar samples and 9 plagioclase (An_{22}–An_{63}) samples from a variety of igneous rocks; all contained less than 0.003 percent of BeO, the limit of sensitivity. Bray (1942b, p. 790) was not able to detect beryllium spectrographically in 17 samples of feldspar from either pegmatites or related igneous rocks near Jamestown, Colo. Substitution of beryllium in feldspars is stable when the beryllium is in tetrahedral positions in place of silicon or aluminum (Schiebold, 1931).

Available data on nepheline (Tolmacev and Filippov, 1934; Goldschmidt and Peters, 1932, p. 366) indicate that beryllium may have about the same solubility in the nepheline lattice as in that of the alkali feldspar. However, nepheline seems to have a higher average beryllium content than feldspar minerals. Most of the analyzed nepheline and feldspar minerals are from pegmatites. A lower beryllium content for these minerals in finer grained intrusive rocks may be surmised from spectrographic analyses of igneous rocks. Feldspathoids other than nepheline have not been analyzed for beryllium.

Analytical data for the amphiboles, micas, feldspars, and feldspathoids show approximately the same maximum beryllium content for each, this suggests that beryllium substitution is controlled by a feature common to these minerals. This common feature is the presence of four-coordinated aluminum, permitting the substitution of BeSi for AlAl. Silicates of this type, including all the framework silicates except quartz, all the sheet silicates, and hornblende in the chain silicate group, should have comparable solid solubilities for beryllium. Therefore, when formed in environments of similar beryllium concentration, these minerals

TABLE 6.—*Beryllia content of 14 samples of feldspar*

Mineral	Rock	Locality	BeO (percent)	Reference
Microcline microperthite	Granite pegmatite	Risey, Norway	<0.000X	Goldschmidt and Peters, 1932, p. 366.
Do	do	Pikes Peak, Colo	.00X	Do.
Do	Pegmatite(?)	U. S. S. R.(?)	.04	Filippov and Tolmacev, 1935.
Soda microcline	Syenite pegmatite	Langesundfiord, Norway	.00X	Goldschmidt and Peters, 1932, p. 366.
Do	do	Laven, Norway	.00X	Do.
Microcline	Perthite zone, granite pegmatite.	Ridge pegmatite, Red Hill, Maine.	.003	(1)
Perthite	do	do	.003	(1)
Microcline	Granite pegmatite	Rumford, Maine	.003	(1)
Albite	Tactite	Mill Creek, Mont	.0X	(2)
Do	Granite pegmatite	Newry and Rumford, Maine	.002	(1)
Do	do	do	.006	(1)
Do	do	Kragero, Norway	.01	Goldschmidt and Peters, 1932, p. 366.
Labradorite	Anorthosite	Sogon, Norway	<.00X	Do.
Bytownite	do	do	<.000X	Do.

[1] Spectrographic analysis by J. D. Fletcher; specimens collected by V. E. Shainin.
[2] Spectrographic analysis by A. A. Chodos.

should contain comparable quantities of beryllium. However, a wide range is to be expected, owing to the variety of geologic environments in which the minerals crystallize.

BERYLLIUM IN IGNEOUS ROCKS

UNITED STATES LOCALITIES

The few data on the beryllium content of igneous rocks in the United States are summarized in table 7. Some of these analyses, originally stated in terms of percent beryllium, were converted to percent BeO in order to facilitate comparisons with results of the present investigation. Most of the original analyses were stated to only one significant figure; consequently, the converted result gives an impression of greater accuracy than was intended by the analyst.

Besides the semiquantitative determinations listed in table 7, many qualitative determinations have been made most with negative results. Spectrographic tests of a representative suite of igneous rocks from the Spanish Peaks region, Colorado, showed negative results for beryllium, but the limit of detection was about 0.02 percent Be (Knopf, 1936, p. 1779). Spectrographic analyses of 425 miscellaneous rocks and ores were tabulated by Freeman (1942, p. 777, 778) and only one, a weathered granite, contained more than the detectable limit of 0.001 percent Be. Bray (1942a, p. 431; 1942b, p. 784, 785) reported qualitative spectrographic analyses of 19 samples of Precambrian granites, 9 samples of Tertiary granodiorite, and 7 samples of Tertiary quartz monzonite, all from Colorado, and 9 samples of granite and 2 of granodiorite from Massachusetts. None showed beryllium, but the sensitivity of the tests is not stated.

TABLE 7.—*Beryllia content of igneous rocks of the United States, as published*

Rock	Locality	BeO (percent)	SiO_2 (percent)	Reference
Obsidian	Yellowstone Park, Wyo	0.01	75	Goldschmidt and Peters, 1932, p. 365.
Nepheline syenite	Magnet Cove, Ark	.00X	49.7	Do.
Granite porphyry	Babyhead, Llano County, Tex	.004	75.20	Sandell and Goldich, 1943, p. 169.
Granite	Graniteville, Mo	.003	76.81	Do.
Granodiorite	Bear Mountain, Gillespie County, Tex.	.003	76.77	Do.
Granite	Granite Mountain, Burnet County, Tex.	.002	73.02	Do.
Rhyolite	Devils Track River, Cook County, Minn.	.002	73.6	Do.
Granite	Cassaday quarry, Llano County, Tex.	.001	72.15	Do.
Albite-nepheline syenite	Litchfield, Maine	.001	60.39	Goldschmidt and Peters, 1932, p. 365.
Quartz monzonite	Town Mountain, Llano County, Tex.	.0008	68.15	Sandell and Goldich, 1943, p. 169.
Granitic rocks [1]	Minnesota	.0008	------	Do.
Granite	Malmo, Aitkin County, Minn	.0006	71.19	Do.
Diabase	Minnesota(?)	.0005	52.70	Sandell, 1949, p. 91.
Do	Do	.0003	46.88	Do.
Quartz monzonite	Bagdad, Ariz	<.0004	64.49	Anderson, 1950a, p. 617–18.
Dunite	Jackson County, N. C	.000X	------	Goldschmidt and Peters, 1932, p. 363.

[1] Composite of five samples.

Many igneous rocks in the United States were analyzed spectrographically for beryllium (table 8). Though a variety of rock types was included in the present sampling, particular attention was paid to silicic and alkalic intrusive rocks, for experience of previous workers appeared to indicate that these are most likely to contain beryllium. The composite alkalic intrusive rocks at Iron Hill, Colo., northeastern New Mexico, Magnet Cove, Ark., and in Trans-Pecos Texas, were sampled extensively and account for the many rare and uncommon rock types included in the table. With the exception of granite, less emphasis was directed to the more common igneous rocks of the Western States. Granodiorite and other intermediate types are poorly represented.

The lower limit of beryllium determination for some samples was as high as 0.004 percent BeO but for most samples it was 0.001 percent BeO or less. The table indicates that those rocks that contain more than 0.001 percent BeO are mainly of silicic or alkalic varieties, whereas those of less than this amount are for the most part the more mafic types. Notable exceptions to this generalization occur in the Iron Hill rocks, where uncompaghrite (melilite-diopside rock) and pyroxenite, which are low in silica and alkalis, contain most of the beryllium, whereas nepheline syenite and soda syenite show abnormally low beryllium content.

FOREIGN LOCALITIES

Spectrographic analyses of many igneous rocks from localities outside the United States are included in the reports of Goldschmidt and Peters (1932), Rodolico (1943), Rodolico and Pieruccini (1943), Wager and Mitchell (1943), Sahama (1945a; 1945b), and Nockolds and Mitchell (1948). Beryllium was among the minor elements determined or looked for in many of the samples. Data for these samples and for a few others from miscellaneous foreign sources are summarized in table 9. The results compare favorably with those obtained for igneous rocks in the United States (table 8).

TABLE 8.—*Beryllia content of igneous rocks of the United States, as analyzed for this study*

Rock	Form	Locality	Associated metals	Number of analyses [1]	Percent BeO		
					High	Low	Average
Feldspathoidal:							
Melanocratic:							
Nepheline pyroxenite	Stock	Iron Hill, Gunnison County, Colo	None	1			<0.001
Analcite gabbro	Plug	Huerfano Butte, Huerfano County, Colo	do	1			[2].002
Shonkinite	Dike	Magnet Cove, Hot Springs County, Ark	Fe	1			<.001
Theralite	Stock	Gordon Butte, Meagher County, Mont	None	1			<.0001
Madupite	Sheet	Leucite Hills, Sweetwater County, Wyo	do	1			<.001
Malignite (some nepheline-syenite pegmatite).	Dike	Wind Mtn., Otero County, N. Mex	Be	10	0.03	0.001	.016
Leucocratic:							
Nepheline syenite	Dike	Magnet Cove, Hot Springs County, Ark	Fe	4	.002	<.001	.001
Do	Plug(?)	Little Rock, Pulaski County, Ark	Al	[3] 1			[2].000X
Do	Stock	Bauxite, Saline County, Ark	do	[3] 1			[2].000X
Do	Laccolith	Wind Mtn., Otero County, N. Mex	Be	[4] 1			.0050
Do	do	do	do	6	.0074	<.001	.005
Do	Sill	Black Mtn., Otero County, N. Mex	None	1			.0066
Do	Dikes	Wykertown, Sussex County, N. J	None	2	.00X	.00X	.00X
Do	Sill	Sussex, Sussex County, N. J	do	[5] 1			[2].000X
Do	do	Beemerville, Sussex County, N. J	do	[5] 2	.002	.000X	.001
Analcite-nepheline syenite	Plug(?)	Little Wind Mtn., Otero County, N. Mex	do	1			.002
Nepheline-sodalite syenite	Ring dike	Red Hill, Carroll County, N. H	do	1			[2].000X
Nepheline syenite pegmatite (see also malignite).	Dikes	Wind Mtn., Otero County, N. Mex	Be	3	.0074	<.001	.003
Pulaskite	Stock	Little Rock, Pulaski County, Ark	Al	2	.000X	<.001	[2].000X
Leucite syenite porphyry	Dike	Magnet Cove, Hot Springs County, Ark	do	2			
Phonolite	Sills	Chico, Colfax County, N. Mex	None	5	.007	.001	[2].003
Do	Dikes	Bryant, Saline County, Ark	do	[6] 3	.002	.000X	.001
Do		Annie Creek, Lawrence County, S. Dak	do	[7] 5	.001	<.001	[2]<.001
Orendite	Sheet	Leucite Hills, Sweetwater County, Wyo	do	1			<.001
Ijolite	Stock	Iron Hill, Gunnison County, Colo	do	8	.001	<.001	<.001
Do. (altered)	do	do	do	2	<.0001	<.0001	<.0001
Do	Dike	Magnet Cove, Hot Springs County, Ark	do	2			.007
Uncompaghrite	do	Iron Hill, Gunnison County, Colo	do	7	.0098	<.001	.0037
Do. (altered)	do	do	do	13	.0041	<.001	.0019
Monchiquite	do	Magnet Cove, Hot Springs County, Ark	Fe	1			<.001
Wyomingite	Sheet	Leucite Hills, Sweetwater County, Wyo	None	1			<.001
Syenitic:							
Porphyritic syenite	Plug	Cornuda Mtn., Otero County, N. Mex	None	2	.002	.0008	[2].001
Do	Sills	Dog Mtn., Hudspeth County, Tex	do	1			<.004
Do	Laccolith	Cerro Diablo, Hudspeth County, Tex	do	1			<.001
Do	Plug	Hueco Tanks, El Paso County, Tex	do	1			[2].001
Do	do	Cerro Alto, El Paso County, Tex	do	1			[2].004
Syenite	Ring dike(?)	Wylie Mts., Culberson County, Tex	do	1			[2].002
Do	Plugs	San Pedro Mts., Santa Fe County, N. Mex	Cu, W	1			[2].0004
Do	Sheets	Ortiz Mts., Santa Fe County, N. Mex	Cu, Au	2			[2]<.0004
Do	Ring dike(?)	Red Hill, Carroll County, N. H	None	1			[2]<.000X
Soda syenite	Dike	Iron Hill, Gunnison County, Colo	do	3	<.0005	<.0005	<.0005
Trachyte	Sill(?)	Chico, Colfax County, N. Mex	do	1			[2]<.001
Granitic:							
Granite	Batholith	Bartlett, N. H	Fe, Be	[8] 2	.0032	.0017	.0025
Do	Stock	Iron Mtn., Albany County, Wyo	Fe, Ti	1			<.001
Do	do	Mt. Antero, Chaffee County, Colo	Mo, Be	[9] 1			.018
Do	do	Wylie Mts., Culberson County, Tex	None	1			[2].0002
Do	Batholith	Harney Peak, Pennington County, S. Dak	Be, Sn, Li	[10] 6			.0009
Do	Stock	Star mine, Harrison Pass, Elko County, Nev	W	2	.0078	<.0001	.0004
Do	do	Rose Creek mine, Pershing County, Nev	W	1			.0015
Do	do	Nevada Scheelite mine, Mineral County, Nev	W	1			.0007
Do	do	Round Valley mine, Tungsten Hills, Calif	W	1			<.0001
Do	do	Rocky Canyon, Humboldt Range, Nev	None	2	.0011	.001	.001
Albite granite	do	Sheeprock Mts., Tooele County, Utah	Be, U	4	.0052	.0024	.0037
Granite porphyry	Dike	Limerick Canyon, Humboldt Range, Nev	None	1			<.0001
Rhyolite porphyry	do	Victorio Mts., Luna County, N. Mex	Be, W	1			.002
Do	do	Cave Peak, Culberson County, Tex	W	1			<.001
Rhyolite breccia	Plug	do	do	1			<.001

See footnotes at end of table.

TABLE 8.—*Beryllia content of igneous rocks of the United States, as analyzed for this study*—Continued

Rock	Form	Locality	Associated metals	Number of analyses[1]	Percent BeO		
					High	Low	Average
Granitic—Continued							
Rhyolite		San Antonio Mt., Sandoval County, N. Mex	None	[11] 1			0.0005
Aplite (altered)	Dike	Sheeprock Mts., Tooele County, Utah	Be, U	1			.0098
Aplite	do	do	do	3	0.0049	0.001	.0019
Do	do	Star mine, Harrison Pass, Elko County, Nev	W	1			<.0002
Do	do	Limerick Canyon, Humboldt Range, Nev	None	1			.0007
Do	do	Oreana area, Humboldt Range, Nev	do	3	.0015	.001	.0012
Do	do	Round Valley mine, Inyo County, Calif	W	1			.0011
Do	do	Nevada-Massachusetts Co. mine, Pershing County, Nev.	do	1			.0008
Aplite-pegmatite	do	Rocky Canyon, Humboldt Range, Nev	None	2	.0007	<.0001	.0003
Aplitic granite	Stock(?)	Aeroplane mine, Tungsten Hills, Calif	W	1			.0001
Intermediate:							
Granodiorite	Dike	Santa Rita, Grant County, N. Mex	Zn, Pb, Cu	1			[2] .0004
Do	Stock	Nevada-Massachusetts Co. mine, Pershing County, Nev.	W	1			<.0001
Do	do	Ragged Top mine, Pershing County, Nev	W	1			.0013
Do	do	Victory mine, near Gabbs, Nev	W	1			.0034
Quartz monzonite	Sheet	Hanover, Grant County, N. Mex	Zn, Cu, Pb	1			[2] <.0004
Do	Stock	Little Dragoon Mts., Cochise County, Ariz	W, Cu, Zn	[12] 2	.0016	.0014	.0015
Do	do	Panther Canyon, Humboldt Range, Nev		1			.0016
Do	do	Aeroplane mine, Tungsten Hills, Calif	W	1			<.0001
Do	do	Union mine, Atolia district, Calif	W	1			<.0001
Quartz diorite	do	Pine Creek mine, Inyo County, Calif	W	1			.0044
Do	do	Aeroplane mine, Tungsten Hills, Calif	W	1			<.0001
Do	do	Little Sister mine, Inyo County, Calif	W	1			<.0001
Hornblende andesite		Paliza Canyon, Sandoval County, N. Mex	None	[11] 1			.0004
Anorthosite	do	Iron Mtn., Albany County, Wyo	Fe, Ti	1			<.001
Mafic:							
Gabbro	Dike	Sandus, Sanders County, Mont	Cu	[7] 1			[2] <.001
Do	do	Iron Mtn., Albany County, Wyo	Fe, Ti	1			<.001
Diabase	do	Morley, Las Animas County, Colo	None	2	<.0004	<.0004	[2] <.0004
Basalt	Flows	Chico, Colfax County, N. Mex	do	2	<.001	<.001	[2] <.001
Pyroxenite	Stock	Iron Hill, Gunnison County, Colo	do	10	.0033	<.0001	.001
Biotite pyroxenite	do	do	do	5	<.001	<.001	<.001
Lamprophyre	Dike	Fort Washakie, Fremont County, Wyo	do	1			<.001
Do	do	Snowmass Mtn., Pitkin County, Colo		1			<.001

[1] Unless otherwise noted, all analyses are of samples collected during this investigation.
[2] Determined on plates exposed for general scanning, and not for precise determination of BeO.
[3] Material collected by Mackenzie Gordon, U. S. Geological Survey.
[4] Composite.
[5] Material collected by A. S. Wilkerson, New Jersey Bureau of Mineral Research.
[6] Material collected by Fred Hildebrand, University of Chicago.
[7] Material collected by the Mine, Mill, and Smelter Survey, U. S. Geological Survey.
[8] Material collected by D. M. Henderson, University of Illinois.
[9] Material collected by J. W. Adams, U. S. Geological Survey.
[10] Material collected by J. J. Norton, U. S. Geological Survey.
[11] Material collected by C. S. Ross, U. S. Geological Survey.
[12] Material collected by J. R. Cooper, U. S. Geological Survey.

DISTRIBUTION OF BERYLLIUM IN IGNEOUS ROCKS

The average BeO content of various types of igneous rock is important to a basic understanding of beryllium geochemistry. Furthermore, this information may indicate what kinds of rock are favorable for beryllium prospecting, and what amounts may be considered significant in a given rock type. Goldschmidt and Peters (1932, p. 370) made the first detailed estimate of the content of beryllium in igneous rocks, as follows:

Rock type	BeO (*percent*)
Average igneous rock	0.0005
Nepheline syenite	.01
Granite	.001
Gabbro	[1] .0003

[1] Added later (Goldschmidt, Hauptmann, and Peters, 1933, p. 364).

Since then other estimates have been made, somewhat increasing the amounts for both granite and average igneous rock and substantially reducing the figure for feldspathoidal rocks. However, recent estimates by Sandell (1952, p. 212–213), based on fluorimetric determinations of beryllium in composite samples of igneous rocks from various localities, agree essentially with the values given by Goldschmidt and Peters for granite, gabbro, and average igneous rock.

The analyses by Goldschmidt are not strictly comparable with those of some later analysts because his are given only in powers of ten, although the figures given by others may not be precise. On the other hand, the greater accuracy of the more recent determinations has been offset by discovery of a wider range in beryl-

TABLE 9.—*Beryllia content of igneous rocks from foreign localities*

Rock	Locality	Number of samples	BeO content, in percent: High	BeO content, in percent: Low	BeO content, in percent: Average	Reported by—
			FELDSPATHOIDAL			
Melanocratic types	Portugal	2	0.0X	0.00X	0.01	Goldschmidt and Peters (1932).
Do	Fennoscandia	1			<.001	Do.
Leucocratic types	Greenland	1			.0X	Do.
Do	Portugal	2	.01	.001	.005	Do.
Do	Fennoscandia	7	.01	<.001	.003	Do. Zilbermintz and Roschkova (1933).
Do	Hungary	2	.001	.001	.001	Goldschmidt and Peters (1932).
Do	Brazil	2	.00X	.00X	.00X	Do.
Do	Southern Russia	1			<.01	Zilbermintz and Roschkova (1933).
Do	Canada	2	<.001	<.001	<.001	Goldschmidt and Peters (1932).
Mixture	World	[1] 22			.001	Goldschmidt and Peters (1933).
			SYENITIC			
Syenite	Fennoscandia	1			0.001	Goldschmidt and Peters (1932).
Do	do	[1] 19			.0006	Sahama (1945a).
Trachyte	Italy	2	0.0030	0.0022	.0026	Rodolico and Pieruccini (1943).
			GRANITIC			
Granite	Italy	2	0.0033	0.0021	0.0027	Pieruccini (1943).
Do	Germany	[1] 14			.002	Goldschmidt and Peters (1932).
Do	Italy	2	.0018	.00046	.0011	Pieruccini (1943).
Do	Germany	5	.00X	<.001	.001	Goldschmidt and Peters (1932).
Do	Fennoscandia	[1] 54			.001	Sahama (1945b).
Do	do	2	.00X	.001	.00X	Goldschmidt and Peters (1932).
Do	do	[1] 42	.0003	.0003	.0003	Sahama (1945b).
Do	Scotland	3	<.001	<.001	<.001	Nockolds and Mitchell (1948).
Do	Fennoscandia	5	.0003	<.0003	<.0003	Sahama (1945b).
Granophyre	Greenland	2	<.003	<.003	<.003	Wager and Mitchell (1943).
Aplite	Scotland	1			<.001	Nockolds and Mitchell (1948).
Obsidian	Various	3	.001	.001	.001	Goldschmidt and Peters (1932).
Granodiorite and adamellite.	Scotland	9	<.001	<.001	<.001	Nockolds and Mitchell (1948).
Tonalite	Germany-Fennoscandia	3	.001	<.001	<.001	Goldschmidt and Peters (1932).
Do	Scotland	1			<.001	Nockolds and Mitchell (1948).
			MAFIC			
Diorite	Italy	1			0.0011	Pieruccini (1943).
Do	Scotland	9	<0.001	<0.001	<.001	Nockolds and Mitchell (1948).
Gabbro	Germany	[1] 11			.0003	Goldschmidt and others (1933).
Do	Greenland	7	<.003	<.003	<.003	Zilbermintz and Roschkova (1933).
Do	Scotland	6	<.001	<.001	<.001	Nockolds and Mitchell (1948).
Do	Fennoscandia	[1] 24			<.0001	Sahama (1945a).
Diabase	Germany	3	<.001	<.001	<.001	Goldschmidt and Peters (1932).
Basalt	do	1			<.001	Do.
Peridotite	Scotland	2	<.001	<.001	<.001	Nockolds and Mitchell (1948).
Dunite	do	1			<.001	Do.
"Ultrabasics"	Fennoscandia				<.0001	Sahama (1945a).

[1] Mixture.

lium content for a given rock than was previously expected. An attempt has been made to adjust the average BeO contents for igneous rock types to fit the data obtained in the present investigation; the following values are suggested:

Rock type	BeO (*percent*)
Average igneous rock	0.001
Feldspathoidal rocks	.0025
Granitic rocks	.002
Syenitic rocks	.001
Intermediate rocks	.0007
Mafic and ultramafic rocks	.0001

The present study has provided much information concerning the presence of beryllium in alkalic intrusive rocks in the United States, as most of these were sampled in detail. The average value of 0.01 percent BeO given originally by Goldschmidt and Peters for nepheline syenite seems much too high, as the only analyses in their data that exceeded the figure were the very extraordinary "sodalite-eudialyte rock" (alkalic syenite) and "pedrosite" (alkalic hornblendite). Their revised figure of 0.003 percent BeO (Goldschmidt, Hauptmann, and Peters, 1933, p. 364) is close to that proposed by us. The analytical data of Goldschmidt and Peters on rocks from Magnet Cove, Ark., compare favorably with our results. (See tables 7 and 8.) They report 0.004 percent BeO in nepheline syenite from that locality, whereas the present investigation disclosed a maximum of 0.002 percent BeO and an average of about 0.001 percent.

The average beryllium content of feldspathoidal rocks gives little weight to the less abundant mafic varieties. However, the average beryllium content of the mafic varieties probably exceeds the total average by as much as 0.001 percent BeO. At Iron Hill, Colo., Wind Mountain, N. Mex., and Alter-Pedrosa, Portugal, the highest contents were all in pyroxene- or amphibole-rich rocks, but in southern Norway the highest was in laurdalite, a type of nepheline syenite commonly poor in minerals of the pyroxene and amphibole groups. In comparing the chemical analyses and modes so far available, no consistent correlation between beryllium content and mineralogy is apparent. The tendency for higher BeO content in the mafic types may be attributed to the admittance of larger amounts of beryllium into the lattice of aegirite than into other minerals of feldspathoidal rocks (see table 3) and to the tendency for pyroxene and amphiboles to crystallize last in many alkalic intrusive bodies (Fersman, 1929, p. 22–27).

The granites analyzed in connection with the present investigation (see table 8) average somewhat higher in beryllium content than those of Goldschmidt and Peters (table 9) or Sandell and Goldich (table 7), being about 0.004 percent BeO. However, many of the samples probably are not representative: those from Sheeprock Mountains, Utah, and Mount Antero, Colo., are from areas known to be rich in beryl, and others are from small granitic intrusive bodies in metal-mining districts of the western United States. Although such rocks probably do not contribute greatly to the world average for granitic rocks, they should serve to raise the beryllium content somewhat above the minimal values obtained for other granites. The value of 3 ppm beryllium (about 0.0008 percent BeO) suggested by Sandell (1952, p. 212) for the average granite thus may be too low, and the 0.002 percent BeO suggested by Goldschmidt, Hauptmann, and Peters (1933, p. 364) is taken as a suitable compromise for the present. Results of our analyses seem to indicate that granitic rocks associated with major ore deposits have higher than average beryllium content. Nonfeldspathoidal syenites appear to contain less beryllium than granites, although they have not been sampled extensively. Quantitative data on granodiorites are lacking.

The new analyses contribute little to the knowledge of beryllium content of the more mafic rocks, except to confirm that they most commonly contain less than 0.001 percent BeO. The only high value was obtained from a pyroxenite associated with the alkalic intrusive at Iron Hill, Colo. The average value given is that of Goldschmidt, modified by the determinations of Sahama.

Analyses of extrusive rocks are few, but those available do not differ noticeably in BeO content from the average for the corresponding intrusive rocks.

The beryllia content of the average igneous rock was calculated by the method of Knopf (1916, p. 620) and, like the figures on which it is based, must be considered as tentative. The value of 0.001 percent BeO thus obtained is intermediate with respect to averages ranging from 0.0005 to 0.002 percent BeO given by others (Goldschmidt and Peters, 1932, p. 371; Noddack and Noddack, 1934, p. 173; Sandell and Goldich, 1943, p. 181; Sandell, 1952, p. 213).

In comparing the new averages for the various rock types with that of the average igneous rock, the writers confirmed their earlier conclusion that beryllium is concentrated in granites and feldspathoidal rock, but the difference in average BeO content for granite and feldspathoidal rocks is much less than formerly supposed. The formation of granite and feldspathoidal rocks is attended by a concentration of alkalies and volatile components, and apparently beryllium tends to be concentrated in the process. In feldspathoidal rock the process of differentiation apparently is such that beryllium tends to be concentrated in the more mafic facies.

MODE OF OCCURRENCE

At most localities where beryllium has been detected in igneous rocks the beryllium-bearing mineral or minerals have not been determined. The occurrence of beryl and phenakite as miarolitic fillings, schlieren, segregations, and individual grains in granite at Mount Antero, Colo., and in the Sheeprock Mountains, Utah, suggest that these minerals may be present in other beryllium-bearing granites. Microscopic beryl in granite was described by Hartley (1902, p. 285).

The theoretical upper limits for BeO content in igneous rocks containing no beryllium minerals (that is, beryl, helvite, etc.) may be approximated by totalling the maxima (see table 3) for the various mineral species in the rock. For an average granite this would be about 0.02 percent BeO, with mica as the principal carrier. However, most of the analyzed rock minerals are of specimens from pegmatites and are therefore most likely to be saturated with beryllium, but also are more likely to contain inclusions of beryl and other beryllium minerals. The grade of beryl ore in pegmatite zones (Hanley and others, 1950, p. 11) suggests that the average BeO content of most pegmatites does not greatly exceed 0.02 percent, or that of an average granite. Possibly the beryllium in some granites containing this amount of BeO may be present in part as minute crystals of beryl or phenakite.

In feldspathoidal rocks beryllium may be present as an accessory constituent in minerals, mainly in aegirite. Goldschmidt and Peters (1932, p. 366) give the following analytical data on minerals from a nepheline-syenite pegmatite at Laven, Langesundsfiord, Norway:

Mineral	BeO (*percent*)
Aegirite	0.1
Nepheline	.0X
Soda-microcline	.00X
Lepidomelane	.00X

The theoretical maximum beryllium content for an average nepheline syenite is approximately 0.04 percent BeO. Even in the pegmatitic phase of these rocks, beryllium minerals are rare. Furthermore, pegmatite is not so common in feldspathoidal rocks as in granitic rocks. Detailed analytical work on the feldspathoidal rocks from Wind Mountain, N. Mex., indicates that all the beryllium is present in rock minerals, and that it is nearly as abundant in the parent rock as in pegmatite. The highest contents were found in the malignite (aegirite-rich) facies of the pegmatitic rocks and in the aegirite-rich hornfels associated with it.

BERYLLIUM IN SEDIMENTARY ROCKS

CLASTIC DEPOSITS

The concentration of beryllium in clastic sedimentary rocks depends largely upon the effect of weathering on the beryllium-bearing minerals and the extent to which gravity may have concentrated these minerals. The weathering of beryllium minerals has not been studied as such, but some information was obtained on chemical weathering of beryllium minerals through study of hydrothermally altered beryl and danalite.

Altered beryl from pegmatites in Brazil (Kerr, 1946b) and Korea (Iwase and Ukai, 1944) shows an increase in water and a decrease in silica, alkalies, and specific gravity. In these and other studies of altered beryl, the effect of alteration on beryllium content is not certain. Generally some beryllium is lost, although in the Korean material a slight gain perhaps due to secondary bertrandite was noted.

Some investigators are of the opinion that the water in beryl analyses is due to included alteration products (Caglioti and Zambonini, 1928; Folinsbee, 1941, p. 488). However, the fact that beryl loses water slowly and irreversibly at 800°C (Allen and Clement, 1908, p. 115–116) indicates that the water is probably held in the beryl structure rather than in the structure of an alteration product. According to Kerr (1946b, p. 436) and Waldschmidt and Adams (1942, p. 34), kaolinite and muscovite are products of highly altered beryl. At temperatures as high as 300°C, beryl was stable in laboratory experiments that largely decomposed feldspars and many other silicates (Norton, 1939, p. 11).

Danalite has been found altered to phenakite, siderite, sphalerite, and pyrite (Palache, 1907, p. 252–254), but no other alterations of the helvite group minerals have been recorded.

Aside from the rare presence of bertrandite, retention of beryllium in the alteration product is uncertain. Although Kerr's analysis of the kaolinite-rich product showed 0.24 percent BeO, he assumed in his calculations that this was owing to contamination by beryl (1946b, p. 439–440). Probably most beryllium minerals do not weather chemically except under extraordinary circumstances. Many of the silicate minerals in which beryllium is a minor constituent, such as feldspar, nepheline, and micas, decompose easily under surface conditions. The decomposition involves an intermediate dissolved state (Correns and Engelhardt, 1938) in which there is a breakdown of the oxygen tetrahedra, accompanied by the release of colloidal silica and beryllium.

The specific gravity of most beryllium minerals, which is 2.6 to 2.9, is so close to that of quartz that no mechanical concentration can be expected in sandy sediments. Instead, the beryllium minerals that may have been localized originally, as in granitic pegmatites, tend to be dispersed. Close to a rich source of beryl, a sufficient concentration may be present to make recovery profitable; removal of other minerals in solution or suspension may improve the grade. Such placer beryl has been reported from Minas Gerais, Brazil (Moraes, 1933, p. 291) where it is associated with diamond and tourmaline.

Beryl has poor cleavage and a hardness of 7 and therefore might be expected to persist in sediments. Freise (1931) conducted experiments to show quantitatively the relative resistances of various minerals to abrasion. Part of his results, showing the resistance of beryl in comparison to other silicates, are tabulated below:

Mineral	*Abrasion resistance (Hematite=100)*
Quartz	245
Beryl	270–465
Chrysoberyl	300
Idocrase	330
Grossularite-andradite	320–420

The many treatises on the mineralogy of sediments do not mention beryl, but this may be due to several factors: (1) beryl is in the light fraction, whereas the heavy fraction is usually of greater interest to the petrographer, (2) because of dispersion the number of beryl grains will be very small except near a very rich source, and (3) grains of beryl may be mistaken for apatite and possibly for quartz. Some rarer but more easily distinguished beryllium minerals such as euclase (Spencer, 1924) and gadolinite (Hutton, 1950, p. 662) have been found in clastic sediments.

In finer sediments, small amounts of beryllium may occur in micas and clays. Together with some material absorbed from solution, these probably account for the small amount of beryllium found in shales. Goldschmidt and Peters (1932, p. 367) found 0.001 percent BeO in a composite sample of 36 shales.

A detailed study of beryllium in some Italian sediments was made by Pieruccini (1943; see also Carobbi and Pieruccini, 1941), the results of which are summarized below:

Rock	*Number of samples*	BeO *Percent* *High*	*Low*	*Average*
Sandstone	8	0.00070	0.00030	0.00045
Shale	4	.00056	.00030	.00050
Limestone	4	.00056	.00036	.00039

Pieruccini found that in coarser sediments most of the beryllium is in the cement and that the amount is larger where the cement is argillaceous. Some of the marls he tested have comparatively high beryllium content; in others the cementing calcite is low in beryllium, thus reducing the BeO content of the rock. He emphasizes the role of source rocks in the beryllium content of sediments. Although no minerals of mafic igneous rocks were found in the sediments that were low in beryllium, the presence of elements such as copper, cobalt, nickel, and platinum in the samples suggests these rocks as a probable source of the sediments.

Few clastic sediments were sampled in the present investigation, but many sedimentary rocks have been analyzed in connection with other investigations of the Geological Survey. Unfortunately, the lower limit of beryllium determination in this work was 0.001 percent BeO, and as the analyses did not detect beryllium in the majority of samples (see table 10), they give only a rough indication of beryllium content. A large proportion of the samples are from phosphatic formations and associated oil shales. The oil shales contain a little more beryllium than the phosphate rock, indicating that beryllium does not tend to substitute for phosphorous in these sediments.

A maximum of 0.004 percent BeO was found in each of two shale specimens of Devonian age sampled: the Helms formation north of Van Horn, Tex., and the Chattanooga shale from Tennessee. The former contains veinlets of gypsum, limonite, and several fine-grained unidentified minerals; the mode of occurrence of the beryllium is unknown.

CHEMICAL AND RESIDUAL DEPOSITS

The chemistry of solution, transportation, and deposition of beryllium in connection with processes of weathering and sedimentation has been only partly worked out. The tendency for beryllium to follow aluminum in these processes applies only where the two metals are in solution in surface waters, and it is due to their precipitation as hydroxides under alkaline conditions. A similar tendency in relation to iron and manganese might be expected. Apparently, little beryllium is transported in surface waters under prevailing conditions of temperature and pH. Its concentration in sediments of chemical origin is, therefore, unlikely and is more to be expected in residual deposits, such as laterites, in which aluminum, iron, and manganese are concentrated.

Strock (1941b, p. 860) found 0.001 ppm of beryllium in the waters of Saratoga Springs, N. Y.; the beryllium probably is nonmagmatic in origin. In discussing the presence of zirconium in the same water, he postulated that it was in solution as the complex zirconocarbonate ion $(ZrO(CO_2)_2)^{-2}$, and says (p. 868), "Beryllium should form an even more stable complex anion than ZrO, and the fact that $BeCO_3$ is formed only in presence of excess CO_2 and its known tendency to form soluble double salts are undoubtedly manifestations of its tendency to form such stable complex anions." Although this might be admitted as a possible mode of transport of beryllium in natural waters, it is difficult to share Strock's conviction without experimental evidence for even the zirconium analogy.

Apparently, beryllium has not been detected in sea water, but by analogy with aluminum, the expected amount would be only 10^{-8} percent BeO, which is well below the limit of detection. Beryllium was not detected in limestones analyzed in the present investigation (see table 10) nor in a series of flints and other siliceous precipitates studied by Miropolsky and Borovick (1944). Marine sediments which may be partly clastic and partly chemical were found to contain <0.001 percent BeO in some deep sea cores from the Challenger expedition (Goldschmidt and Peters, 1932, p. 367), and an average of 0.0037 percent BeO was found in three cores from the Mediterranean (Landergren, 1948a).

Beryllium might be expected in bauxite and clay deposits because of its association with aluminum and with alkalic igneous rocks from which such deposits

TABLE 10.—*Beryllia content of sedimentary rocks, other than coal, in the United States*

Sediment	Age	Formation	Locality	Number of samples[1]	BeO content[2]		
					High	Low	Average
Sandstones							
Sandstone	Devonian-Mississippian	Chattanooga, Hardin, Maury, Meridan.	Hickman and DeKalb Counties, Tenn.	[3] 1			0.007
Do	Devonian	Chattanooga(?)	Jackson County, Tenn.	[3] 1			.004
Do	Permian	Phosphoria	Sweetwater County, Wyo.	[3] 19	<0.001	<0.001	<.001
Glauconitic sandstone	Tertiary	Manasquan(?)	Medford, Burlington County, N. J.	[3,4] 7	<.001	<.001	<.001
Do	do	Harnerstone(?)	Sewell, Gloucester County, N. J.	[3] 4	<.001	<.001	<.001
Sand (titanium placers)	Recent		Jacksonville Beach, Fla.	[3] 3	<.001	<.001	<.001
Sand (chromite placer)	do		Cle Elum, Kittitas County, Wash.	[3] 1			<.001
Sand (gold placer)	do		Idaho County placers, Idaho	[3] 19	<.001	<.001	<.001
Sand (titanium placers)	do		Brevard County, Fla.	[3] 2	<.001	<.001	<.001
Sand (tin placer)	do		Gibbonsville, Lemhi County, Idaho	[3] 3	<.001	<.001	<.001
Sand (gold-chromite placer)	do		Coos County, Oreg.	[3,4] 3	<.001	<.001	<.001
Garnetiferous sand	do		Fernwood, Benewah County, Idaho	[3] 1			.0004
Shales							
Carbonaceous shale	Pennsylvanian	Stigler	Haskell County, Okla.	[3] 3	0.001	<0.001	<0.001
Do	Triassic	Newark	Cumnock, Lee County, N. C.	[3] 1			<.001
Lignitic oil shale			Elsinore, Riverside County, Calif.	[3] 1			.004
Phosphatic shale	Devonian-Mississippian	Chattanooga, Hardin, Maury, Meridan.	Hickman and DeKalb Counties, Tenn.	[3] 5	.002	[5] <.001 (2)	.001
Do	Permian	Phosphoria	Conda, Caribou County, Idaho	[3] 4	<.001	<.001	<.001
Do	do	do	Lincoln County, Wyo.	[3] 2	<.001	<.001	<.001
Do	Upper Ordovician	Marquoketa	Dubuque County, Iowa	[3] 4	.0001	<.0001	.0001
Oil shale	Devonian	Chattanooga(?)	White and Jackson Counties, Tenn.	[3] 9	.003	[5] <.001 (8)	<.001
Do	Permian	Phosphoria	Beaverhead and Powell Counties, Mont.	[3] 25	.001	[5] <.001 (19)	<.001
Siltstone and shale		Canutillo	Franklin Mountains, El Paso County, Tex.	[3] 3	<.001	<.001	<.001
Shale, black and oolitic	Devonian	Helms	Sierra Diablo, Culberson County, Tex.	7	.004	<.001	.002
Shale	Devonian-Mississippian	Chattanooga, Hardin, Maury, Meridan.	Hickman and DeKalb Counties, Tenn.	[3] 15	.004	[5] <.001 (12)	.001
Do	Upper Ordovician	Cason	Batesville, Ark.	[3] 11	<.001	<.001	<.001
Do	Permian	Phosphoria	Beaverhead and Powell Counties, Mont.	[3] 52	.001	[5] <.001 (49)	<.001
Do	Devonian	Helms	Hueco Mts., El Paso County, Tex.	[3] 1			<.001
Do	Permian	Phosphoria	Sweetwater County, Wyo.	[3] 8	<.001	<.001	<.001
"Clay"	do	do	do	[3] 25	<.001	<.001	<.001
Clay with barite	Recent		Sweetwater, McMinn County, Tenn.	[3] 4	<.001	<.001	[1] <.001
Lignitic clay	Eocene	Nanfalia	Bakerhill, Barbour County, Ala.	[3] 1			.002
Limestones							
Limestone	Mississippian	Upper Lake Valley	Santa Rita, Grant County, N. Mex.	1			<0.0004
Do	Pennsylvanian-Permian	Hueco	Wind Mtn., Otero County, N. Mex.	1			<.0004
Miscellaneous							
Residual manganese			Shannon County, Mo.	[3] 1			0.05
Do			Rock Run district, Cherokee County, Ala.	[3] 1			.03
Do			Cave Springs district, Polk County, Ga.	[3] 1			.02
Do			Batesville district, Pike County, Ark.	[3] 6	0.01	0.008	.01
Do	Early Tertiary		Southwest Virginia district, Smythe County, Va.	[3] 2	.02	.01	.01
Do	do		Appalachian district, Bland County, Va.	[3] 3	.01	.005	.007
Residual manganese (tailings).	Recent		Cartersville district, Bartow County, Ga.	[3] 13	.01	.006	.009
Phosphate rock	Permian	Phosphoria	Beaverhead and Powell Counties, Mont.	[3] 22	.001	[5] <.001 (17)	<.001
Phosphate gravel	Pliocene	Bone Valley	Polk and Hillsborough Counties, Fla.	[3] 7	<.001	<.001	<.001
Sulfur, gypsum, and salt	?	?	New Gulf, Wharton County, Tex.	[3] 7	.001	[5] <.001 (6)	<.001
Do	?	?	Plaquemines Parish, La.	[3] 11	<.001	<.001	<.001

[1] Samples collected in the present investigation, unless otherwise noted.
[2] BeO determined on plates exposed for general scanning, not for determination of BeO alone.
[3] Samples collected by the Mine, Mill, and Smelter Survey, U. S. Geological Survey.
[4] Concentrate or tailings sample only.
[5] Number in parentheses indicates the number of analyses in which beryllium was not detected.

commonly are derived. Samples of bauxite from various localities have been analyzed for beryllium with disappointing results, as indicated below:

Locality	*Percent* BeO	*Reference*
Jamaica	0.05	[1]
Arkansas	.000X to 0.0006	[1] and Goldschmidt and Peters (1932, p. 367).
Hungary	.005 to 0.01	Szelenyi (1937).
Yugoslavia	.0038	Minguzzi (1943).
France	.00X	Goldschmidt and Peters (1932, p. 367).
Haiti	.0008	Goldich and Bergquist (1947, p. 76).
Dominican Republic	.0006	Do.
Dutch Guiana	.001	[1]

[1] Unpublished analyses from the files of the U. S. Geological Survey.

Many of the kaolinites analyzed by Wheeler and Burkhardt (1950) are also of low beryllium content. Comparison of beryllium content of the Arkansas bauxites and kaolinites with that of the nepheline syenites and pulaskites similar to those from which they were derived (see table 8), indicates that the beryllium was concentrated much less than aluminum, contrary to theoretical expectation. Data are as yet too few, however, to support any conclusion regarding beryllium concentration in bauxites and residual clays.

Landergren (1943, 1948b) determined the beryllium contents of several hundred iron ores of all types, mostly from Sweden, but including samples from elsewhere in Europe and the United States. The lateritic iron ores of Northern Ireland were all below the limit of sensitivity—0.001 percent BeO. Finnish bog iron ores, which are more strictly precipitates, were also mostly below the limit. Oolitic and other marine types averaged 0.001 percent BeO. Goldschmidt and Peters (1932, p. 368) did not detect beryllium in the few samples of iron ore they analyzed, including the Clinton, N. Y., material. A sample of limonite from New Zealand was reported to contain 0.01 percent BeO; in another, beryllium was not detected (Becker and Gaddum, 1937).

Although Goldschmidt and Peters (1932, p. 368) did not detect beryllium in several samples of residual manganese ore, the manganese deposits sampled by the U. S. Geological Survey during World War II showed an average of about 0.01 percent BeO (see table 10). In most of these deposits the manganese came from quartzites and dolomites of early Paleozoic age, but they may have undergone more than one cycle of concentration (Stose and Miser, 1922, p. 52–55). Available analyses indicate no separation of beryllium between concentrates and tailings during milling of the manganese ore. The beryllium mineral is not known.

In the Embreeville district, Tennessee, rapid weathering of the Shady dolomite of Cambrian age has produced minable concentrations of iron, manganese, zinc, and lead (Secrist, 1924, p. 141–145). Samples taken at the Embree mill by the U. S. Geological Survey in 1943 showed as much as 0.08 percent BeO in the tailings and an average of 0.03 percent. Although analyses of the unweathered Shady dolomite are not available, the high beryllium content of the ore suggests that beryllium has been concentrated with the other elements during weathering.

COAL DEPOSITS

That beryllium tends to be concentrated in certain plants was discovered by Sestini (1888), who believed that beryllium replaced magnesium in the plant tissue. Apparently, there has been no further investigation of beryllium enrichment in plants during growth. Numerous analyses of coal ash indicate that beryllium tends to be concentrated during plant decomposition and coal formation. Goldschmidt (1937, p. 669) estimated beryllium to be enriched by a factor of about 50 in the average coal. The details of the enrichment process are discussed by Haberlandt (1944) who, by analogy with germanium, concludes that beryllium and other trace elements were concentrated in coal as stable organic complexes similar to porphyrin (pyrrolidine).

The first comprehensive study of trace elements in coal was by Goldschmidt and Peters (1933), who found a maximum of 0.1 percent BeO (average 0.0[illegible] percent) in ashes of coal from England and Germany. Zilbermintz and Rusanov (1936) studied ashes of more than 600 coal samples from Russia and found 38 with more than 0.001 percent BeO; 3 contained more than 0.01 percent, and 1 contained 0.04 percent BeO. Similar investigations conducted by Nazarenko (1937) in Russia, Lopez de Azcona and Puig (1947) in Spain, Reynolds (1948) in the United Kingdom, and Uzamasa (1949) in Japan and Manchuria revealed small amounts of beryllium in the ashes of coals from these countries. A summary of the literature on trace constituents in coal was compiled by Gibson and Selvig (1944).

The beryllium content of 21 samples from a number of Colorado, Wyoming, Virginia, and West Virginia coal fields are given in table 11.

TABLE 11.—*Beryllia in ash of coals of the United States*

Age	*Formation*	*Location*	*Number of samples*	BeO *content (percent)*		
				High	*Low*	*Average*
Late Cretaceous	Mesaverde	Colorado	9	0.0025	<0.0006	0.0013
Do	do	Wyoming	2	.001	.0008	.0009
Do	Vermejo	Colorado	3	.0017	.0006	.0011
Do	Laramie	do	2	.0008	<0.0006	.0004
Carboniferous		West Virginia	1			.014
Do		Virginia	3	.01	.0014	.004
Do		West Virginia	1			.006

Ashes of eastern coals of Carboniferous age average 0.008 percent BeO. Ashes of western coals of Cretaceous age, however, average about 0.001 percent BeO, which corresponds to the average content of shales or of igneous rocks. The reason for the different BeO contents in coals of Carboniferous and Cretaceous age and the manner of occurrence of the beryllium in the coal is not known.

Beryllium has been looked for but not found in a number of marine plants (Cornu, 1919), but traces have been found in algae (Lagrane and Tchakirian, 1939). There seems to be little concentration of beryllium during the formation of petroleum, as only traces have been found in petroleum ashes (Katchenkov, 1948).

BERYLLIUM IN METAMORPHIC ROCKS

Only isochemical metamorphic rocks (those which have not received metasomatic additions of material while being changed by heat and pressure) are included under this heading. Some calc-silicate rocks which may belong in this category are discussed with the pyrometasomatic deposits, with which they are associated. Metamorphic rocks as thus defined would be expected to show little difference in composition from the sedimentary or igneous rocks from which they were derived. Local concentrations of beryllium by the processes of metamorphic differentiation are conceivable but probably rare.

Analyses for beryllium have been made of a large number of schists and gneisses from a wide range of metamorphic facies, principally in Finland (Sahama, 1945a, p. 38–39), Sweden (Landergren, 1948b, p. 77–78), and Greenland (Wager and Mitchell, 1943, p. 286–287). In more than 80 percent of these rocks the content was below the limits of detection; which ranged from 0.003 to 0.0003 percent BeO. Of those in which beryllium was detected, quartz-biotite schist from the Striberg iron district in Sweden contained 0.011 percent BeO, but the rest were below 0.005 percent. No rocks of this type were sampled during the present investigation; a few recent analyses of metamorphic rocks by the Geological Survey show little or no BeO.

BERYLLIUM IN PYROMETASOMATIC AND RELATED DEPOSITS

PREVIOUS AND PRESENT INVESTIGATIONS

Pyrometasomatic deposits containing beryllium were first described by Goldschmidt (1911) in his monumental work on the metamorphic rocks of the region around Oslo, Norway. Helvite is associated with garnet, idocrase, diopside, magnetite, fluorite, and other minerals in these deposits, which were regarded as having little commercial value. Helvite was also reported in pyrometasomatic deposits at Lupikko, Finland (Trustedt, 1907), Schwarzenburg, Germany (Peck, 1904), Bartlett, N. H. (Huntington, 1880), and Casa La Plata, Argentina (Fischer, 1925; 1926). Goldschmidt and Peters (1932) devoted a great deal of their study of the geochemistry of beryllium to this type of rock. Landergren (1948b) determined beryllium in several pyrometasomatic deposits in Sweden. The analytical results for European localities are given in table 12. The discovery of idocrase of high beryllian content

TABLE 12.—*Beryllia in pyrometasomatic rocks from Germany, Norway, and Sweden*

[All analyses of rocks from Sweden from Landergren (1948b),[1] others from Goldschmidt and Peters (1932)]

Description	Locality	Number of samples	BeO (percent) High	BeO (percent) Average
Skarn[2]-magnetite	Nordmark region, Sweden.	6	0.03	0.01
Banded quartz-hematite, skarn-magnetite, sulfides.	Skinnskatteberg region, Sweden.	12	.03	.01
Quartz-magnetite, skarn-hematite	Silvberg-Sater region, Sweden.	6	.03	.01
Grossularite[3]-diopside-wollastonite hornfels.	Thale-Friedrichsbrunn, Germany.	1	------	.01
Grossularite[3]-diopside-anorthite hornfels.	Braulage, Germany.	1	------	.01
Skarn-magnetite, cummingtonite.	Persberg region, Sweden.	6	.02	.007
Calcite-magnetite, quartz-hematite, actinolite-skarn-magnetite, others.	Norberg region, Sweden.	17	.03	.007
Skarn-magnetite	Uppland region, Sweden.	12	.02	.006
Calcite-magnetite	Stallberg, Sweden	2	.008	.006
Diopside-skarn-magnetite.	Garpenberg region, Sweden.	7	.02	.004
Skarn-magnetite, quartz-magnetite.	Sodermanland region, Sweden.	4	.008	.004
Amphibole skarn, cummingtonite skarn, quartz-amphibole skarn.	Nora-Viker region, Sweden.	4	.03	.004
Anorthite-cordierite hornfels.	Thale-Friedrichsbrunn, Germany.	1	------	.001
Anorthite-diopside hornfels.	Aarvold-Grorud, Norway.	1	------	.001
Grossularite-diopside hornfels.	Aro, Norway	1	------	.001
Skarn-magnetite	Grythyttan region, Sweden.	4	<.003	<.003
Manganoan olivine, magnetite, mica, others.	Ljusnarsberg region, Sweden.	9	<.003	<.003
Skarn-magnetite, quartz-skarn-magnetite.	Norrbarke region, Sweden.	3	<.003	<.003
Anorthite-hypersthene hornfels.	Aarvold, Norway	1	------	<.001
Andradite skarn	Grua, Norway	2	<.001	<.001

[1] A total of 150 analyses, mostly of gangue from pyrometasomatic iron deposits. Some metamorphosed quartz-iron sediments included where associated with silicates. Minimum content 0.003 percent BeO at all localities.
[2] Skarn is a type of tactite, generally rich in andradite and hedenbergite.
[3] Grossularite or idocrase or both.

at Franklin, N. J. (Palache and Bauer, 1930, p. 31) raised hopes that idocrase in other deposits might be similarly rich in beryllium; however, Zilbermintz and Roschkova (1933) showed that beryllian idocrase occurs only rarely.

Interest in pyrometasomatic beryllium was revived by the discovery of helvite at Iron Mountain, N. Mex. (Strock, 1941a). In a detailed survey of this deposit, Jahns (1944a; 1944b) found that beryllium occurred in greatest amount as helvite associated with magnetite and fluorite, in a tactite having a finely banded structure of diffusion-replacement origin ("ribbon rock"). Other tactites rich in magnetite, fluorite, grossularite, idocrase, and other silicates contain less beryllium.

Although the deposit at Iron Mountain is not ore at present, it has focused attention on tactite deposits as potential sources of beryllium. The present investigation included sampling of a large number of pyrometasomatic deposits in the western United States. The results are summarized in table 13, along with some

TABLE 13.—*Beryllia content of some pyrometasomatic and related deposits of the United States*

Locality	Number of samples [1]	BeO content			Mineralogy [2]	Associated metals [2]	Associated intrusive rocks [2]
		High	Low	Average			
Bartlett, Carroll County, N. H.	[3] 2	1.6	1.0	1.5	Magnetite, hematite, *danalite*, galena chalcopyrite, fluorite, quartz.	Fe, Be	Granite.
Iron Mtn., Sierra County, N. Mex.	(4)	3.5	.4	.7	Magnetite, fluorite, *helvite*	Be, Fe, W	Granite.
Do	(4)	.85	.1	.2	*Grossularite* (0.19), *idocrase* (1.09), *helvite*, fluorite, chlorite.		
Magnet Cove, Hot Springs County, Ark.	1			.028	*Idocrase* (0.04), phlogopite	Fe	Nepheline syenite.
Star mine, Elko County, Nev.	3	.056	.0044	.027	Garnet, diopside, epidote, quartz, calcite, scheelite.	W	Biotite granite, quartz monzonite.
Mill Creek, Anaconda, Mont.	1			.022	Idocrase, fluorite, calcite, hedenbergite, biotite.	None	Diorite.
Dragoon Mts., Cochise County, Ariz.	4	.04	.004	[5] .02	Garnet, epidote, hematite, galena, sphalerite.	Pb, Zn	Granite.
Victorio Mts. district, Luna County, N. Mex.	10	.1	.003	.02	Garnet, calcite, *helvite*, serpentine, *idocrase* (0.2), fluorite.	W, Be	Rhyolite porphyry.
Victory tungsten deposits, Mammoth Range, Nye County, Nev.	1			.014	Biotite, chlorite, amphibole(?), pyroxene(?).	W	Granodiorite.
Drumlummon mine, Marysville, Mont.	1			.011	Quartz, garnet, mica, feldspar	Au, Ag	Quartz monzonite.
Carpenter district, Grant County, N. Mex.	9	.02	<.001	.01	Quartz, fluorite, galena, sphalerite, garnet, chlorite, *helvite*.	Pb, Zn	Do.
Gallinas district, Lincoln County, N. Mex.	[6] 1			[6] .008	Magnetite, actinolite	Fe	Syenite porphyry.
Rose Creek, Pershing County, Nev.	6	.024	.0032	.0078	Diopside, actinolite, feldspar, quartz, scheelite, pyrite.	W	Granite to diorite.
Capitan district, Lincoln County, N. Mex.	[6] 1			[5] .005	Muscovite, tremolite	Fe	"Aplite."
Wind Mtn., Otero County, N. Mex.	10	.026	<.001	.005	Aegerite, riebeckite, feldspar, eudialite, wollastonite, garnet.	Be	Nepheline syenite pegmatites.
Cave Peak, Culberson County, Tex.	3	.0005	<.004	<.004	Spurrite, merwinite; epidote, calcite, garnet, idocrase.	W, Be	Granite and rhyolite.
Marble Canyon, Culberson County, Tex.	7	<.004	<.004	<.004	Brucite, calcite, quartz, diopside, akermanite, wollastonite.	None	Syenite.
Quitman Mts., Hudspeth County, Tex.	9	<.004	<.004	<.004	Garnet, actinolite, epidote, hematite, quartz, idocrase.	Cu, W, Pb	Quartz monzonite.
Sierra Prieta, Hudspeth County, Tex.	2	<.004	<.004	<.004	Calcite, unidentified silicates	None	Phonolite.
Panther Canyon area, Humboldt Range, Pershing County, Nev.	12	.0078	<.0001	.0023	Diopside, idocrase, feldspar, epidote, tremolite, others.	None	Aplite, granite porphyry.
Nevada-Massachusetts Co. mines, Mill City district, Pershing County, Nev.	30	.004	<.0001	.002	Garnet, epidote, quartz, calcite, scheelite.	W	Granodiorite.
Franklin district, Sussex County, N. J.	[7] 10	.003	<.0004	.002	*Willemite* (0.005), franklinite, calcite, garnet, diopside (0.01), zincite, rare idocrase (3.95), and barylite.	Zn	Granite pegmatite.
Oreana mine, Humboldt Range, Pershing County, Nev.	3	.0031	.0008	.0018	"Tactite and silicated marble"	None	Aplite, pegmatite.
Pine Creek mine, Inyo County, Calif.	5	.0037	<.0001	.0017	Garnet, diopside, epidote, quartz, feldspar, scheelite, molybdenite.	W, Mo	Quartz diorite.
Ragged Top mine, Trinity Range, Pershing County, Nev.	5	.0019	<.0001	.0013	Garnet, diopside, scheelite	W	Granodiorite.
Johnson district, Cochise County, Ariz.	[11] 12	.005	<.0004	.001	Garnet, diopside, epidote, chalcopyrite, sphalerite, *idocrase* (0.005).	Cu	Quartz monzonite.
Burro Mts., Grant County, N. Mex.	[12] 1			[5] .001	Silicates, scheelite	W	Quartz monzonite(?).
Bisbee, Cochise County, Ariz.	[8 9] 1			[5] <.001	Calcite, pyrite, tremolite, diopside, chalcopyrite.	Cu	Granite porphyry.
Christmas mine, Gila County, Ariz.	[8 9] 1			[5] <.001	Garnet, idocrase, epidote, quartz, magnetite, pyrite, chalcopyrite.	Cu	Quartz diorite.

See footnotes at end of table.

TABLE 13.—*Beryllia content of some pyrometasomatic and related deposits of the United States*—Continued

Locality	Number of samples [1]	BeO content			Mineralogy [2]	Associated metals [2]	Associated intrusive rocks [2]
		High	Low	Average			
Ajo, Pima County, Ariz.	[8,9] 1			[5] <0.001	Chlorite, epidote, sericite, orthoclase, chalcopyrite, pyrite.	Cu	Quartz monzonite.
Control mines, Oracle, Pima County, Ariz.	[8] 1			[5] <.001	Calcite, garnet, epidote, quartz, chalcopyrite, galena, sphalerite.	Cu, Pb, Zn	Hornblende diorite.
Greenhorn Mts., Kern County, Calif.	[8] 3	<0.001	<0.001	[5] <.001	Quartz, biotite, garnet, epidote; wollastonite, scheelite, pyrrhotite.	W, Mo	Granodiorite.
Darwin, Inyo County, Calif.	[8] 3	<.001	<.001	[5] <.001	Wollastonite, idocrase, grossularite, epidote, scheelite, pyrite, fluorite.	W, Pb, Ag	Quartz diorite.
Tungsten Hills, Inyo County, Calif.	27	.0045	<.0001	<.001	Quartz, calcite, garnet, epidote, scheelite.	W.	Granite, quartz monzonite.
Calumet mine, Chaffee County, Colo.	7	<.001	<.001	<.001	Garnet, magnetite, actinolite, epidote, kaolinite, calcite, quartz, pyrite.	Fe	Granodiorite.
Monarch mining district, Chaffee County, Colo.	6	<.001	<.001	<.001	Garnet, epidote, quartz, calcite, pyrite, limonite.	Au	Quartz monzonite.
Grayback mining district, Costilla County, Colo.	3	<.001	<.001	<.001	Garnet, epidote, actinolite, diopside, magnetite.	Au	Monzonite porphyry.
Italian Mtn., Gunnison County, Colo.	11	.0013	<.0001	<.001	Garnet, actinolite, graphite, quartz, idocrase.	Au	Quartz monzonite.
Snowmass Mtn. area, Gunnison County, Colo.	8	<.001	<.001	<.001	Garnet, epidote, hematite, pyrite, quartz, calcite, diopside.	None	Granite
Tomichi Mining district, Gunnison County, Colo.	19	<.001	<.001	<.001	Garnet, epidote, magnetite, pyrite, chalcopyrite, galena, sphalerite.	Pb, Zn, Ag	Quartz monzonite.
Rico mining district, Montezuma County, Colo.	1			<.001	Garnet, epidote, galena, sphalerite, chlorite.	Pb, Zn	Do.
Breckenridge mining district, Summit County, Colo.	3	<.001	<.001	<.001	Garnet, epidote, magnetite, pyrite	Au	Quartz monzonite porphyry.
Mackay district, Custer County, Idaho.	[8] 4	<.001	<.001	[5] <.001	Andradite, chalcopyrite, pyroxene, pyrite, pyrrhotite, fluorite, magnetite.	Cu	Granite porphyry.
Georgetown district, Deer Lodge County, Mont.	7	<.001	<.001	<.001	Magnetite, olivine, dolomite, hornblende, epidote.	Fe, Au, Cu	Granodiorite.
Garnet district, Granite County, Mont.	2	<.001	<.001	<.001	Garnet, diopside, magnetite	Au, Cu	Do.
Philipsburg district, Granite County, Mont.	3	<.001	<.001	<.001	Calcite, quartz, pyrolusite, magnetite, serpentine.	Mn, Ag	Do.
Red Lion district, Granite County, Mont.	2	<.001	<.001	<.001	Quartz, limonite, sericite, dolomite	Au	Do.
Edwards, St. Lawrence County, N. Y.	[8,9] 1			[5] <.001	Calcite, diopside, tremolite, pyrite, sphalerite, willemite.	Zn	Granitic pegmatite.
Cornwall, Lebanon County, Pa.	[8] 3	<.001	<.001	[5] <.001	Magnetite, diopside, actinolite, phlogopite, calcite.	Fe, Cu, Co	Quartz diabase.
West Tintic mining district, Juab and Utah Counties, Utah.	[8] 3	<.001	<.001	[5] <.001	Magnetite, specularite, garnet, epidote, diopside, tremolite, quartz, scheelite.	Au, Ag, W	Quartz monzonite and granodiorite.
Tintic mining district, Juab County, Utah.	[8] 5	<.001	<.001	[5] <.001	Magnetite, specularite, quartz, epidote, garnet, diopside.	Au, Ag, Te	Quartz monzonite.
Little Cottonwood mining district, Salt Lake County, Utah.	[8] 2	<.001	<.001	[5] <.001	Idocrase, quartz, garnet	Ag, Cu, Pb	Do.
Ophir mining district, Tooele County, Utah.	[8] 1			[5] <.001	Marble, epidote	Pb, Ag	Monzonite and lamporphyre dikes.
Garfield Peak, Natrona County, Wyo.	1			<.001	Quartz, calcite	None	Latite.
Bayard, Grant County, N. Mex.	5	.002	[10] <.0004 (1)	[5] .0009	Hedenbergite, sphalerite, pyrite, rhodonite, garnet.	Cu, Zn	Quartz monzonite.
Mt. Silver Heels, Como, Colo.	3	.0010	.0004	.0008	Magnetite, garnet, epidote	Au	Do.
Cuchillo Negro district, Sierra County, N. Mex.	3	.001	.0005	[5] .0007	Calcite, garnet, epidote, quartz, galena, sphalerite.	Pb, Zn	Granite (?).
Morenci, Greenlee County, Ariz.	[8] 2	.0005	<.0001	[5] <.0005	Andradite, diopside, tremolite, pyrite, magnetite, chalcopyrite.	Cu, Zn	Diorite to granite porphyries.
Sybille Creek, Wheatland, Wyo.	6	.0013	<.0001	.0005	Sericite, actinolite, idocrase, calcite, biotite, garnet.	None	Granite.
Hornet mine, Rio Arriba County, N. Mex.	2	.0008	<.0003	[5] .0004	Quartz, calcite, garnet, pyrite, galena, sphalerite.	Pb, Zn	Granodiorite.
Sedalia mine, Chaffee County, Colo.	1			.0004	Actinolite, idocrase, garnet, sphene, pyrite.	Cu	None.
Courtland, Cochise County, Ariz.	2	<.0004	<.0004	[5] <.0004	Garnet, epidote, pyrite, chalcopyrite.	Cu	Quartz monzonite.
Tombstone, Cochise County, Ariz.	4	.0007	<.0004	[5] <.0004	Garnet, calcite, tremolite, idocrase	Ag, Pb, Cu, Mn	Granodiorite.
Empire district, Pima County, Ariz.	4	<.0004	<.0004	[5] <.0004	Garnet, diopside, quartz, calcite; wollastonite.	W	Quartz monzonite.
Helvetia, Pima County, Ariz.	9	.002	<.0004	[5] <.0004	Garnet, diopside, chalcopyrite	Cu	Granite and alaskite porphyries and aplites.
Mineral Hill and Twin Buttes districts, Pima County, Ariz.	14	.001	<.0004	[5] <.0004	Garnet, quartz, epidote, pyrite	Zn, Pb, Cu, W	Granodiorite granite.
Patagonia district, Santa Cruz County, Ariz.	9	<.0004	<.0004	[5] <.0004	Garnet, quartz, chalcopyrite, galena, sphalerite.	Cu, Pb, Zn	Quartz monzonite and granite porphyry.

See footnotes at end of table.

TABLE 13.—*Beryllia content of some pyrometasomatic and related deposits of the United States*—Continued

Locality	Number of samples[1]	BeO content			Mineralogy[2]	Associated metals[2]	Associated intrusive rocks[2]
		High	Low	Average			
Cimarroncito district, Colfax County, N. Mex.	4	<0.0004	<0.0004	[5]<0.0004	Garnet, diopside, hematite, hornblende, pyrite, chalcopyrite.	Cu	Quartz monzonite.
Elizabethtown, Colfax County, N. Mex.	3	<.0004	<.0004	[5]<.0004	Diopside, hornblende, scapolite(?)	Au	Monzonite porphyry.
Do	3	.0004 [10]	<.0004 (2)	[5]<.0004	Epidote, hematite	Fe	Do.
Organ Mts., Dona Ana County, N. Mex.	9	.0004 [10]	<.0004 (8)	[5]<.0004	Garnet, quartz, hematite, sphalerite, altaite.	Cu, Ag, Pb	Monzonite to quartz monzonite.
Eureka district, Grant County, N. Mex.	7	<.0004	<.0004	[5]<.0004	Garnet, pyroxene, chalcopyrite	Cu, Mo, W	Monzonite.
Fierro, Grant County, N. Mex	1			[5]<.0004	Magnetite, serpentine	Fe	Quartz monzonite.
Hanover, Grant County, N. Mex	10	.0008 [10]	<.0004 (8)	[5]<.0004	Garnet, hedenbergite, epidote, magnetite, ilvaite, pyrite, sphalerite.	Zn	Do.
Pinos Altos, Grant County, N. Mex	2	<.0004	<.0004	[5]<.0004	Calcite, sphalerite, pyrite, chalcopyrite.	Cu, Zn	Granodiorite.
Santa Rita, Grant County, N. Mex	10	.001	<.0004	[5]<.0004	Epidote, garnet, pyrite, chalcopyrite, magnetite.	Cu, Zn	Quartz monzonite.
Apache Hills, Hidalgo County, N. Mex.	4	<.0004	<.0004	[5]<.0004	Garnet, epidote, pyrite.	Cu, W	Quartz monzonite porphyry.
Peloncillo Mts., Hidalgo County, N. Mex.	3	<.0004	<.0004	[5]<.0004	Garnet, galena, sphalerite	Pb, Zn	Monzonite porphyry.
Jones Camp district, N. Mex	[6] 1			[5]<.0004	Actinolite	Fe	Diabase.
Tres Hermanas Mts., Luna County, N. Mex.	2	<.0004	<.0004	[5]<.0004	Garnet, amphibole, calcite	Zn	Granite porphyry.
Ortiz district, Santa Fe County, N. Mex.	2	<.0004	<.0004	[5]<.0004	Garnet, hornblende	Cu	Syenite.
San Pedro district, Santa Fe County, N. Mex.	11	<.0004	<.0004	[5]<.0004	Garnet, calcite, hornblende, epidote	Cu, W	Do.
Potosi district, Humboldt County, Nev.	[8] 5	.0003	<.0001	.0003	Epidote, quartz, garnet, scheelite	W, Cu, Au, As	Granodiorite.
Rawhide district, Mineral County, Nev.	12	.0028	<.0001	.0002	"Tactite and hornfels"	W	Granite.
Ouray mining district, Ouray County, Colo.	2	.0002	.0002	.0002	Garnet, magnetite, epidote, quartz, limonite.	Au	Quartz monzonite.
Beaver-Tarryall mining district, Park County, Colo.	7	.0001	.001	.0001	Garnet, epidote, magnetite, quartz, calcite, phlogopite.	Au	Do.
Geneva claims, Chaffee County, Colo	3	<.0001	<.0001	<.0001	Molybdenite, garnet, pyrite, galena, calcite.	Mo	Granite.
Georgetown area, Clear Creek County, Colo.	1			<.0001	Garnet, epidote	None	Do.
Gold Brick mining district, Gunnison County, Colo.	2	<.0001	<.0001	<.0001	Garnet, magnetite, quartz, pyrite, chalcopyrite.	Au	Diorite and granite.
Tincup mining district, Gunnison County, Colo.	3	<.0001	<.0001	<.0001	Magnetite, garnet, specularite, epidote.	Fe	Quartz diorite.
Rush Basin area, Montezuma County, Colo.	1			<.0001	Garnet, specularite, epidote, quartz	None	Monzonite.
Montezuma mining district, Summit County, Colo.	2	<.0001	<.0001	<.0001	Garnet, epidote, quartz, sulfides	Au	Quartz monzonite.
Toll Mountain area, Deer Lodge County, Mont.	1			<.0001	Garnet, diopside, hedenbergite	None	Granite.
Neihart-Yogo Peak area, Cascade County, Mont.	3	<.0001	<.0001	<.0001	Pyroxene, epidote, garnet, calcite, prehnite, thomsonite, orthoclase, idocrase, magnetite, wollastonite, sphene, eudialite, merwinite.	None	Lamprophyre.
Elkhorn mining district, Jefferson County, Mont.	3	<.0001	<.0001	<.0001	Epidote, garnet, pyrrhotite, calcite, scapolite.	Pb, Zn	Granite.
Spring Hills mine, Lewis and Clark Counties, Mont.	1			<.0001	Garnet, olivine, scapolite, titanite, epidote.	Au	Diorite.
Silver Star mining district, Madison County, Mont.	2	<.0001	<.0001	<.0001	Hedenbergite, garnet, epidote, hornblende, calcite, magnetite, pyrrhotite.	Au	Granite.
Ophir mining district, Powell County, Mont.	1			<.0001	Garnet, epidote, calcite	Au	Quartz monzonite.
Priests Pass area, Powell County, Mont.	1			<.0001	Garnet, calcite	Au	Do.
Highland mining district, Silver Bow County, Mont.	2	<.0001	<.0001	<.0001	Garnet, epidote, magnetite, diopside, actinolite, pyrite, chalcopyrite.	Au	Diorite and quartz monzonite.
Haystack Stock, Sweet Grass County, Mont.	1			<.0001	Garnet, epidote, quartz, actinolite	None	Quartz monzonite.

[1] Samples collected by the U. S. Geological Survey during the present investigation, unless otherwise noted.

[2] Minerals, metals, and intrusive rocks spacially associated in the mineral deposit, not necessarily related in time or genesis. Known beryllium-bearing minerals in italics, their maximum beryllium content for that deposit in parentheses.

[3] Samples collected by D. M. Henderson, University of Illinois.

[4] Data from Jahns (1944a, p. —, 76).

[5] Determinations on plates for general scanning, not for precise determination o BeO alone.

[6] Samples collected by V. C. Kelley, U. S. Geological Survey.

[7] Samples furnished through courtesy of the New Jersey Zinc Co.

[8] Samples collected by Mine, Mill, and Smelter Survey, U. S. Geological Survey.

[9] Tailings or slag samples only.

[10] Numbers in parentheses indicate number of samples having a BeO content below limit of sensitivity.

[11] Six of the samples collected by J. R. Cooper, U. S. Geological Survey.

[12] Sample collected by Elliot Gillerman, U. S. Geological Survey.

earlier determinations from the files of the U. S. Geological Survey. The minerals, metals, and intrusive rocks of each deposit are also tabulated, although in most places they probably are unrelated in origin and time of deposition to the beryllium.

Extensive sampling shows that only a small number of pyrometasomatic deposits contain more than 0.001 percent BeO, the average for the earth's crust. Only 15 percent of the United States deposits sampled contain more than 0.005 percent BeO. The Swedish deposits are of somewhat better grade. In most of the pyrometasomatic deposits that have been analyzed throughout the world, beryllium was not detected.

CHARACTERISTICS OF BERYLLIUM-BEARING DEPOSITS

Some of the common minerals in the beryllium-bearing pyrometasomatic rocks are helvite, idocrase, garnet (mostly andradite), magnetite, fluorite, scheelite, and diopside-hedenbergite. Theoretically, these minerals may form in any metamorphic temperature and pressure facies from "pyroxene hornfels" down to "epidote amphibolite" (Turner, 1948, p. 70–90). Paragenetic data from the few deposits studied in detail indicate that deposition of helvite is possible through this entire range of temperature.

Idocrase commonly is associated with helvite in beryllium-bearing tactites. (See table 13; also tables 12 and 13 of Glass, Jahns, and Stevens, 1944). Because grossularite and idocrase are similar in structure and composition, although idocrase is slightly poorer in aluminum, one might wonder why beryllium occurs in idocrase-bearing tactites in preference to grossularite-bearing tactites. Idocrase in normal metamorphosed limestones may form in equilibrium with grossularite and diopside, grossularite and calcite, or diopside and calcite (wollastonite may take the place of calcite at higher temperatures), but only if the composition of the rock is less aluminous than grossularite itself (Turner, 1948, p. 91). Holser (1953, p. 607) has noted in Victorio Mountains, N. Mex., that helvite forms in rocks having relative low alumina content. At Rose Creek, Nev., beryllium occurs without the aluminum garnet (grossularite), the principal minerals being diopside, actinolite, and feldspar. Thus, among metamorphosed limestones, beryllium is more likely to be found in those that were originally low in argillaceous material and to which little alumina has been added in the metamorphic process.

Actually, the nature of equilibrium relations between idocrase and grossularite is in some doubt. Kerr (1946a, p. 58) observes that both minerals form after marmorization of limestone but before intense replacement. According to Osborne (1932, p. 221–222), idocrase may be "generated during retrogressive metamorphism with which was associated a change promoted by falling temperature, and at pressures under which grossular was not stable. . . The data available concerning the various grades suggest that while this mineral may occur with grossular and wollastonite, it is also stable in a lower grade where these two minerals fail to develop." The nature of the implied pressure change is not discussed. Tilley (1927, p. 375) suggested that both idocrase and grossularite might form at lower temperatures than normal when subjected to the shearing stresses of regional metamorphism.

A further reason for the association of beryllium and idocrase may be due to fluorine. Fluorine-rich idocrase and fluorite are common minerals in beryllium-bearing deposits and thus may be a clue to the occurrence of helvite or other beryllium minerals. Although the idocrase-fluorite association is not found in all pyrometasomatic deposits containing beryllium, the Darwin, Calif., deposit is the only one sampled at which these minerals were found without beryllium. Idocrase without fluorite or beryllium was found at several localities. In the Carlingford district, Ireland, are several varieties of idocrase, some associated with simple isochemically metamorphosed limestones, and others associated with "pneumatolytic" alteration around pegmatites. Regarding the associations, Osborne (1932, p. 222) says, "Where pneumatalytic metamporhism operates in an aureole, fluorine, if available, enters the constitution of vesuvianite, but it is suggested here that vesuvianite which is due entirely to diaphoretic changes * * * will be fluorine free." The implication that fluorine-rich idocrase and associated products are of pneumatolytic origin may be valid. In the absence of experimental data the nature of the beryllium-fluorine relations in pyrometasomatic deposits remains conjectural.

Magnetite and scheelite are commonly found in deposits containing beryllium minerals. In most of the deposits, however, helvite formed later than magnetite, mainly in open cavities. At Iron Mountain, N. Mex., scheelite is also earlier than helvite. The helvite in tactite in the Victorio Mountains may be exceptional (Holser, 1953, p. 606) in that it appears to be contemporaneous with the other silicates and to have formed at relatively high temperature. Scheelite is present but magnetite is not.

Most of the Nevada and California scheelite-bearing tactite deposits sampled during the present investigation contain more beryllium than the average pyrometasomatic deposit (see table 13). As yet the beryllium-bearing minerals in these deposits and their positions in the mineral sequence are not known. The relation between beryllium and iron or tungsten, although not clearly defined, is in marked contrast to the negative correlation of beryllium with copper, zinc, or lead.

Landergren (1948b) found little correlation between type of ore and beryllium content in the pyrometasomatic iron deposits of Sweden. In the United States, however, beryllium was not found in deposits containing magnetite with olivine or derived serpentine like those at Fierro, N. Mex. The lack of beryllium can hardly be due to an excess of magnesium, as magnesium-rich pyroxene or amphibole is a common associate of beryllium-bearing pyrometasomatic deposits and may occur in such a deposit to the exclusion of garnet. The fact that olivine normally forms at higher temperatures than pyroxene or amphibole may account for the apparent lack of correlation between olivine and beryllium in these deposits.

Jahns (1944b, p. 179–189) suggests that the banded and orbicular structures observed at Iron Mountain, N. Mex., may be a clue to the presence of beryllium in tactite. He notes that similar tactite were previously described from Seward, Alaska, and Pitkaranta, Finland. The former was tested and found to contain beryllium. In the latter area, helvite occurs in intimate association with idocrase and fluorite (Trustedt, 1907); the idocrase has been found to contain 0.18 percent BeO (Zilbermintz and Roschkova, 1933, p. 253). None of the beryllium-bearing tactite sampled in the present investigation showed banding of this type, but banded and orbicular structures are common in magnetite-serpentine rocks that lack beryllium, as at Philipsburg, Mont., and in the Quitman Mountains, Tex.

Jahns (1944b, p. 196–204) postulates that the banded beryllium-bearing tactite is of hydrothermal origin, in contrast to massive tactites of simpler mineralogy, which may be pneumatolytic. He infers that the latter are less likely to contain beryllium. The helvite deposit in the Victorio Mountains, N. Mex., is massive and of simple mineralogical composition. The difficulty of distinguishing the actions of liquid and gaseous solutions at high temperature does not exclude the possibility that even this deposit may be hydrothermal. Whatever the details of their origin, such massive tactite cannot be excluded as possible sources of beryllium.

Results of analyses show that simple metamorphic hornfels, quartzite, and marbles that surround tactite deposits are notably lacking in beryllium. It must be presumed to have been added to the tactite, along with other constituents, by solution probably derived from an igneous source. The commonly held theories of magmatic differentiation imply that beryllium should be concentrated with late products of differentiation, such as granite or nepheline syenite and associated pyrometasomatic deposits. Actually beryllium-bearing pyrometasomatic deposits are more commonly associated with rocks of intermediate composition, such as granodiorite and monzonite. Though some beryllium is found in the contact zone of feldspathoidal intrusive rocks, the tactite zones adjacent to these rocks generally are small and poorly developed.

RELATED OCCURRENCES

Helvite at the Grandview mine, Carpenter district, New Mexico (Weissenborn, 1948), is nearly all found as sharp, tiny tetrahedra on quartz and fluorite crystals in vugs and in veins. In some places the quartz was coated with chalcedony before deposition of the helvite. Although a small amount of garnet and other silicates are found replacing the limestone in the Grandview mine, the manner of occurrence suggests that the helvite is a low-temperature mineral, more closely related to vein filling than to pyrometasomatism.

The zinc deposits at Franklin and Sterling Hill, N. J., bear little relation to any other deposits in the world, with the possible exception of those at Langban, Sweden (Palache, 1929b). The rare mineral barylite has been found at only these two New Jersey localities. Brown idocrase, similar to that in which a large amount of beryllium has been found, is of rare occurrence in the Franklin mine, and the blue variety (cyprine), which contains a small amount of beryllium, is even rarer. Palache (1929a, p. 10–11) believed that these minerals were a product of pneumatolytic action around intruded late pegmatites. No beryl has been found in the pegmatites, or elsewhere in the district. A large amount of beryllium at low concentration is contained in the great masses of willemite and associated zincian-manganian diopside. The pegmatites were formed after deposition of willemite and may have reconcentrated a little beryllium in their vicinity. It is a mystery why some of the beryllium does not occur as helvite, especially because of the excess of manganese, zinc, and iron.

Beryl is found in mica and amphibole schists at the Izumrudnie (emerald) district of the southern Urals (Fersman, 1929, p. 74–116); Habachtal, Salzburg, Austria (Koenigsberger, 1913); Leydsdorp, South Africa (Le Grange, 1930); Keene, N. H. (Olson, 1942, p. 372); and the Black Hills, S. Dak. (Page and others, 1953, p. 46). At all of the localities for which detailed geologic description is available, the beryl is near granitic pegmatites that are beryl-bearing. At the Tungsten King mine, Arizona, beryl occurs in the chlorite schist in the hanging wall of the quartz-beryl-tungsten vein. More remarkable are two similar occurrences in which the beryl is in marble (Just, 1926; Chhibber, 1945). Studies of these deposits indicate that the beryllium has been added to the wall rock from the pegmatite or vein (see also Stoll, 1945). Apparently, this mode of occurrence is rare for beryl, as most beryl pegmatites do not introduce beryllium into the wall rock even in trace amounts. In most of the deposits mentioned, the beryl in the wall rock is much less abundant than in the associated pegmatites. With the exception of the Urals deposits, which are quite large, they are of little economic importance unless the beryl is of gem quality.

BERYLLIUM IN VEIN DEPOSITS

Beryllium minerals, chiefly beryl or helvite, have been found sparsely disseminated in certain types of veins. Such veins generally contain ores of useful metals and are thus well suited to recovery of beryllium as a byproduct. The published descriptions of beryl-bearing veins are tabulated and discussed by Holser (1953, p. 604–605 and Adams, 1953). More than 100 high-temperature veins in the western United States were sampled and analyzed for beryllium. Previously, a large number of vein samples collected by the U. S. Geological Survey had been analyzed qualitatively. These analytical data are summarized in table 14. Analyses for several miscellaneous deposits that are not strictly veinlike are included in the table.

Those veins in which beryllium minerals have been noted, as well as those in which beryllium was found by sampling, fall largely into three groups: quartz-tungsten veins; quartz-gold veins; and manganese-lead-zinc veins.

QUARTZ-TUNGSTEN VEINS

Beryllium appears to be more common in quartz-tungsten veins than in other kinds of veins, the association having been noted at a dozen or more localities throughout the world. In some deposits, as exemplified by the Boriana mine, Mohave County, Ariz. (Hobbs, 1944, p. 254), the quartz veins contain fluorite, wolframite, and sulfides. Generally, beryllium occurs in beryl, which is found only in small amounts. In some veins of this type the beryl may be altered to phenakite or bertrandite, but no helvite has been noted. In the Tungsten King mine, Arizona, beryl occurs in a scheelite-bearing vein. However, scheelite veins in Nevada and California sampled during the present investigation contain little or no beryllium; this indicates that beryllium and tungsten are not invariably associated.

Beryl occurs early in the mineral sequence in the few instances where it has been studied. At the Victorio Mountains, N. Mex., deposits, it forms a selvage on the walls; and at Mount Antero, Colo., and Irish Creek, Va., it immediately follows the formation of some of the quartz. In a few places, as at Hill City, S. Dak., and Irish Creek, Va., the beryl-bearing quartz veins contain cassiterite instead of tungsten minerals. Studies of foreign deposits (Tetyaev, 1918; Turner, 1919) where both tin and tungsten occur in the veins indicate that cassiterite may be later in the mineral sequence than tungsten minerals. At Irish Creek, cassiterite and beryl are nearly contemporaneous (Koschmann, Glass, and Vhay, 1942, p. 280).

The occurrence of beryllium in quartz veins containing tin and tungsten suggests that it might also be expected in molybdenum deposits. Molybdenite is a major constituent in a beryl-bearing vein at Mount Antero, Colo., and at the Black Pearl mine, Yavapai County, Ariz., and the two minerals occur together in several veins in Asia. However, most of the molybdenite deposits in the United States that have been tested contain little beryllium, including those at Climax, Colo., Red River, N. Mex., and Bunker Hill, Ariz.

Although the content of beryllium probably varies markedly throughout a given vein, as is true for tungsten, it appears to average 0.0X percent BeO for those tungsten veins in which beryllium is present. In two veins sampled in detail (Tungsten King mine, Little Dragoon district, Arizona, and Eloi claim, Victorio Mountains, New Mexico), there is no correlation between tungsten and beryllium content, although most samples high in beryllium content also contained appreciable tungsten. The vein system at the Tungsten King mine extends for several thousand feet but has been sampled for beryllium over only a small part of its length.

Some veinlike bodies that are otherwise similar to those described above contain feldspar (Norman, 1945; Carne, 1911, p. 58, 67) and are probably transitional between the quartz-tungsten-beryllium veins and quartz-rich parts of pegmatites. Several of the quartz-tungsten-beryllium veins appear to be related to neighboring pegmatites.

QUARTZ-GOLD VEINS

Samples of gold ores from the epithermal veins in the Oatman district, Mohave County, Ariz., and the hypothermal veins in the Bald Mountain district, Lawrence County, S. Dak., contain about 0.01 percent BeO (see table 14). In both districts (Wilson, Cunningham, and Butler, 1934, p. 80–115; Connolly, 1927, p. 60–94) the gangue includes carbonates and fluorite. The beryllium-bearing mineral has not been determined.

TABLE 14.—*Beryllia in some veins and related deposits in the United States*

Locality	Number of samples [1]	Percent BeO			Mineralogy [2]	Principal metals
		High	Low	Average		
Victorio Mts., N. Mex.: Eloi-Morloch claims	7	0.02	0.005	0.02	Quartz, *beryl*, muscovite, wolframite	W.
Mount Antero, Chaffee County, Colo.: California mine.	[3] 1			.016	Quartz, *beryl*, molybdenite	Mo.
Providence Mts., San Bernardino County, Calif.: Scheelite Ray mine.	2	.01	.01	[5] .01	Scheelite, quartz	W.
Little Dragoon Mts., Cochise County, Ariz.: Tungsten King mine.	4	.052	.0008	.01	Quartz, scheelite, *beryl*, chlorite	W.
San Francisco district, Mohave County, Ariz	[4, 6] 7	.03	[7] <.001 (3)	[5] .01	Quartz, calcite, orthoclase, gold, fluorite	Au.
Bald Mtn. district, Lawrence County, S. Dak	[4] 4	.02	.01	[5] .01	Quartz, dolomite, glauconite, pyrite, gold, arsenopyrite, sylvanite, fluorite.	Au.
Thomas Range, Juab County, Utah: Bell Hill mine.	1			[5] .00X	Fluorite, clay, hematite, calcite	F.
Vance County, N. C.: Hamme mine	[4, 6] 3	.008	.004	[5] .007	Quartz, wolframite	W.
Warren and Lyman, Grafton County, N. H	[4] 2	.006	.006	[5] .006	Sphalerite, galena	Zn, Pb.
Apache district, Sierra County, N. Mex.: Midnight mine.	2	.01	<.0004	[5] .005	Quartz, bornite, garnet, epidote	Cu.
Red River, Taos County, N. Mex.: Questa mine	5	.004	.0005	.004	Quartz, calcite, molybdenite	Mo.
Butte district, Silver Bow County, Mont	8	.007	.0005	.003	Galena, sphalerite, rhodonite, rhodochrosite, pyrite, *helvite*.	Pb, Zn.
Black Range, Catron County, N. Mex.: Taylor Creek mine.	1			[5] .002	Cassiterite	Sn.
Burro Mts., Grant County, N. Mex.: Long Lost Brother claim.	1			[5] .002	Fluorite, manganese oxides	F.
Creede district, Mineral County, Colo	2	.002	.002	[5] .002	Amethyst, galena, sphalerite	Ag, Au, Pb, Zn.
Terlingua district, Brewster County, Tex	[4] 4	.005	<.001(3)	[5] .002	Cinnabar, calcite, gypsum, pyrite	Hg.
Holden, Chelan County, Wash	[4, 6] 3	.001	[7] .001(1)	[5] .001	Chalcopyrite, pyrite, sphalerite	Cu, Zn, Au.
Sundance area, Crook County, Wyo	2	.00X	.000X	[5] .001	Fluorite, quartz, calcite, limonite	F.
Mother Lode district, Eldorado, Calaveras, and Amador Counties, Calif.	[4, 6] 23	.002	<.001	[5] .001	Quartz, gold, ferrodolomite, sericite, albite, pyrite.	Au.
Little Dragoon Mts., Cochise County, Ariz.: Bluebird mine.	[8] 3	.0019	.0005	.001	Quartz, muscovite ("greisen"), huebnerite, scheelite, fluorite, *beryl*.	W.
Encampment district, Carbon County, Wyo	2	.002	<.0001	.001	Chalcopyrite, pyrite, bornite, covellite, siderite, quartz, malachite, azurite.	Cu.
Silver Crown district, Laramie County, Wyo	2	<.001	<.001	<.001	Chalcopyrite, quartz, azurite, malachite, pyrite, limonite.	Cu.
Juneau, Alaska: Alaska-Juneau mine	[4, 6] 1			[5] <.001	Quartz, calcite, rutile, tourmaline, pyrite, gold	Au, Ag, Pb.
Metaline district, Pend Oreille County, Wash	[4] 28	<.001	<.001	[5] <.001	Sphalerite, galena	Zn, Pb.
Northport district, Stevens County, Wash.: Van Stone mine.	[4] 1			[5] <.001	Galena, sphalerite, tetrahedrite	Zn, Pb.
Republic district, Ferry County, Wash.: Knob Hill mine.	[4] 1			[5] <.001	Quartz, tetrahedrite, pyrite, chalcopyrite	Au.
Mehama, Marion County, Ore	[4] 3	<.001	<.001	[5] <.001	Sphalerite	Zn.
Glen County, Calif.: Gray Eagle mine	[4] 5	<.001	<.001	[5] <.001	Chromite	Cr.
Guerneville, Sonoma County, Calif.: Mount Jackson mine.	[4, 6] 2	<.001	<.001	[5] <.001	Chalcedony, cinnabar, pyrite	Hg.
San Luis Obispo County, Calif.: Costro mine	[4, 6] 2	<.001	<.001	[5] <.001	Chromite	Cr.
Rociada, San Miguel County, N. Mex.: Azure Chief mine.	1			[5] <.0004	Quartz, garnet, epidote, bornite, hematite	Cu.
Willow Creek, San Miguel County, N. Mex.: Pecos mine.	1			[5] <.0004	Quartz, chlorite, actinolite, muscovite, tourmaline, pyrite, sphalerite, galena, chalcopyrite.	Zn, Pb.
Cherry Creek district, White Pine County, Nev	10	.0009	<.0001	.0003	Quartz, feldspar, scheelite, sulfides	W.
Wauconda district, Okanagan County, Wash	[4] 4	.0003	<.0001	[5] .0002	Quartz, calcite, gold	Au.
Douglas County, Ore.: Bonanza mine	[4] 3	.0004	<.0001	[5] .0002	Cinnabar, pyrite, calcite, quartz	Hg.
Clark Fork district, Banner County, Idaho: Whitedelf mine.	[4] 4	.0003	<.0001	[5] .0002	Siderite, quartz, galena, tetrahedrite	Pb.
Tincup district, Gunnison County, Colo	6	.0013	<.0001	.0002	Molybdenite, galena, sphalerite, huebnerite, quartz, pyrite.	Mo, W, Au.
Gallinas district, Lincoln County, N. Mex.: Red Cloud mine.	[9] 1			.0002	Fluorite, barite, calcite, bastnaesite	F.
Oroville district, Okanogan County, Wash	[4] 4	.0002	<.0001	[5] .0001	Quartz, galena, chalcopyrite, pyrite, marcasite	Pb, Cu.
Marshall Lake district, Idaho County, Idaho	[4] 4	.0004	<.0001	.0001	Molybdenite, pyrite, galena, quartz	Au, Ag.
Monarch district, Chaffee County, Colo	3	.0004	<.0001	.0001	----do	Mo.
Jamestown district, Boulder County, Colo	2	.000X	<.000X	[5] .0001	Fluorite, galena, sphalerite, tetrahedrite, quartz, clay, pyrite, chalcopyrite.	Pb, Zn.
Beaverhead County, Mont.: Poison Lake mine	1			[5] <.000X	Fluorite, thorite, monazite, pyrite, quartz, feldspar, calcite.	F.
St. Peters Dome district, El Paso County, Colo.: Sheffield claim.	1			[5] <.000X	Fluorite, galena, sphalerite, quartz, pyrite, clay, kasolite.	F, Pb, Zn.
Querida area, Custer County, Colo	1			.000X	Pyrite, quartz, limonite, galena, sphalerite, pyrargyrite.	Ag.
Mountain Pass, San Bernardino County, Calif	[10] 3	<.000X	<.000X	[5] <.000X	Calcite, barite, bastnaesite	Ce, etc.
Lake City district, Hinsdale County, Colo	8	.0002	[7] <.0001 (6)	<.0001	Galena, sphalerite, rhodochrosite, quartz	Au, Ag.

See footnotes at end of table.

TABLE 14.—*Beryllia in some veins and related deposits in the United States*—Continued

Locality	Number of samples [1]	Percent BeO			Mineralogy [3]	Principal metals
		High	Low	Average		
Atolia district, San Bernardino County, Calif.	8	<0.0001	<0.0001	<0.0001	Quartz, scheelite, pyrite, calcite, stibnite	W.
White Pine County, Nev.: San Pedro mine	2	<.0001	<.0001	<.0001	Quartz, gold	Au.
Basin district, Jefferson County, Mont.	2	<.0001	<.0001	<.0001	Galena, sphalerite, auriferous pyrite, chalcopyrite, scheelite.	Cu, Au, Pb, Zn.
Centennial district, Albany County, Wyo.	2	<.0001	<.0001	<.0001	Calcite, pyrite, garnet, sericite, limonite, quartz.	Au.
Albany County, Wyo.: Rambler mine	2	<.0001	<.0001	<.0001	Covellite, azurite, malachite, quartz	Cu, Pt.
Montezuma district, Summit County, Colo.	2	<.0001	<.0001	<.0001	Galena, sphalerite, manganosiderite, rhodochrosite, pyrite.	Ag, Pb, Zn.
Ophir district, San Miguel County, Colo.	1			<.0001	Galena, sphalerite, pyrite, wolframite, quartz, tetrahedrite.	Ag, Pb, Zn.
Ouray district, Ouray County, Colo.	2	<.0001	<.0001	<.0001	Galena, sphalerite, chalcopyrite, pyrite, rhodochrosite, dolomite.	Ag, Pb, Zn.
Platoro-Summitville district, Conejos County, Colo.	4	<.0001	<.0001	<.0001	Chalcopyrite, galena, sphalerite, quartz	Ag, Au.
Poughkeepsie Gulch district, San Juan County, Colo.	11	<.0001	<.0001	<.0001	Quartz, galena, sphalerite, barite, tetrahedrite, rhodochrosite, rhodonite, pyrite.	Au, Pb, Zn.
Upper Blue River area, Summit County, Colo.	3	<.0001	<.0001	<.0001	Diopside, galena, sphalerite, molybdenite, pyrite, chalcopyrite, specularite.	Au, Ag.
Upper Uncompahgre district, Ouray County, Colo.	6	<.0001	<.0001	<.0001	Galena, sphalerite, pyrite, fluorite, huebnerite, hematite, chalcopyrite, rhodochrosite.	Au, Pb, Zn.
Wagon Wheel Gap, Mineral County, Colo.	1			<.0001	Fluorite	F.
Congress, Yavapai County, Ariz.	[4,6] 1			[5] <.001	Quartz, pyrite, gold	Au.
Globe district, Gila County, Ariz.: Castle Dome mine.	[4,6] 1			[5] <.001	Quartz, pyrite, chalcopyrite, molybdenite, sphalerite, galena.	Cu.
Jerome, Yavapai County, Ariz.	[4,6] 2	<.001	<.001	[5] <.001	Quartz, dolomite, chlorite, pyrite, sphalerite, chalcopyrite.	Au, Cu.
Mammoth, Pinal County, Ariz.	[4,6] 4	<.001	[7] <.001 (3)	[5] <.001	Quartz, orthoclase, sphalerite, galena, wulfenite, vanadinite, fluorite.	Zn, Pb.
Pinal County, Ariz.: Childs-Alwinkle Mine	[4] 4	<.001	<.001	[5] <.001	Quartz, calcite, molybdenite, bornite, chalcopyrite.	Mo. Cu, Pb.
Vulture, Maricopa County, Ariz.	[4] 7	<.001	<.001	[5] <.001	Quartz, pyrite, galena, sphalerite, gold	Pb, Zn, Cu.
Walker and Big Bug districts, Yavapai County, Ariz.	[4] 25	<.001	<.001	[5] <.001	Quartz, calcite, pyrite, sphalerite, chalcopyrite, galena.	Cu, Au, Ag.
Wallapai district, Mohave County, Ariz.	[4,6] 6	<.001	[7] <.001 (5)	[5] <.001	Quartz, pyrite, chalcopyrite, arsenopyrite, galena, molybdenite.	Au.
Weaver and Black Rock districts, Yavapai County, Ariz.	[4,6] 3	<.001	<.001	[5] <.001	Quartz, pyrite, galena, chalcopyrite	Au.
Pershing County, Nev.: Majuba Hill mine	[4] 23	<.001	<.001	[5] <.001	Cassiterite, chalcopyrite, pyrite, arsenopyrite, quartz, tourmaline, fluorite.	Sn, Cu, Ag, U.
Pioche, Lincoln County, Nev.	[4,6] 1			[5] <.001	Galena, sphalerite, pyrite, siderite	Au, Ag.
Tintic, Utah County, Utah	[4,6] 1			<.001	Quartz, barite, pyrite, galena, enargite	Cu.
Blackbird (and Nicholia) districts, Lemhi County, Idaho.	[4] 4	<.001	<.001	[5] <.001	Quartz, siderite, pyrite, chalcopyrite, pyrrhotite, galena, cobaltite, smaltite.	Cu, Pb, Co.
Shoshone County, Idaho (three mines)	[4,6] 9	<.001	[7] <.001 (6)	[5] <.001	Galena, sphalerite	Zn, Pb, Ag.
Warm Springs district, Blaine County, Idaho	[4] 4	<.001	<.001	[5] <.001	Quartz, galena, sphalerite, pyrite	Zn, Pb.
Judith Mts., Fergus County, Mont.: Spotted Horse mine.	[4,6] 1			[5] <.001	Gold	Au.
Little Rockies district, Phillips County, Mont.	[4,6] 2	<.001	<.001	[5] <.001	Quartz, muscovite, pyrite, gold, fluorite	Au.
Stillwater County, Mont.	[4] 8	<.001	<.001	[5] <.001	Chromite, serpentine	Cr.
Casper Mtn., Natrona County, Wyo.	2	<.001	<.001	<.001	Serpentine, asbestos	
Albany County, Wyo.: Strong mine	1			<.001	Molybdenite, azurite, malachite, chalcopyrite, tetrahedrite.	Cu.
Laramie County, Wyo.: Welcome mine	1			<.001	Hematite	Fe.
Boulder district, Boulder County, Colo.	[4] 7	.001	[7] <.001 (2)	[5] <.001	Quartz, ferberite, hematite, magnetite, fluorite	W.
Gold Hill, Boulder County, Colo.: Copper King mine.	[4] 5	<.001	<.001	[5] <.001	Chalcopyrite, niccolite, pyrrhotite, pentlandite, pyrite.	Cu, Ni.
Bonanza district, Saguache County, Colo.	2	<.001	<.001	<.001	Galena, sphalerite, rhodochrosite, zunyite, fluorite.	Au.
Hillsboro district, Sierra County, N. Mex.	[4] 22	<.001	<.001	[5] <.001	Quartz, pyrite, chalcopyrite, bornite, gold	Cu.
Lordsburg, Hidalgo County, N. Mex.: Bonney mine.	[4,6] 2	<.001	<.001	[5] <.001	Quartz, muscovite, chlorite, pyrite, sphalerite, chalcopyrite.	Zn, Cu.
Shafter district, Presidio County, Tex.: Presidio mine.	[4,6] 1			[5] <.001	Dolomite, quartz, galena, sphalerite, argentite	Ag, Pb, Au.
Tri-State district, Kansas and Oklahoma	23	<.001	<.001	<.001	Galena, sphalerite, marcasite, chert, barite	Pb, Zn.
Keystone, Pennington County, S. Dak.	[4] 5	.01	<.001	[5] <.001	Quartz, gold, arsenopyrite, ferrodolomite, biotite.	Au.
Lead, Lawrence County, S. Dak.: Homestake mine.	[4] 5	<.001	<.001	[5] <.001	Cummingtonite, biotite, quartz, carbonate, arsenopyrite, pyrite, pyrrhotite, gold.	Au.
Upper Mississippi Valley district, Lafayette and Iowa Counties, Wis.	[4] 6	<.001	<.001	[5] <.001	Calcite, marcasite, sphalerite, galena	Zn, Pb.
Rosiclaire, Hardin County, Ill.	[4] 8	<.001	[7] <.001 (6)	[5] <.001	Calcite, fluorite, galena, sphalerite, pyrite	Zn, Pb, F.
Central Missouri district, Moniteau County, Mo.	[4,6] 1			[5] <.001	Calcite, sphalerite, galena	Zn, Pb.

See footnotes at end of table.

TABLE 14.—*Beryllia in some veins and related deposits in the United States*—Continued

Locality	Number of samples [1]	Percent BeO			Mineralogy [2]	Principal metals
		High	Low	Average		
Little Missouri R., Pike County, Ark.	[4] 16	<0.001	<0.001	[5] <0.001	Cinnabar	Hg.
Alexander City, Tallapoosa, Ala.: Hog Mtn. mine	[4] 12	<.001	<.001	[5] <.001	Quartz, chlorite, muscovite, gold	Au.
Ducktown, Polk County, Tenn.	[4,6] 20	<.001	<.001	[5] <.001	Quartz, pyrrhotite, pyrite, chalcopyrite	Cu, Fe.
Goin, Clairborne County, Tenn.	[4] 7	<.001	<.001	[5] <.001	Sphalerite, galena, calcite	Zn, Pb.
Mascot, Knox County, Tenn.	[4,6] 6	<.001	<.001	[5] <.001	Dolomite, sphalerite, pyrite	Zn.
Gratz, Owen County, Ky.	[4] 6	<.001	<.001	[5] <.001	Sphalerite, galena, calcite	Zn, Pb.
Keweenaw region, Michigan	[4] 12	<.001	<.001	[5] <.001	Copper, epidote, quartz, calcite, adularia	Cu.
Sanford Lake, Essex County, N. Y.	[4,6] 1	----------	----------	[5] <.001	Ilmenite, magnetite	Ti Fe, V.
Galax, Carroll County, Va.	[4] 11	<.001	<.001	[5] <.001	Quartz, amphibole, biotite, pyrrhotite, chalcopyrite.	Cu.
Virgilina, Halifax County, Va.: Red Bank mine	[4,6] 1	----------	----------	[5] <.001	Quartz, hematite, gold	Au.
Spottsylvania County, Va.: Valzinco mine	[4] 4	<.001	<.001	[5] <.001	Quartz, chlorite, pyrite, sphalerite, chalcopyrite, galena.	Pb, Zn.
Allegheny County, N. C.: Ore Knob mine	[4,6] 1	----------	----------	[5] <.001	Pyrrhotite, pyrite, chalcopyrite, quartz	Cu.
Finley, Caldwell County, N. C.	[4] 2	<.001	<.001	[5] <.001	Ilmenite, rutile, chlorite, talc	Ti.
Union County, N. C.: Howie mine	[4,6] 1	----------	----------	[5] <.001	Quartz, biotite, chlorite, pyrite, gold	Au, Ag.
Kershaw, Lancaster County, S. C.: Haile mine	[4,6] 1	----------	----------	[5] <.001	Quartz, muscovite, pyrite, gold, molybdenite	Au, Ag.
Orange County, Vt.: Elizabeth mine	[4] 3	<.001	<.001	[5] <.001	Quartz, feldspar, chalcopyrite, pyrrhotite	Cu.
Shelburne, Coos County, N. H.	[4] 1	----------	----------	[5] <.001	Galena, sphalerite	Pb, Zn.
Marysvale, Piute County, Utah: Freedom No. 2 claim.	1	.001	----------	[5] .000X	Fluorite, pyrite, wad, uranophane, autunite, pitchblende.	U.
Red River, Taos County, N. Mex.: Chokecherry Canyon.	1	----------	----------	.0007	Fluorite, calcite, quartz	None.
Elko County, Nev.: Good Hope mine	1	----------	----------	.0007	Barite	Ba.
Climax, Lake County, Colo.: Climax mill	[9] 10	.0006	.0001	.0006	Quartz, molybdenite, pyrite, topaz, wolframite, chalcopyrite, cassiterite.	Mo, W.
Animas Forks district, San Juan County, Colo.	12	.0021	<.0001	.0006	Rhodonite, galena, sphalerite, pyrite, quartz	Au, Ag.
Minerva district, White Pine County, Nev.	5	.0017	<.0001	.0006	Quartz, calcite, scheelite	W.
Bland district, Sandoval County, N. Mex.: Big Sambo mine.	2	.0007	.0005	.0006	Quartz, calcite	Au.
Winfield district, Chaffee County, Colo.	4	.0011	.0001	.0005	Molybdenite, bismuthinite, pyrite, fluorite	Mo, Bi, Au.
Sacramento Pass district, White Pine County, Nev.	7	.0008	<.0001	.0005	Quartz, feldspar, scheelite, sulfides	W.
Mineral Point district, San Juan County, Colo.	4	.0016	<.0001	.0004	Galena, sphalerite, rhodonite, rhodochrosite, pyrite.	Au, Hg.
Elizabethtown, Colfax County, N. Mex.; Baldy Deep mine.	1	----------	----------	[5] <.0004	Quartz, molybdenite, calcite	Au, Mo.
Eureka, Grant County, N. Mex.: National and American mine.	4	<.0004	<.0004	[5] <.0004	Siderite, calcite, arsenopyrite, pyrite	W, Cu.
Lordsburg, Hidalgo County, N. Mex.: Eighty-five mine.	3	<.0004	<.0004	[5] <.0004	Quartz, muscovite, hematite, chalcopyrite, tourmaline.	Cu.

[1] All samples collected during the present investigation by the U. S. Geological Survey, unless otherwise stated.
[2] Mineral association in the vein, not necessarily related to time or origin. Listed in approximate order of abundance; known beryllium minerals in italics.
[3] Samples collected by J. W. Adams, U. S. Geological Survey.
[4] Samples collected by Mine, Mill, and Smelter Survey, U. S. Geological Survey.
[5] Beryllium determinations on plates exposed for general scanning, not for quantitative beryllium determinations.
[6] Mill concentrates or tailings only.
[7] Number in parentheses indicates number of samples having BeO content below the limit of sensitivity.
[8] Samples collected by J. R. Cooper, U. S. Geological Survey.
[9] Samples collected by U. S. Bureau of Mines.
[10] Samples collected by J. C. Olson, U. S. Geological Survey.

A quartz vein cutting limestone at the Midnight mine in the Apache district, Sierra County, N. Mex., may be related to this type (Harley, 1934, p. 85). Ore from the vein, which contains gold and silver in addition to bornite and other copper sulfides, was found to contain 0.01 percent BeO.

The few veins of this type that we sampled showed little or no beryllium and there is little indication that beryllium is at all common in quartz-gold veins. No veins of this type are reported to contain tungsten, although at Bald Mountain, S. Dak., tungsten deposits nearby are believed to be related in origin (Connolly, 1927, p. 95–97).

MANGANESE-LEAD-ZINC VEINS

Originally described from Kapnik, Hungary (Szabo, 1882), beryllium-bearing veins of this type are found in the United States at the Sunnyside mine, Colorado (Burbank, 1933a, p. 521), and Butte, Mont. (Hewett, 1937). Rhodonite, rhodochrosite, and other manganese minerals occur with quartz, helvite, and sulfides, with helvite last in the mineral sequence.

From mineral associations and structure relations we infer that the manganese-helvite veins are of somewhat lower temperature than the tungsten-beryl veins. However, only veins that are rich in manganese contain helvite, in which manganese is an essential constituent. We know of no vein deposit in which beryl and helvite are found.

OTHER VEINS

The helvite-bearing vugs and veins of the Carpenter district, Grant County, N. Mex., are probably similar to manganese-lead-zinc vein deposits; the helvite seems to have no genetic relation to silicate minerals. Some rhodonite was found in the Grandview mine, although not directly in association with the helvite. Fluorite, which is prevalent at the Grandview mine, is found also at the Sunnyside mine, Colorado, and at several of the mines in the Butte district, Montana.

The veins in Colombia (Oppenheim, 1948), from which most of the world's emeralds are mined, are unique. Small fractures in limestones and shales are filled with calcite, dolomite, beryl, parasite, pyrite, quartz, and rarely barite and fluorite.

BERYLLIUM IN HOT-SPRING DEPOSITS

Beryllium has not been mentioned in the many detailed reports on the chemistry of volcanoes or those on the volcanic fumarole and hot-spring areas of Yellowstone and Katmai, but it may not have been specifically looked for. Using enrichment procedures, Kuroda (1939, 1940) was able to detect a maximum of about 0.000001 percent BeO in waters of a large number of the Japanese acid-sulfate hot springs. Beryllium was reported or its presence inferred in mineral springs studied by Mazade (1852), Bechamp (1866), and Fresenius (1933), but there is no indication of what proportion of these waters are juvenile. Detailed geochemical data given by Strock (1941b) indicate that the waters of Saratoga Springs—which contain more beryllium than yet measured in any other mineral water—are entirely meteoric, although the source of the beryllium itself is not postulated.

Beryllium has been noted at several localities in material deposited by hot springs. At Steamboat Springs, Nev., calcareous sinter and siliceous mud, both of recent origin and rich in pyrite and stibnite, contained 0.0002 to 0.0008 percent BeO (Brannock, and others, 1948, p. 224). Ferruginous and calcareous material from two hot springs in Sandoval County, N. Mex., contained less than 0.0005 percent BeO, except for one sample of ferruginous material that contained 0.00X percent.[4] Sediments in a carbonate mineral spring in Germany were found to contain 0.0016 percent BeO (Rezek and Tomic, 1942). None of these deposits represent appreciable enrichment over the average beryllium content of the crust; in particular the Be to Al ratio has not increased.

During the present investigation samples were taken from three tufa deposits that were presumably formed by hot springs no longer active. Data for these samples are tabulated below:

Location	*Material*	BeO (*percent*)[1]
Golconda, Humboldt County, Nev.	Manganese-iron-tungsten-rich tufa.	0.016
Do	Calcareous tufa (overlying above-mentioned tufa).	< .0001
Sodaville, Mineral County, Nev.	Manganese-tungsten ore	.007
Cove Creek, Hot Springs County, Ark.	Tufa	.003
Ouray, Ouray County, Colo.	do	.08

[1] Analyses by U. S. Geological Survey.

The relatively large amount of BeO in the material from Golconda, Nev., presumably is due to deposition of beryllium with the manganese, iron, and tungsten. The beryllium mineral in the deposit is not known; but as the tungsten has been adsorbed in amounts of as much as 6 percent in very fine grained masses of cryptomelane and psilomelane without forming minerals of its own (Kerr, 1946a, p. 78–79; 1940, p. 1377–1387), the beryllium may have been similarly adsorbed. Shallow veins are associated with the tufa deposits, and a very close connection between hot springs, fumarolic, and epithermal deposits seems well established. Deposits similar to those at Golconda are quite rare, and by analogy, the similar and much lower grade beryllium deposits cannot be expected to be important as a source of beryllium. If the beryllium is adsorbed in the manganese minerals, the recovery problems would be even greater than they are for tungsten.

Though of doubtful commercial value, the deposit of Golconda may provide important information regarding the origin of beryllium in hot springs. Scheelite deposits occur in the vicinity of Golconda, and Kerr points out that underlying scheelite or wolframite veins may possibly have been the source of tungsten in the spring waters. In line with this reasoning, beryl-bearing tungsten veins or helvite-bearing tactites conceivably may have furnished beryllium. The scheelite deposits of this region probably are related to Cretaceous intrusive rocks, whereas the hot-spring deposits are thought to be of Pleistocene age. The thermal waters may have leached tungsten and beryllium from the earlier deep-seated deposits and carried these elements to the surface. Beryllium-bearing hot springs may thus serve as a guide to deposits of relatively high beryllium content at depth. Sampling of all tactites and high-temperature veins in the vicinity of such springs seems warranted.

[4] Analyses by A. T. Myers, U. S. Geological Survey, of material collected by C. S. Ross.

ASSOCIATION OF BERYLLIUM WITH OTHER ELEMENTS

A large proportion of the samples analyzed for beryllium in the present investigation were also analyzed spectrographically for other elements. All samples analyzed are included, whether or not they contained any beryllium. The data are compiled in table 15, by States, districts, and sample number.

Many other spectrographic analyses for beryllium are in the files of the U. S. Geological Survey, most having been made during World War II in the countrywide sampling of mine, mill, and smelter products. The spectrographic data for those samples that showed more than 0.001 percent BeO are given in table 16. The analyses that showed 0.001 percent BeO or less have been summarized in tables 8, 10, 11, 13, and 14. The localities sampled are shown in figure 2.

The older analyses of table 16 may be of a lower order of accuracy than those of table 15. Reanalysis for beryllium of several of the older samples indicates that the earlier determinations may be high by a factor of as much as four. Resampling at some localities also suggests that some of the older samples may have been contaminated in an unknown fashion with as much as 0.2 percent BeO. However, reanalyses of samples of tactite from Nevada were in agreement with earlier results.

The reliability of determinations for elements other than beryllium has not been tested, but inaccuracies may have been introduced by contamination in grinding. Most of the samples were processed in a routine manner by commercial crushing and grinding equipment. Sandell (1947) has shown that even when reasonable precautions are taken by hand grinding in a Plattner mortar, as much as 0.028 percent iron is added to quartz and feldspar. Recent tests conducted by Myers and Barnett (1953) of the U. S. Geological Survey with standard grinding equipment showed additions of as much as 1.5 percent iron and 0.1 percent manganese in routine processing of these minerals.

Correlations between beryllium and other elements are not apparent from the data provided in the tables. Unfortunately, the list of elements for which spectrographic determinations are available does not include some of those most likely to be correlated with beryllium. In igneous and metamorphic rocks, for example, two of the elements most important in determining the mineralogy are silicon and aluminum, and few determinations of these have been made in samples tested for beryllium. Analyses for fluorine, with which a correlation might be expected, are also lacking. Gravimetric analyses for tungsten of samples from the Little Dragoon Mountains, Ariz., and Victorio Mountains, N. Mex., showed no significant relation to beryllium determinations. Some correlation between beryllium and zirconium was noted in the feldspathoidal rocks of the Raton volcanic region, New Mexico, and the Trans-Pecos Region of New Mexico and Texas.

Geochemical relations between beryllium and certain other elements, particularly tin, tungsten, and fluorine, are suggested by the mineral associations noted in beryllium occurrences in veins and pyrometasomatic deposits (see tables 13 and 14), although they are not without exceptions. The apparent association of beryllium and fluorine is particularly striking. Fluorite occurs in two-thirds of all the beryl-bearing quartz veins so far reported throughout the world and in most of the helvite-bearing veins and pyrometasomatic deposits. Idocrase where associated with helvite contains abnormal amounts of fluorine as well as beryllium. The average fluorine content of igneous rocks is 0.04 percent in gabbro, 0.085 percent in granite, and 0.103 percent in nepheline syenite (Koritnig, 1951, p. 111). These figures show an approximate straight-line correlation with the corresponding averages for beryllia, there being approximately 30 times as much fluorine as beryllia in igneous rocks, plus an additional 0.03 percent fluorine.

Lindgren (1933, p. 179) postulated a relation between fluorite distribution and magmatic differentiation in the western United States. He noted that intrusive rocks of intermediate composition near the Pacific Coast are succeeded by silicic intrusive rocks farther east, and finally by a belt of alkalic intrusives along the Rocky Mountain front. Fluorite is most abundant in the rocks and mineral deposits along the eastern margin of the Rocky Mountains, particularly in the southern part. A corresponding concentration of beryllium in this zone might be expected because of the association of fluorine and beryllium in igneous rocks and mineral deposits. While the beryllium-bearing deposits of Iron Mountain and the Victorio Mountains, N. Mex., may be cited in support of this thesis, the virtual absence of beryllium elsewhere along the Rocky Mountain front and its presence in tactite deposits in Nevada and California are opposed. Although the fluorite deposits of the Southern Rocky Mountains are believed to have a genetic relation to intruded igneous bodies nearby (Rothrock, Johnson, and Hahn, 1946, p. 21), the mineralogy of many of them suggests a relatively low temperature origin that would not be favorable for deposition of beryllium.

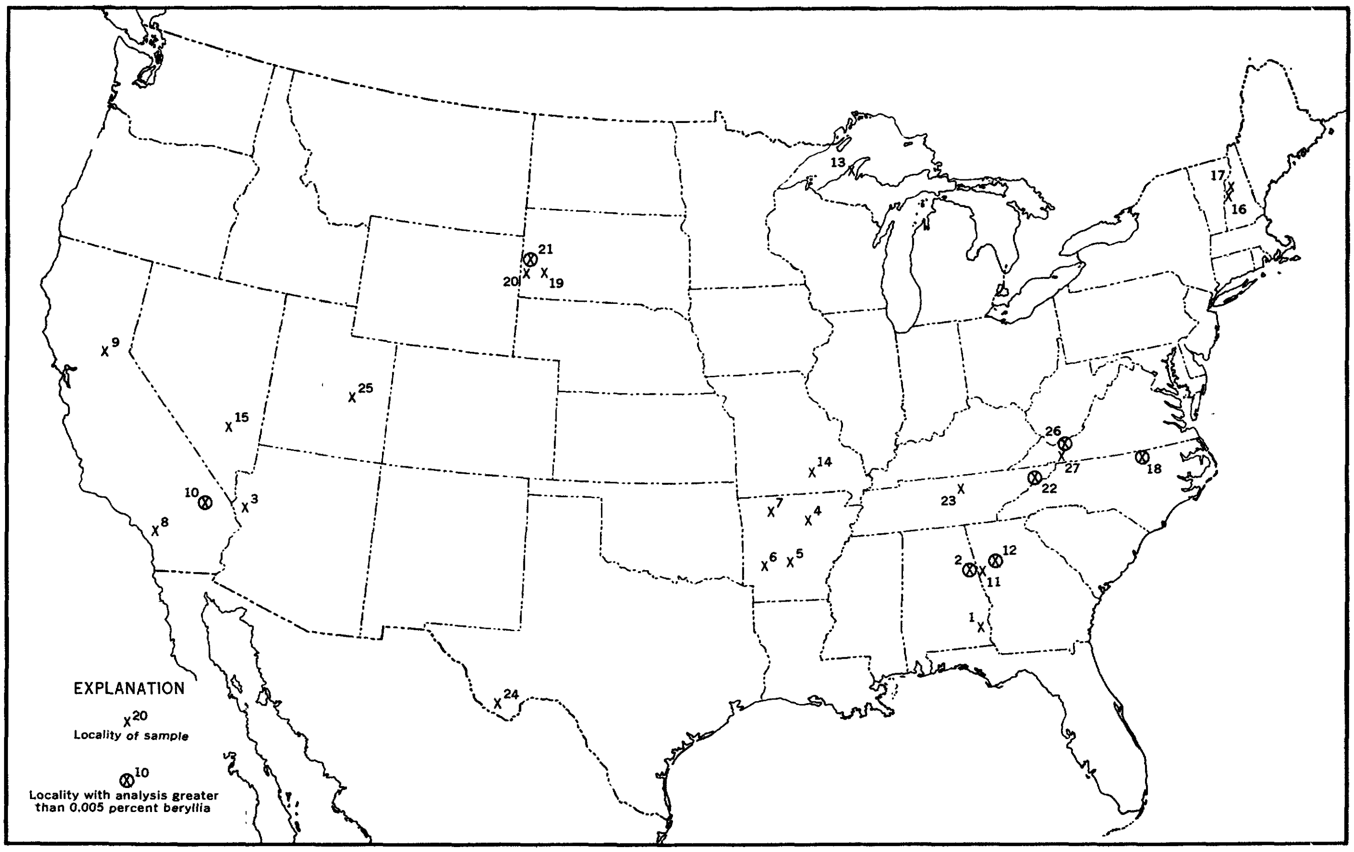

FIGURE 2.—Index map of localities listed in table 16.

Alabama

1. Bakerhill lignite
2. Rock Run district, Emerson mine

Arizona

3. San Francisco district

Arkansas

4. Batesville
5. Fletcher mine
6. Glenwood district
7. St. Joe district

California

8. Elsinore lignite
9. Mother Lode district
10. Providence Mountains district, Scheelite Ray mine

Georgia

11. Cave Springs district, Callahan mine
12. Cartersville district

Michigan

13. Houghton district

Missouri

14. Rocky Creek mine

Nevada

15. Tem Piute district

New Hampshire

16. Grafton County lead-zinc mines
17. Ore Hill mine

North Carolina

18. Hamme mine

South Dakota

19. Keystone district
20. Maitland district
21. Trojan and Lead districts

Tennessee

22. Bumpass Cove district, Embree mine
23. Central Tennessee black shales

Texas

24. Terlingua district

Utah

25. South Temple Mountain

Virginia

26. Appalachian district
27. Southwest Virginia district, Glade Mountain mine

TABLE 15.—*Spectrographic analyses, in percent, for other*

[Analysts, F, Janet D. Fletcher; M, K. J. Murata; C, A. A. Chodos. nd, not determined; leaders (----) looked

	Locality and sample	Analyst	BeO	Sb	As	Ba	Bi	B	Cd	CaO	Cr	Co	Cu	Ga	Ge	In	Fe_2O_3
	ARIZONA (see fig. 21)																
	Cochise County:																
	Courtland-Gleeson district:																
1	329-551	F	------	------	------	0.00X	0.0X	------	------	X0	0.00X	0.000X	0.0X	0.00X	------	nd	3-6
2	552	F	------	------	------	.00X	------	------	------	6-10	.00X	.00X	X.0	.00X	------	nd	X0
	Gordon and Abril mines:																
3	329-543	F	0.04	------	------	.00X	.0X	------	0.0X	X0	.00X	.00X	.0X	.00X	------	nd	3-6
4	547A	F	.007	------	------	.00X	.00X	------	------	X0	------	.000X	.0X	.00X	------	nd	3-6
5	549	F	.004	------	------	.000X	------	------	------	6-10	.00X	.00X	.00X	.00X	------	nd	6-10
6	550	F	.02	------	------	.000X	.0X	------	.0X	6-10	.00X	.0X	.X	.00X	------	nd	6-10
	Little Dragoon Mts.:																
7	329-449	F	.0007	------	------	.0X	------	------	------	3-5	.00X	.00X	.X	.00X	------	nd	3-6
8	450	F	.0007	------	------	.0X	------	------	------	6-10	.00X	.00X	.X	.00X	------	nd	3-6
9	451	F	.0007	------	------	.0X	------	------	------	6-10	.00X	.00X	.0X	.00X	------	nd	3-6
10	453	F	.0007	------	------	.0X	------	0.00X	------	1-3	.00X	------	.0X	------	------	nd	1-3
	Tombstone district:																
11	329-539	F	------	0.X	0.0X	.00X	------	.000X	.0X	3-6	.00X	.00X	.X	------	------	nd	1-3
12	540	F	------	------	------	.00X	------	.00X	------	X0	.00X	------	.0X	.00X	------	nd	1-3
13	544	F	------	------	------	.00X	------	.000X	------	X0	.00X	------	.0X	.00X	------	nd	1-3
14	546	F	.0007	------	------	.0X	.00X	.0X	------	X0	.00X	.00X	.0X	.00X	------	nd	1-3
	Pima County:																
	Empire district:																
15	329-524	F	------	------	------	.00X	------	.00X	------	X0	.00X	.000X	.00X	.000X	------	nd	1-3
16	525	F	------	------	------	.00X	------	------	------	X0	.00X	.000X	.0X	.00X	------	nd	X0
17	526	F	------	------	------	.00X	.0X	------	------	X0	.00X	.00X	.0X	.000X	------	nd	X0
18	527	F	------	------	------	.00X	.X	------	------	X0	.00X	.00X	.X	.00X	------	nd	X0
	Helvetia district:																
19	329-510	F	------	------	------	------	------	------	------	X0	.00X	.000X	.X	.000X	------	nd	3-6
20	512	F	.0004	------	------	------	------	------	------	6-10	.00X	.00X	X	.00X	------	nd	3-6
21	514	F	.002	------	------	.00X	------	------	------	6-10	.00X	.000X	.X	.00X	------	nd	3-6
22	515	F	.0004	------	------	.0X	------	------	------	X0	.000X	------	.X	.00X	------	nd	3-6
23	516	F	------	------	------	.00X	.00X	------	------	6-10	.00X	------	.X	.000X	------	nd	3-6
24	517	F	------	------	------	.00X	------	------	------	6-10	.00X	------	.X	.00X	0.00X	nd	3-6
25	520	F	------	------	------	------	------	------	------	6-10	.00X	.00X	X	.00X	------	nd	X0
26	521	F	------	------	------	------	------	------	------	6-10	.00X	.00X	X	.00X	------	nd	X0
27	523	F	.0004	------	------	.00X	------	------	------	6-10	.00X	.000X	X	.000X	.00X	nd	3-6
	Pima County:																
	Pima district:																
28	329-490	F	------	------	------	.000X	------	------	------	X0	.000X	------	.0X	.00X	------	nd	X0
29	491	F	------	------	------	.00X	.00X	------	------	6-10	.000X	------	.X	.00X	------	nd	X0
30	494	F	------	------	------	.00X	.00X	------	------	6-10	.000X	.00X	.X	.00X	------	nd	X0
31	496	F	.001	------	------	.00X	.00X	------	------	6-10	.00X	.000X	.00X	.00X	------	nd	3-6
32	497	F	.001	------	------	.00X	------	------	------	6-10	.000X	------	.X	.00X	------	nd	X0
33	498	F	------	------	------	.00X	------	------	------	6-10	.000X	.000X	.00X	.00X	------	nd	3-6
34	499	F	------	------	------	.0X	------	------	------	X0	.000X	------	.0X	.00X	------	nd	X0
35	501	F	------	------	------	.00X	------	.00X	------	X0	.00X	------	.00X	.00X	0.00X	nd	3-6
36	502	F	------	------	------	.00X	------	.000X	------	.3-0.6	.000X	------	.00X	------	------	nd	1-3
37	503	F	------	------	------	.00X	------	.000X	------	.3-0.6	.000X	------	.00X	------	------	nd	1-3
38	506	F	.0004	------	------	.00X	------	------	------	6-10	.000X	------	.00X	.00X	.0X	nd	X0
39	507	F	------	------	------	.00X	------	------	------	X0	.00X	------	.00X	.00X	.00X	nd	X0
40	508	F	------	------	------	.00X	.00X	------	------	6-10	.00X	.00X	.X	------	------	nd	3-6
41	509	F	------	------	------	.0X	.0X	------	.0X	6-10	.00X	.00X	.X	------	------	nd	3-6
	Santa Cruz County:																
	Patagonia district:																
42	329-528	F	------	------	------	.00X	------	------	------	X0	.000X	.00X	.X	.00X	------	nd	X0
43	529	F	------	------	------	.00X	.X	------	.0X	6-10	.00X	.00X	X	------	------	nd	X0
44	531	F	------	------	------	.00X	.00X	------	------	6-10	.00X	.00X	.0X	.000X	------	nd	3-6
45	532	F	------	------	------	.00X	------	------	------	X0	.00X	------	.0X	.00X	------	nd	X0
46	533	F	------	------	------	.00X	.0X	------	.0X	6-10	.00X	.00X	.X	------	------	nd	3-6
47	535	F	------	------	------	.00X	.00X	------	------	X0	.00X	.00X	.X	.00X	------	nd	X0
48	536	F	------	------	------	.00X	.00X	------	------	6-10	.00X	.000X	.0X	.00X	------	nd	X0
49	537	F	------	------	------	.00X	.00X	------	------	6-10	.00X	.000X	.0X	.00X	------	nd	6-10
50	538	F	------	------	------	.00X	------	------	------	6-10	.000X	.00X	.0X	.00X	------	nd	X0

elements in samples analyzed for beryllium

for but not found; asterisk (*) percent of element rather than oxide. Major, more than 1 percent].

	La	Pb	MgO	Mn	Mo	Ni	Nb	Ag	Na_2O	Sr	Ta	Sn	Ti	W	U	eU	eU_3O_8	V	Y	Zn	Zr
1	------	0.00X	0.3-0.6	0.X	------	0.00X	------	nd	nd	0.00X	------	------	0.X	------	nd	0.001	nd	0.00X	------	0.X	0.0X
2	------	.000X	.3-0.6	.X	------	.00X	------	nd	nd	.00X	------	------	.X	------	nd	.001	nd	.00X	------	.0X	.0X
3	------	.X	.1-0.3	X	0.00X	.00X	------	0.00X	nd	.0X	------	0.00X	.0X	------	nd	------	nd	.0X	------	X	.00X
4	------	.00X	.1-0.3	.X	.00X	.00X	------	.000X	nd	.0X	------	------	.0X	------	nd	------	nd	.00X	------	.0X	.00X
5	------	------	.3-0.6	.X	------	.00X	------	------	nd	.0X	------	------	.0X	------	nd	------	nd	.00X	------	.X	.00X
6	------	.00X	.6-1	.X	------	.00X	------	.000X	nd	.0X	------	------	.0X	0.0X	nd	------	nd	.00X	------	X	.00X
7	------	------	.6-1	.X	.00X	.000X	------	.000X	nd	.0X	------	------	.X	.0X	nd	.001	nd	.00X	------	.X	.0X
8	------	------	.6-1	.X	.00X	.000X	------	.000X	nd	.0X	------	------	.X	.0X	nd	.001	nd	.00X	------	.X	.00X
9	------	------	.6-1	.X	.00X	.000X	------	.000X	nd	.0X	------	------	.X	.0X	nd	.003	nd	.00X	------	.0X	.0X
10	------	------	.3-0.6	.X	.00X	.00X	------	------	nd	.00X	------	------	.X	------	nd	.001	nd	------	------	.0X	.00X
11	------	X	.03-0.06	X0	.00X	.00X	------	.0X	nd	.0X	------	------	.0X	------	nd	.003	nd	.00X	------	X	.00X
12	------	.00X	.1-0.3	.0X	------	.00X	------	------	nd	.00X	------	------	.X	------	nd	.001	nd	.0X	------	------	.0X
13	0.0X	.0X	.1-0.3	.0X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	.004	nd	.0X	------	------	.0X
14	.0X	.0X	.1-0.3	.0X	------	.00X	------	.000X	nd	.0X	------	------	.X	------	nd	------	nd	.0X	------	.0X	.0X
15	------	.000X	.6-1.0	.X	------	.00X	------	------	nd	.00X	------	------	.X	------	nd	------	nd	.00X	------	------	.00X
16	------	------	.1-0.3	.X	------	.00X	------	------	nd	.00X	------	------	.0X	------	nd	------	nd	.0X	------	------	.00X
17	------	.000X	.3-0.6	.X	.00X	.00X	------	------	nd	.00X	------	------	.0X	.X	nd	------	nd	.0X	------	------	.00X
18	------	.00X	.1-0.3	.X	.00X	.00X	------	.00X	nd	.00X	------	------	.0X	.X	nd	.001	nd	.0X	------	------	.00X
19	------	------	.6-1	.X	------	.00X	------	.000X	nd	.00X	------	.00X	.00X	------	nd	.001	nd	.00X	------	.X	.00X
20	.0X	------	.6-1	.X	.0X	.00X	------	.00X	nd	.00X	------	------	.X	------	nd	.001	nd	.00X	0.0X	.0X	.0X
21	------	------	3-6	.X	.00X	.00X	------	.000X	nd	.00X	------	------	.X	------	nd	.001	nd	.00X	------	------	.0X
22	------	.0X	.6-1	.X	.00X	.00X	------	.000X	nd	.00X	------	------	.0X	------	nd	.003	nd	.00X	------	.0X	.0X
23	------	------	.6-1	.X	.00X	.00X	------	.00X	nd	.00X	------	------	.0X	------	nd	.001	nd	.00X	------	------	.00X
24	------	------	.3-0.6	.X	.00X	.00X	------	.000X	nd	.00X	------	.00X	.0X	.X	nd	.001	nd	.00X	------	------	.00X
25	------	------	.6-1	.X	------	.00X	------	.00X	nd	.00X	------	------	.00X	------	nd	.001	nd	.00X	------	.0X	.00X
26	------	------	.6-1	.X	.00X	.00X	------	.000X	nd	.00X	------	.00X	.0X	------	nd	.001	nd	.00X	------	.0X	.00X
27	------	------	.6-1	X	.00X	.00X	------	.00X	nd	.00X	------	.00X	.00X	.0X	nd	.001	nd	.00X	------	.0X	.00X
28	------	------	.1-.3	.X	.00X	------	------	------	nd	.00X	------	.00X	.00X	.0X	nd	nd	nd	.00X	------	------	.00X
29	------	.0X	.1-0.3	.X	.0X	.00X	------	.000X	nd	.00X	------	.00X	.0X	.0X	nd	nd	nd	.00X	------	.0X	.00X
30	------	.00X	.6-1	.X	.00X	.00X	------	.00X	nd	.00X	------	.00X	.0X	------	nd	.002	nd	.00X	------	------	.00X
31	------	.000X	1-3	.X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	.001	nd	.00X	------	------	.00X
32	------	------	.3	.X	.00X	.00X	------	.00X	nd	.00X	------	.00X	.0X	.0X	nd	------	nd	.00X	------	.0X	.00X
33	------	------	.3	.X	.00X	.00X	------	.000X	nd	.00X	------	.00X	.0X	.0X	nd	------	nd	.00X	------	X	.00X
34	------	------	.1-0.3	.X	.00X	.00X	------	------	nd	.00X	------	.00X	.00X	------	nd	.001	nd	.00X	------	------	.00X
35	------	------	.6-1	.X	------	.00X	------	------	nd	.00X	------	------	.X	------	nd	.001	nd	.00X	------	------	.0X
36	------	------	.X	.0X	------	.00X	------	------	nd	.00X	------	------	.0X	------	nd	------	nd	------	------	------	------
37	------	------	.X	.0X	------	.00X	------	------	nd	.00X	------	------	.0X	.X	nd	.001	nd	------	------	------	------
38	------	------	.X	.X	------	.00X	------	------	nd	.00X	------	------	------	------	nd	------	nd	.00X	------	------	.00X
39	------	------	.X	.X	------	.00X	------	------	nd	.00X	------	------	.00X	------	nd	.001	nd	.00X	------	------	.00X
40	------	.X	.6-1	X	.00X	.000X	------	.00X	nd	.00X	------	------	.0X	------	nd	nd	nd	.00X	------	X	.00X
41	------	X	.6-1	.X	.00X	.00X	------	.00X	nd	.00X	------	------	.0X	------	nd	nd	nd	.00X	------	X	.00X
42	------	.X	.06-0.1	.X	.00X	.00X	------	.00X	nd	.00X	------	------	.00X	.0X	nd	.001	nd	.00X	------	.X	.00X
43	------	X0	.1-0.3	X	.00X	.00X	------	.0X	nd	.00X	------	------	.0X	.X	nd	.001	nd	------	------	X0	.00X
44	------	.X	.1-0.3	X	.00X	.000X	------	.000X	nd	.00X	------	------	.0X	.0X	nd	nd	nd	.00X	------	.X	.00X
45	------	.X	.06-0.1	.X	.00X	.00X	------	.000X	nd	.00X	------	------	.0X	------	nd	.001	nd	.0X	------	.0X	.00X
46	------	X	.1-0.3	X	.0X	.00X	------	.00X	nd	.00X	------	------	.0X	.X	nd	.001	nd	------	------	X	.00X
47	------	X	.1-0.3	.X	.00X	.00X	------	.000X	nd	.00X	------	------	.0X	.X	nd	.001	nd	.00X	------	.X	.00X
48	------	.0X	.1-0.3	.X	.00X	.00X	------	.000X	nd	.00X	------	------	.0X	------	nd	------	nd	.0X	------	.X	.00X
49	------	.X	.1-0.3	X	.00X	.00X	------	.00X	nd	.00X	------	------	.X	------	nd	------	nd	------	------	.X	.0X
50	------	.X	.03-0.06	.X	.00X	.00X	------	.000X	nd	.00X	------	------	.00X	.0X	nd	.001	nd	.0X	------	.X	.00X

TABLE 15.—*Spectrographic analyses, in percent, for other*

[Analysts, F, Janet D. Fletcher; M, K. J. Murata; C, A. A. Chodos. nd, not determined; leaders (----) looke

	Locality and sample	Analyst	BeO	Sb	As	Ba	Bi	B	Cd	CaO	Cr	Co	Cu	Ga	Ge	In	Fe_2O_3
	NEW MEXICO (see fig. 29)																
	Catron County, Black Range district:																
51	329-711	F	0.002	----	----	0.00X	----	----	----	0.1–0.3	0.00X	----	0.00X	0.00X	----	nd	3–6
	Colfax County:																
	Cimarroncito district:																
52	329-376	F	----	----	----	.0X	----	----	----	6–10	.00X	----	.0X	.00X	----	nd	6–10
53	377	F	----	----	----	.0X	0.0X	----	----	6–10	.00X	0.00X	X	----	----	nd	10
54	378	F	----	----	----	.0X	----	----	----	6–10	.00X	.000X	.X	.00X	----	nd	X0
55	382	F	----	----	----	.0X	----	----	----	X0	.000X	.000X	.X	.00X	----	nd	X0
	Colfax County:																
	Elizabethtown district:																
56	329-262	F	----	----	----	.0X	----	0.00X	----	3–6	----	.000X	----	----	----	nd	1–3
57	263	F	----	----	----	.0X	----	.00X	----	6–10	.00X	.000X	.000X	.00X	----	nd	1–3
58	267	F	----	----	----	.0X	----	.00X	----	6–10	.00X	----	----	.00X	----	nd	6–10
59	271	F	.0004	----	----	.0X	.00X	----	----	3–6	.00X	.0X	----	.00X	----	nd	X0
60	272	F	----	----	----	.00X	----	----	----	.3–0.6	----	.00X	----	.00X	----	nd	X0
61	273	F	----	----	----	.0X	----	.00X	----	6–10	.00X	.000X	----	.00X	----	nd	3.0
62	274	F	----	----	----	.00X	----	----	----	6–10	.00X	.00X	.000X	.00X	----	nd	X0
63	275	F	----	----	----	.0X	----	----	----	6–10	.00X	.00X	----	.00X	----	nd	3–6
	Raton volcanic region:																
64	329-360	F	.002	----	----	.0X	----	----	----	.6–1	.000X	----	.00X	.00X	----	nd	1–3
65	361	F	.002	----	----	.0X	----	----	----	.6–1	.000X	----	.00X	.00X	----	nd	1–3
66	364	F	.002	----	----	.0X	----	----	----	.6–1	.00X	----	.00X	.00X	----	nd	1–3
67	365	F	.002	----	----	.0X	----	.00X	----	.6–1	.000X	----	.00X	.00X	----	nd	1–3
68	367	F	----	----	----	.X	----	----	----	3–6	.0X	.00X	.00X	.00X	----	nd	3–6
69	369	F	.007	----	----	.0X	----	----	----	.6–1.0	.000X	----	.00X	.00X	----	nd	1–3
70	372	F	----	----	----	.0X	----	----	----	1–3	.00X	.00X	.00X	.00X	----	nd	3
71	373	F	----	----	----	.0X	----	----	----	1–3	.000X	----	.00X	.00X	----	nd	1–3
	Dona Ana County:																
	Organ district:																
72	329-790	F	----	----	----	.0X	.00X	nd	----	6–10	.00X	.00X	.0X	----	----	nd	X0
73	791	F	.0004	----	----	.00X	.0X	nd	----	X0	.000X	.000X	.X	----	----	nd	X0
74	793	F	----	----	----	.0X	----	nd	----	X0	.00X	.000X	.00X	.00X	----	nd	6–10
75	794	F	----	----	----	.00X	.0X	nd	----	X0	----	.000X	.X	.00X	----	nd	X0
76	796	F	----	----	----	.0X	.0X	nd	----	6–10	.00X	.000X	.0X	.00X	----	nd	1–3
77	797	F	----	----	----	.00X	.0X	nd	0.0X	6–10	----	.0X	.X	----	----	nd	3–6
78	797a	F	----	----	----	.00X	.0X	nd	----	6–10	.00X	.000X	.0X	.00X	----	nd	X0
79	799	F	----	----	----	.0X	----	nd	----	6–10	----	.00X	.X	.00X	----	nd	3–6
80	802	F	----	----	----	.00X	----	nd	----	6–10	----	----	.0X	----	----	nd	.3–0.6
	Grant County:																
	Burro Mountains:																
81	329-318	F	.002	----	----	.X	----	----	----	X0	.000X	----	.00X	----	----	nd	.1–0.3
82	319	F	.001	----	----	.00X	----	.00X	----	6–10	.00X	.00X	.X	.00X	----	nd	3–6
	Carpenter district:																
83	329-735-6	F	.01	----	----	.00X	.0X	----	.0X	6	.00X	.000X	.0X	----	----	nd	3–6
	Central district:																
84	329-276	F	----	----	----	.0X	----	----	----	X0.0	----	.000X	.00X	----	----	nd	3–6
85	277	F	.0008	----	----	.0X	----	.00X	----	3	.0X	.000X	.00X	.00X	----	nd	3
86	280	F	----	----	----	.0X	----	----	----	6–10	.00X	.00X	.00X	.000X	----	nd	X0
87	281	F	----	----	----	.0X	----	.0X	----	X0	----	.00X	.0X	.00X	----	nd	X0
88	284	F	.0004	----	----	.0X	----	.0X	----	X0	.00X	.00X	.0X	.00X	----	nd	X0
89	286	F	----	----	----	.00X	----	.0X	----	X0	.00X	.000X	.0X	----	----	nd	X0
90	287	F	----	----	----	.00X	----	.0X	----	3–6	----	.00X	.00X	.00X	----	nd	X0
91	288	F	----	----	----	.0X	----	.0X	----	6–10	.0X	----	.00X	.00X	----	nd	1–3
92	289	F	*.000X	----	----	.000X	----	.00X	----	X	.000X	----	.00X	----	0.0X	nd	X
93	291	F	----	----	----	.00X	----	.00X	----	6–10	.00X	.00X	.0X	.00X	----	nd	X0
94	292	F	----	----	----	.00X	----	.00X	----	6–10	.00X	.00X	.X	.00X	----	nd	X0
95	293	F	----	----	----	.0X	----	.0X	----	6–10	.00X	.00X	.X	.00X	----	nd	6–10
96	294	F	.0004	----	----	.0X	----	.0X	----	3–6	.0X	.000X	.00X	.00X	----	nd	1–3
97	295	F	----	----	----	.00X	----	.0X	----	X0	.00X	----	.00X	.00X	----	nd	6–10
98	296	F	.001	----	----	.00X	----	----	----	6–10	.00X	.00X	.0X	----	----	nd	1–3
99	297	F	----	----	----	.00X	----	.0X	----	X0	----	----	.00X	----	----	nd	.0X
100	301	F	----	----	----	.00X	----	----	----	X0	.00X	.00X	.0X	----	----	nd	X0
101	302	F	----	----	----	.00X	----	----	----	X0	----	.00X	.00X	----	----	nd	X0
102	303	F	----	----	----	.00X	----	----	----	X0	.00X	.000X	.0X	----	----	nd	X0
103	305	F	----	----	----	.0X	----	.00X	----	1–3	.000X	----	.00X	.00X	----	nd	1–3
104	306	F	----	----	----	.0X	----	.00X	----	3–6	.000X	.00X	.X	.00X	----	nd	X0
105	308	F	----	----	----	.0X	----	.00X	----	X0	.00X	.00X	.0X	----	----	nd	6–10
106	730	F	.001	----	----	.00X	.0X	----	.0X	3–6	----	.0X	.X	----	----	nd	3
107	732	F	.0008	----	----	.00X	----	----	----	6	.000X	.00X	.0X	----	----	nd	3–6
108	734	F	----	----	----	.000X	----	----	----	6–10	----	.000X	.0X	----	----	nd	3–6
109	807	F	.002	----	----	.000X	----	----	----	6–10	----	.00X	.0X	----	----	nd	3–6

elements in samples analyzed for beryllium—Continued

for but not found; asterisk (*) percent of element rather than oxide. Major, more than 1 percent].

	La	Pb	MgO	Mn	Mo	Ni	Nb	Ag	Na_2O	Sr	Ta	Sn	Ti	W	U	eU	eU_3O_8	V	Y	Zn	Zr
51	0.0X	0.00X	0.0X	0.X	---	0.00X	---	---	nd	0.00X	---	0.X	0.0X	---	nd	0.002	nd	0.00X	0.0X	---	0.0X
52	---	---	.3-0.6	.X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	---	nd	.0X	---	---	.00X
53	---	.00X	.3-0.6	.0X	0.00X	.00X	---	0.00X	nd	.0X	---	---	.0X	---	nd	.001	nd	.0X	---	---	.00X
54	---	---	.3-0.6	.X	---	.00X	---	.000X	nd	.0X	---	---	.0X	---	nd	.001	nd	.00X	---	---	.00X
55	---	---	.6-1.0	.0X	.00X	.00X	---	.000X	nd	.0X	---	---	.0X	---	nd	---	nd	.00X	---	---	.00X
56	---	.00X	0.6-1	.0X	.X	.00X	---	---	nd	.0X	---	---	.0X	---	nd	---	nd	---	---	---	.00X
57	---	---	3-6	.X	.00X	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.002	nd	.0X	---	---	.0X
58	---	---	.6-1	.X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	.001	nd	.0X	---	0.0X	.00X
59	---	---	.6-1	.X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	---	nd	.00X	---	---	.00X
60	---	---	.3-0.6	.0X	.00X	.00X	---	---	nd	.00X	---	---	.X	0.0X	nd	---	nd	.00X	.00X	---	.0X
61	---	---	.6-1	.X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	.001	nd	.0X	---	---	.0X
62	---	.0X	.6-1	.X	.00X	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.001	nd	.0X	---	.0X	.00X
63	.0X	.000X	.6-1	.X	.00X	.00X	---	---	nd	.0X	---	---	.X	---	nd	---	nd	.0X	---	---	.00X
64	.0X	---	.3-0.6	.X	---	.00X	0.0X	---	nd	.0X	---	---	.X	---	.003	.005	nd	.00X	---	---	.0X
65	.0X	.00X	.1-0.3	.X	---	.00X	.0X	---	nd	.0X	---	---	.X	---	.003	.007	nd	---	---	---	.0X
66	.0X	.00X	.3-0.6	.X	---	.00X	.0X	---	nd	.0X	---	---	.X	---	.002	.007	nd	.00X	---	---	.0X
67	.0X	.00X	.1-0.3	.X	---	.00X	.0X	.000X	nd	.0X	---	---	.X	---	.002	.006	nd	---	---	---	.0X
68	.0X	---	3-6	.0X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	.002	nd	.0X	---	---	.00X
69	.0X	.00X	.1-0.3	.X	---	.00X	.0X	---	nd	.0X	---	---	.X	---	.004	.010	nd	.00X	.0X	---	.X
70	.0X	---	1-3	.0X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	.001	nd	.0X	---	---	.0X
71	---	---	.3-0.6	.0X	---	.000X	---	---	nd	.0X	---	---	.X	---	nd	.003	nd	.00X	---	---	.00X
72	---	.0X	.1-0.3	.X	.00X	.00X	---	.000X	nd	.00X	---	.00X	.00X	---	nd	.001	nd	.00X	---	.0X	.00X
73	---	.00X	.3	.X	---	.00X	---	.000X	nd	.00X	---	.00X	.00X	---	nd	.002	nd	.00X	---	.0X	.00X
74	---	.00X	.6-1	.X	---	.00X	---	---	nd	.0X	---	.00X	.X	.0X	nd	.001	nd	.00X	---	.0X	.00X
75	---	.0X	.3-0.6	.X	.00X	.00X	---	.000X	nd	.00X	---	---	.X	---	nd	---	nd	.00X	---	.X	.00X
76	---	.00X	1-3	.X	---	.00X	---	---	nd	.0X	---	---	.X	.0X	nd	.001	nd	.0X	---	.X	.00X
77	---	.0X	.1-0.3	.X	---	.00X	---	.00X	nd	.0X	---	---	.0X	---	nd	---	nd	.00X	---	X.	.00X
78	---	.0X	6-10	.X	---	.00X	---	.00X	nd	.0X	---	---	.0X	---	nd	---	nd	.00X	---	.X	.00X
79	---	.000X	.6-1	.X	---	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.002	nd	.00X	---	---	.0X
80	---	X-X0	0	.0X	---	.000X	---	.00X	nd	.0X	---	---	.00X	---	nd	---	nd	---	---	.X	---
81	---	.00X	.X	.X	---	.00X	---	.000X	nd	.0X	---	---	---	---	nd	.001	nd	.00X	.0X	---	---
82	---	---	.6-1	.0X	.0X	.00X	---	---	nd	.0X	---	.00X	.0X	.X	nd	---	nd	.0X	.00X	---	.00X
83	---	X	.6-1	.X	.00X	.00X	---	.00X	nd	.00X	---	---	.0X	---	nd	---	nd	---	---	X.	.00X
84	---	.0X	.6-1	X.0	---	.00X	---	.000X	nd	.0X	---	---	.00X	---	nd	---	nd	.00X	---	.0X	.00X
85	---	.00X	.3-0.6	.X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	.003	nd	.0X	.0X	---	.0X
86	---	---	.3-0.6	.X	.00X	.00X	---	.000X	nd	.0X	---	---	.0X	---	nd	---	nd	.00X	---	.0X	.00X
87	---	.000X	.1-0.3	.X	.00X	.00X	---	.000X	nd	.00X	---	---	.0X	---	nd	---	nd	.00X	.00X	.0X	.0X
88	---	.0X	.6-1	X	.00X	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.001	nd	.00X	.00X	.X	.00X
89	---	.000X	.0X	.X	---	.00X	---	---	nd	.00X	---	---	.00X	---	nd	---	nd	---	.00X	.0X	.00X
90	---	---	.3-0.6	.X	---	.00X	---	---	nd	.00X	---	---	.00X	---	nd	---	nd	---	.00X	.0X	.0X
91	---	.000X	.6-1	.0X	---	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.002	nd	.0X	---	---	.0X
92	---	.0X	.X	X0	---	.00X	---	---	nd	.0X	---	---	.00X	.0X	nd	---	nd	.00X	---	.X	---
93	---	.000X	.6-1	.X	.00X	.00X	---	---	nd	.0X	---	---	.X	---	nd	.001	nd	.00X	.00X	.X	.0X
94	.0X	---	.6-1	.X	---	.00X	---	.000X	nd	.00X	---	---	.X	---	nd	.001	nd	.00X	.00X	---	.0X
95	---	---	1-3	.0X	.00X	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.002	nd	.0X	---	---	.00X
96	---	.000X	3-6	.X	---	.00X	---	.00X	nd	.0X	---	---	.X	---	nd	.002	nd	.0X	---	.0X	.00X
97	---	---	.6-1	.X	---	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.001	nd	.0X	---	---	.00X
98	---	.00X	.1-0.3	X	---	.00X	---	.000X	nd	.0X	---	---	.00X	---	nd	.001	nd	---	---	X	.00X
99	---	.000X	.0X	.0X	---	---	---	---	nd	.0X	---	---	.00X	---	nd	---	nd	.00X	---	---	---
100	---	.000X	.3-0.6	.X	.00X	.00X	---	.000X	nd	.0X	---	---	.X	---	nd	.001	nd	.00X	---	X	.00X
101	---	.000X	.6-1	.X	.00X	.00X	---	.000X	nd	.0X	---	---	.00X	---	nd	---	nd	---	---	.0X	.00X
102	---	---	.6-1	.X	---	.00X	---	---	nd	.0X	---	---	.0X	---	nd	---	nd	---	---	.X	.00X
103	---	---	.6-1	.0X	---	.00X	---	---	nd	.0X	---	---	.X	---	nd	.003	nd	.00X	.00X	---	.0X
104	---	---	6-10	.X	---	.00X	---	---	nd	.000X	---	---	.0X	---	nd	.001	nd	---	---	---	.00X
105	---	---	.6-1	.X	---	.00X	---	---	nd	.00X	---	---	.0X	---	nd	.001	nd	.00X	---	.X	.00X
106	---	.0X	.6	.X	---	.000X	---	.00X	nd	.00X	---	---	.00X	---	nd	---	nd	---	---	X0	---
107	---	.X	.6	.X	---	.00X	---	.000X	nd	.0X	---	---	.00X	---	nd	---	nd	---	---	.X	---
108	---	.0X	.3-0.6	X	---	---	---	.000X	nd	.00X	---	---	---	---	nd	nd	nd	.00X	---	.X	.00X
109	---	.X	.1-0.3	.X	---	---	---	.00X	nd	.00X	---	---	---	---	nd	nd	nd	.00X	---	X	.00X

TABLE 15.—*Spectrographic analyses, in percent, for other*

[Analysts, F, Janet D. Fletcher; M, K. J. Murata; C, A. A. Chodos. nd, not determined; leaders (----) looked

	Locality and sample	Analyst	BeO	Sb	As	Ba	Bi	B	Cd	CaO	Cr	Co	Cu	Ga	Ge	In	Fe_2O_3
	NEW MEXICO—Continued																
	Grant County—Continued																
	Pinos Altos district:																
110	329-738	F	----	----	----	0.00X	0.0X	----	0.0X	1-3	0.00X	0.00X	0.X	----	----	nd	X0
111	740	F	----	----	0.0X	.00X	.00X	----	.0X	3-6	.000X	.000X	.0X	----	----	nd	X0
	Hidalgo County:																
	Apache No. 2 district:																
112	329-752	F	----	----	----	.0X	----	----	----	X0	.000X	.00X	.X	----	----	nd	3-6
113	755	F	----	----	----	.00X	----	----	----	X0	.000X	.000X	.0X	----	----	nd	X0
114	781	F	----	----	----	.00X	----	----	----	6-10	.00X	----	.00X	----	----	nd	X0
115	783	F	----	----	----	.0X	----	----	----	X0	.000X	.00X	.X	0.00X	----	nd	3-6
	Hidalgo County:																
	Hachita district:																
116	329-740a	F	----	----	----	.X	.0X	----	----	1-3	.000X	.000X	.0X	.00X	----	nd	6-10
117	741	F	----	----	----	.00X	----	----	----	3-6	.00X	----	.00X	----	----	nd	X0
118	742	F	----	----	.X	.0X	----	----	.0X	3-6	.000X	.000X	.0X	----	----	nd	X0
119	743	F	----	----	----	.00X	----	----	----	.6-1	.000X	----	.00X	----	----	nd	X0
120	744	F	----	----	----	.0X	----	----	----	X0	.00X	----	.00X	----	----	nd	1-3
121	745	F	----	----	----	.0X	----	----	----	X0	.000X	----	.00X	----	----	nd	3-6
122	746	F	----	----	----	.00X	----	----	----	X0	.00X	.0X	X-X0	----	----	nd	X0
123	747	F	----	----	----	.00X	----	----	----	X0	.00X	.00X	.X	----	----	nd	3-6
124	749	F	----	----	----	.0X	----	----	----	6-10	.0X	.00X	.0X	.00X	----	nd	1-3
125	750	F	----	----	----	.00X	----	----	----	6-10	.000X	.00X	.X	----	----	nd	X0
126	751	F	----	----	----	.X	----	----	----	6-10	.00X	----	.00X	----	----	nd	1-3
	Lordsburg district:																
127	329-421	F	----	----	----	.00X	.00X	0.00X	----	.1-0.3	.000X	----	.X	----	----	nd	1-3
128	422	F	----	----	----	.00X	----	.00X	----	1-3	.000X	.000X	.X	----	----	nd	1-3
129	423	F	----	----	----	.00X	.X	----	----	6-10	.000X	.00X	X	----	----	nd	X0
	San Simon district:																
130	329-427	F	----	----	----	.00X	.0X	----	----	X0	.00X	.000X	.00X	.00X	----	nd	3-6
131	429	F	----	----	----	.0X	.00X	----	----	X0	.00X	.00X	.0X	----	----	nd	3-6
132	433	F	----	----	----	.00X	----	----	----	X0	.00X	.000X	.X	----	----	nd	X0
	Lincoln County:																
	Capitan district:																
133	329-810	F	0.005	----	----	.0X	----	.00X	----	3-6	----	----	.000X	.00X	----	nd	1-3
	Gallinas district:																
134	329-808	F	.008	----	----	.00X	----	----	----	3-6	----	.000X	.000X	.00X	----	nd	X0
	Luna County:																
	Tres Hermanas district:																
135	329-759	F	----	----	----	.00X	----	.X	----	X0	.000X	----	.00X	----	----	nd	3
136	760	F	----	----	----	.00X	----	.0X	----	X0	.00X	.000X	.00X	----	----	nd	1-3
	Victorio Mountains:																
137	329-390	F	.02	----	----	.0X	.0X	.000X	----	X0	.00X	----	.0X	.000X	0.00X	nd	1-3
138	392	F	.003	----	----	.00X	.0X	.000X	----	X0	.00X	----	.00X	----	.00X	nd	.6-1
139	393	F	.004	----	----	.00X	.00X	.000X	----	X0	.000X	----	.00X	----	----	nd	.3-0.6
140	399	F	.1	----	----	.0X	.0X	----	.X	X0	.000X	.00X	.0X	.000X	.00X	nd	X0
141	400	F	.02	----	----	.0X	.00X	.000X	----	X0	.000X	----	.0X	----	----	nd	.3-0.6
142	401	F	.2	----	----	.00X	.0X	----	----	6-10	.00X	----	.X	.00X	----	nd	X0
143	402	F	.005	----	----	.00X	.0X	.000X	----	X0	.000X	----	.00X	----	----	nd	.6-1
144	403	F	.002	----	----	.0X	.00X	----	----	1-3	.000X	----	.00X	.00X	----	----	1-3
145	408	F	.03	----	----	.00X	.0X	.000X	.0X	X0	.00X	.000X	.0X	.000X	.0X	----	X0
146	411	F	.006	----	----	.00X	.00X	----	----	X0	.00X	----	.0X	.00X	.0X	----	6-10
147	415	F	.06	----	----	.00X	.X	----	----	X0	.00X	.000X	.00X	.00X	.0X	----	3-6
148	394	F	.005	----	----	.00X	.00X	.00X	----	X0	.000X	----	.0X	----	----	----	.3-0.6
149	416	F	.02	----	----	.0X	.00X	.00X	----	X0	.000X	----	.00X	.000X	.00X	----	1-3
150	417	F	.005	----	----	.0X	.00X	----	----	3-6	.00X	.000X	.00X	.000X	----	----	1-3
151	418	F	.008	----	----	.00X	----	----	----	X0	.00X	.000X	.00X	.000X	.00X	----	X0
152	420	F	.002	----	----	.00X	.0X	----	----	X0	.000X	.000X	.0X	.00X	.0X	----	X0
	San Miguel County:																
	Rociada district:																
153	329-384	F	----	----	----	.00X	----	.00X	----	6-10	.00X	.00X	X	.00X	----	----	X0
	Willow Creek district:																
154	329-385A	F	----	----	----	.00X	.0X	.00X	.0X	.3-0.6	.000X	----	.0X	.00X	----	----	3
	Santa Fe County:																
	New Placers district:																
155	329-323	F	----	----	----	.0X	----	----	----	6-10	.00X	.00X	X	.00X	----	----	6-10
156	324	F	----	----	----	.0X	----	.00X	----	X0	.00X	.00X	.X	.00X	----	----	1-3
157	325	F	----	----	----	.0X	----	.00X	----	X0	.0X	----	.0X	.00X	----	----	3-6
158	326	F	----	----	----	.00X	----	.00X	----	X0	.00X	----	.0X	.00X	----	----	6-10
159	328	F	----	----	----	.0X	----	.00X	----	X0	.00X	.0X	.X	.00X	----	----	3-6
160	333	F	----	----	----	.0X	----	.00X	----	6-10	.00X	.00X	.X	.00X	----	----	3-6
161	334	F	----	----	----	.0X	----	----	----	6-10	.00X	.00X	.X	.00X	----	----	3-6

elements in samples analyzed for beryllium—Continued

for but not found; asterisk (*) percent of element rather than oxide. Major, more than 1 percent]

	La	Pb	MgO	Mn	Mo	Ni	Nb	Ag	Na_2O	Sr	Ta	Sn	Ti	W	U	eU	eU_3O_8	V	Y	Zn	Zr
110	......	0.0X	0.1-0.3	0.X	......	0.00X	......	0.00X	nd	0.000X	......	......	0.0X	......	nd	0.001	nd	......	......	X	0.00X
111	......	X	.3-0.6	.X	......	.00X	......	.00X	nd	.00X	......	......	.00X	......	nd	001	nd	......	......	X	.00X
112	......	......	.6-1	.X	......	.00X	......	......	nd	.0X	......	......	.X	......	nd	......	nd	0.00X	......	......	.00X
113	......	......	.6	.X	0.00X	.00X	......	......	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	......	......	.00X
114	......	.00X	.3	.0X	......	.00X	......	......	nd	.0X	......	......	.0X	......	nd	......	nd	.00X	0.00X	.0X	.00X
115	......	......	.6	.X	......	.00X	......	.000X	nd	.0X	......	......	.0X	......	nd	.001	nd	.00X	......	......	.00X
116	......	.00X	.3-0.6	.0X	......	.000X	......	......	nd	.0X	......	......	.X	0.X	nd	.006	nd	.0X	......	......	.00X
117	......	.0X	.6	X	......	.000X	......	.00X	nd	.0X	......	......	.0X	......	nd	......	nd	......	......	.X	.00X
118	......	.0X	.6-1	X	......	.000X	......	.00X	nd	.0X	......	......	.0X	......	nd	......	nd	.00X	......	X	.00X
119	......	X	.6-1	X-X0	......	......	......	.0X	nd	.00X	......	......	.0X	......	nd	......	nd	......	......	.X	.00X
120	......	.00X	1-3	.X	......	.00X	......	......	nd	.0X	......	......	.X	......	nd	......	nd	.00X	......	......	.0X
121	......	.000X	.1-0.3	.X	......	.000X	......	......	nd	.0X	......	......	.X	......	nd	.002	nd	.00X	......	......	.00X
122	......	.000X	.6-1	.X	......	.0X	......	.00X	nd	.0X	......	......	.X	......	nd	.002	nd	.00X	......	.0X	.00X
123	......	......	3	.X	......	.00X	......	.000X	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	......	.0X	.00X
124	......	.000X	1-3	.0X	.0X	.00X	......	......	nd	.0X	......	......	.X	......	nd	.003	nd	.0X	.00X	......	.00X
125	......	......	.1-0.3	.X	.00X	.00X	......	.000X	nd	.0X	......	......	.0X	......	nd	.001	nd	.00X	......	......	.00X
126	......	......	3-6	.0X	......	.00X	......	......	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	.00X	......	.0X
127	......	X-X0	.1-0.3	.0X	.00X	.00X	......	.00X	nd	.00X	......	......	.X	......	nd	.001	nd	.00X	......	.0X	.00X
128	......	.0X	.6	.X	.00X	.00X	......	.00X	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	......	.0X	.00X
129	......	.X	.6-1	.X	.00X	.00X	......	.00X	nd	.00X	......	......	.0X	.0X	nd	.002	nd	......	......	.0X	.00X
130	......	X	1-3	.0X	......	.00X	......	.00X	nd	.0X	......	......	.X	......	nd	......	nd	.0X	......	.0X	.00X
131	0.0X	.X	3	.0X	......	.00X	......	.00X	nd	.0X	......	......	.X	......	nd	.002	nd	.00X	......	.X	.00X
132	......	.000X	.3	.0X	......	.00X	......	.00X	nd	.0X	......	......	.0X	......	nd	......	nd	.00X	......	.0X	.00X
133	......	......	6-10	.0X	.00X	......		......	nd	.00X	......	......	.0X	......	nd	nd	nd	......	.00X	......	.00X
134	.00X	......	1-3	.0X	.00X	.00X	......	......	nd	.00X	......	......	.X	......	nd	nd	nd	.0X	.00X	......	.00X
135	......	......	1-3	.0X	......	.00X	......	......	nd	.00X	......	0.00X	.0X	......	nd	......	nd	.00X	.00X	......	.00X
136	......	......	.6	.0X	......	.00X	......	......	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	.00X	......	.00X
137	......	.0X	6-10	X	......	.000X	......	.0000X	0.X	.00X	......	.0X	.0X	.02	nd	nd	.003	.00X	......	.X	.00X
138	......	.00X	6-10	X	......	.000X	......	.0000X	.X	.0X	......	.0X	.0X	......	nd	nd	......	.00X	......	.X	.00X
139	......	.00X	6-10	.X	......	......	......	.0000X	.X	.00X	......	.00X	.0X	......	nd	nd	......	.00X	......	.0X	.00X
140	......	.X	1-3	X	.00X	.000X	......	.000X	......	.00X	......	.0X	.0X	.0X	nd	nd	......	.00X	......	X	.00X
141	......	.0X	X0	X	......	......	......	.0000X	......	.00X	......	......	.00X	......	nd	nd	......	.00X	......	.0X	......
142	......	.X	1-3	.0X	.00X	.00X	......	.000X	.X	.00X	......	.00X	.0X	.08	nd	nd	.001	.0X	.00X	.X	.00X
143	......	.0X	X0	X	......	.000X	......	.000X	.X	.00X	......	.00X	.00X	......	nd	nd	.001	.00X	......	.0X	......
144	......	.0X	.6-1	.X	......	.000X	......	.000X	4-7	.0X	......	.00X	.0X	......	nd	nd	.005	.00X	.0X	.0X	.00X
145	......	.X	3-6	X	.00X	.000X	......	.00X	.X	.00X	......	.0X	.X	.0X	nd	nd	......	.0X	......	X	.00X
146	.0X	.000X	1-3	X	......	.000X	......	.0000X	......	.00X	......	.0X	.X	.04	nd	nd	.001	.00X	.00X	.0X	.00X
147	.00X	.X	3-6	X	.00X	.000X	......	.000X	......	.00X	......	.0X	.X	.06	nd	nd	.002	.0X	......	.0X	.00X
148	......	.000X	X0	.X	......	.000X	......	.0000X	.X	.0X	......	.00X	.0X	......	nd	nd	.001	.00X	......	.0X	.00X
149	......	.00X	1-3	.X	.00X	.000X	......	.000X	.X	.00X	......	.00X	.00X	.X	nd	nd	......	.00X	......	.0X	......
150	......	.00X	1-3	.X	.00X	.00X	......	.0000X	.X	.00X	......	.00X	.00X	.2	nd	nd	......	.00X	.000X	.0X	......
151	.00X	......	3-6	.X	......	.00X	......	.0000X	.X	.00X	......	.00X	.0X	......	nd	nd	......	.00X	......	.0X	.00X
152	......	.X	.6-1	X	......	.000X	......	.000X	......	.00X	......	.0X	.X	......	nd	nd	......	.00X	.00X	.X	.0X
153	......	......	3-6	X	.00X	.00X	......	.00X	nd	.0X	......	......	.X	......	nd	.001	nd	.0X	......	......	.00X
154	......	X-X0	.1-0.3	.X	.00X	.00X	......	.X	nd	......	......	......	......	......	nd	......	nd	......	......	X0	.00X
155	......	......	.1-0.3	.X	.0X	.00X	......	.00X	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	......	......	.00X
156	.0X	......	.6-1	.X	.00X	.00X	......	.000X	nd	.0X	......	......	.X	......	nd	.004	nd	.00X	......	......	.00X
157	......	......	.3-0.6	.X	......	.00X	......	......	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	......	......	.00X
158	......	......	.1-0.3	.X	......	.00X	......	......	nd	.00X	......	......	.0X	......	nd	.001	nd	.00X	......	......	.00X
159	......	......	.6-1	.X	.0X	.00X	......	.000X	nd	.0X	......	......	.X	......	nd	.001	nd	.00X	......	......	.00X
160	.0X	......	.3-0.6	.X	.00X	.00X	......	.00X	nd	.0X	......	......	.X	......	nd	.003	nd	.00X	......	......	.00X
161	......	......	.1-0.3	.X	.00X	.00X	......	.00X	nd	.00X	......	......	.0X	......	nd	.001	nd	.00X	......	......	.00X

TABLE 15.—*Spectrographic analyses, in percent, for other*

[Analysts, F, Janet D. Fletcher; M, K. J. Murata; C, A. A. Chodos. nd, not determined; leaders (----) looked

	Locality and sample	Analyst	BeO	Sb	As	Ba	Bi	B	Cd	CaO	Cr	Co	Cu	Ga	Ge	In	Fe_2O_3
	NEW MEXICO—Continued																
	Santa Fe County—Continued																
	New Placers district—Continued																
162	329-336	F	----	----	----	0.0X	----	----	----	X0	0.00X	0.00X	0.X	0.00X	----	----	3-6
163	340	F	----	----	----	.0X	----	----	----	X0	.00X	----	.X	.00X	----	----	3-6
164	341	F	----	----	----	.00X	----	----	----	X0	.00X	----	X	.00X			6-10
165	342	F	----	----	----	.0X	----	----	----	X0	.00X	.00X	.X	.00X	----	----	X0
166	345	F	0.0004	----	----	.X	----	----	----	3-6	.00X	.000X	.0X	.00X	----	----	1-3
	Old Placers district:																
167	329-349	F	----	----	----	.X	----	----	----	3-6	.00X	----	.00X	.00X	----	----	1-3
168	350	F	----	----	----	.X	----	----	----	3-6	.000X	.000X	.00X	.00X	----	----	3-6
169	352	F	----	----	----	.00X	----	----	----	X0	.00X	----	.0X	.00X	----	----	3-6
170	356	F	----	----	----	.0X	----	----	----	X0	.00X	.000X	.0X	.00X	----	----	3-6
171	359	F	----	----	----	.0X	----	----	----	1-3	.000X	----	.00X	.00X	----	----	1-3
	Sierra County:																
	Cuchillo Negro district:																
172	329-700	F	.001	----	0.0X	.00X	0.0X	----	0.0X	3-6	.00X	.00X	.X	----	----	nd	1-3
173	701	F	.0007	----	----	.00X	----	0.000X	----	6-10	.00X	.000X	.00X	.00X	----	nd	1-3
174	702	F	.0005	----	----	.0X	----	----	----	1-3	.00X	.00X	.0X	.00X	----	nd	3-6
175	708	F	.004	----	----	.0X	----	----	----	3-6	.000X	----	.0X	----	----	nd	3
	Apache No. 1 district:																
176	329-705	F	----	----	----	.0X	----	----	----	3-6	.00X	----	.0X	----	----	nd	1-3
177	706	F	.01	----	----	.0X	----	----	----	.3-0.6	.00X	----	.X	----	----	nd	.6-1
	Socorro County, Jones Camp:																
178	329-809	F	----	----	----	.00X	----	----	----	3-6	.00X	.00X	.0X	----	----	nd	3-6
	TRANS-PECOS REGION (see pl. 1)																
	Wind Mountain:																
179	329-129	M	.0051	----	----	.00X	----	----	----	X.0	----	----	.000X	----	----	----	X.0
180	135	F	.006	----	----	.00X	----	.000X	----	1-3	.000X	----	.000X	.00X	----	nd	X0
181	136	F	.003	----	----	.00X	----	.000X	----	X0	.00X	----	.000X	----	----	nd	.6-1
182	145	F	<.001	----	----	.00X	----	.000X	----	X0	.000X	----	.000X	----	----	nd	.3-0.6
183	145A	M	.000X	----	----	.00X	nd	nd	nd	.X	nd	nd	.00X	nd	nd	nd	*Major
184	145B	M	*.00X	nd	nd	----	nd	nd	nd	*Major	nd	nd	.00X	nd	nd	nd	*Major
185	611C	M	.0050	----	----	.00X	----	.00X	----	.X	----	----	.000X	.00X	----	nd	X
186	622	F	.001	----	----	.0X	----	.00X	----	X0	.0X	.00X	.00X	.00X	nd	nd	1-3
187	631	F	----	----	----	.00X	----	----	----	X0	.000X	----	.000X	----	nd	nd	.1-0.3
188	649	F	.004	----	----	.0X	----	----	----	1	.000X	----	.00X	.0X	nd	nd	1-3
189	652	F	.004	----	----	.00X	----	----	----	1	.0X	----	.00X	.0X	nd	nd	1-3
	Cave Peak:																
190	329-077	F	.01	----	----	.0X	----	.00X	----	3-6	.00X	.00X	.00X	----	nd	nd	X0
191	078	F	.004	----	----	.0X	----	.00X	----	.6-1	.00X	----	.000X	.00X	----	nd	3-6
192	079	F	.01	----	----	.0X	----	.00X	----	3-6	.00X	.000X	.00X	.00X	----	nd	6-10
193	680	F	.0005	----	----	.0X	----	.00X	----	X0	.00X	----	.00X	.00X	----	nd	1-3
	Other localities:																
194	329-601	F	.001	----	----	.0X	----	----	----	.3-0.6	.000X	----	.00X	.00X	----	nd	1-3
195	603	F	.004	----	----	.0X	----	.000X	----	.6-1	.00X	----	.00X	.00X	----	nd	3-6
196	609	F	.002	----	----	.0X	----	----	----	6-10	.000X	.00X	.0X	.00X	----	nd	3-6
197	610	F	.0008	----	----	.0X	----	----	----	.3-0.6	.0X	----	.00X	.00X	----	nd	1-3
198	650	M	.0066	----	----	.00X	----	.00X	----	.X	----	----	.000X	.00X	----	----	X.0
199	653	F	.002	----	----	.0X	----	----	----	1-3	.000X	.000X	.00X	.00X	----	nd	1-3
200	688	F	.002	----	----	.0X	----	----	----	1-3	.00X	----	.00X	.00X	----	nd	3-6
	MONTANA (see fig. 67)																
	Anaconda mill and smelter products:																
201	328-952	F	----	----	----	.0X	----	----	----	.3-0.6	----	.000X	.X	----	----	----	3-6
202	963	F	.0004	----	----	.0X	----	.00X	----	.1-0.3	.00X	.000X	.0X	.00X	----	----	3
203	966	F	----	----	----	.0X	----	----	----	1-3	.000X	----	.0X	----	----	----	1-3
204	973	F	----	----	----	.0X	.0X	----	----	.6-1	.00X	.00X	X0	.00X	----	----	X0
205	974	F	.001	----	----	.X	----	----	----	X0	----	----	.0X	----	----	----	1-3
206	975	F	.001	----	----	.0X	----	.00X	----	3-6	.00X	----	.0X	----	----	----	.6-1
207	975A	F	.0004	----	----	.0X	----	.00X	----	X0	.0X	----	.0X	----	----	----	.3
208	975B	F	----	----	----	.0X	----	.00X	----	X0	.0X	----	.0X	----	----	----	.3-0.6
209	977	F	----	----	----	.00X	----	----	----	.3-0.6	.00X	.00X	.0X	----	----	----	3-6
210	981	F	----	----	----	.00X	----	----	----	.6-1	.0X	.00X	.00X	----	----	----	X0
211	988	F	----	----	.X	.0X	.0X	----	----	.3-0.6	.00X	.00X	X0	----	----	----	X0
212	989	F	----	----	.X	.00X	.0X	----	.0X	.1-0.3	.00X	.000X	.X	.0X	0.0X	0.0X	3

elements in samples analyzed for beryllium—Continued

or but not found; asterisk (*) percent of element rather than oxide. Major, more than 1 percent]

	La	Pb	MgO	Mn	Mo	Ni	Nb	Ag	Na_2O	Sr	Ta	Sn	Ti	W	U	eU	eU_3O_8	V	Y	Zn	Zr
162	------	------	0.3-0.6	0.X	------	0.00X	------	------	nd	0.0X	------	------	0.0X	------	nd	0.001	nd	0.00X	------	------	0.00X
163	------	------	.3-0.6	.X	------	.00X	------	0.000X	nd	.0X	------	------	.0X	------	nd	.002	nd	00X	------	------	.00X
164	------	------	.3-0.6	.X	------	.00X	------	.00X	nd	.0X	------	------	.0X	------	nd	.001	nd	.00X	------	------	.00X
165	------	------	.3-0.6	.X	------	.00X	------	.000X	nd	.0X	------	------	.0X	------	nd	.001	nd	.00X	------	------	.00X
166	0.0X	------	.6-1	.0X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	.003	nd	.00X	0.00X	------	.0X
167	------	------	.6-1	.0X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	.003	nd	.00X	.00X	------	.0X
168	.0X	------	.6-1	.0X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	.002	nd	.00X	.00X	------	.0X
169	.0X	------	.3-0.6	.X	------	.00X	------	.000X	nd	.0X	------	------	.X	------	nd	.001	nd	.00X	------	------	.00X
170	------	------	.3-0.6	.X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	------	nd	.0X	------	------	.00X
171	------	------	.3-0.6	.0X	------	.000X	------	------	nd	.0X	------	------	.X	------	nd	.001	nd	.00X	------	------	.00X
172	------	X-X0	.3-0.6	.X	0.0X	.00X	------	.0X	nd	.00X	------	------	.0X	0.0X	nd	------	nd	.00X	------	X0	.00X
173	------	.X	.6-1	.X	------	.00X	------	.000X	nd	.0X	------	0.00X	.X	------	nd	------	nd	.00X	------	.X	.00X
174	------	X	.6-1	.X	------	.00X	------	.000X	nd	.0X	------	------	.X	------	nd	------	nd	.0X	------	.X	.00X
175	------	------	.3-0.6	X-X0	------	.000X	------	.000X	nd	.0X	------	------	.00X	------	nd	------	nd	------	------	.0X	------
176	------	.0X	.6-1	.X	------	.00X	------	.00X	nd	.0X	------	------	.X	------	nd	.002	nd	.00X	------	------	.00X
177	------	.0X	.1	.0X	------	.00X	------	.0X	nd	.00X	------	------	.0X	------	nd	------	nd	------	------	------	------
178	------	------	3-6	.0X	.00X	.00X	------	------	nd	.00X	------	------	.X	------	nd	nd	nd	.0X	------	------	.00X
179	.X	.0X	.0X	X.0	.00X	------	0.53	------	nd	.0X	------	.0X	.0X	.X	nd	------	nd	------	.X	------	Major
180	.0X	.0X	<.1	.X	.00X	------	.0X	.0000X	7-10	.0X	------	.00X	.0X	nd	nd	nd	nd	------	.0X	------	.0X
181	.00X	------	1-3	.0X	------	------	------	------	<1	.0X	------	------	.0X	nd	nd	nd	nd	.00X	.00X	------	.0X
182	------	------	1-3	.0X	------	------	------	------	<1	.0X	------	------	.0X	nd	nd	nd	nd	.00X	.00X	------	.0X
183	.0X	.00X	*.X	.X	nd	nd	.0X	nd	*Major	.00X	nd	.00X	.X	nd	nd	nd	nd	nd	.00X	nd	.X
184	.X	.00X	*.0X	Major	nd	nd	.X	nd	.X	------	nd	------	------	nd	nd	nd	nd	nd	.X	nd	Major
185	.0X	.00X	.X	.X	------	------	.02	------	nd	.00X	------	------	.X	------	nd	nd	nd	------	.0X	------	.0X
186	------	.000X	1-3	.0X	.00X	.00X	------	------	.X	.0X	------	.00X	.X	------	nd	nd	nd	.0X	.00X	------	.0X
187	------	------	X0	.0X	------	------	------	------	.0X	.0X	------	------	------	------	nd	nd	nd	.00X	------	------	------
188	.0X	.000X	.1-0.3	.X	.00X	.00X	.00X	------	7-10	.00X	------	------	.X	------	nd	nd	nd	.00X	.00X	------	.0X
189	.0X	.000X	.1-0.3	.X	.00X	.0X	.0X	------	4-7	.00X	------	------	.0X	------	nd	nd	nd	.00X	.0X	------	.0X
190	.0X	.X	.3-0.6	.X	.00X	.00X	.0X	.000X	1	.0X	------	.000X	.X	nd	nd	nd	nd	.00X	.0X	.0X	.0X
191	.0X	.0X	.1-0.3	.0X	.00X	------	.0X	.000X	<1	.00X	------	.000X	.0X	nd	nd	nd	nd	------	.0X	.0X	.0X
192	.0X	.X	1-3	.X	.00X	.00X	.00X	.0000X	4-7	.0X	------	.000X	.0X	nd	nd	nd	nd	.00X	.0X	.X	.0X
193	------	------	.6-1	.00X	------	.000X	------	------	nd	.0X	------	------	.X	------	nd	.001	nd	.00X	.00X	------	.0X
194	------	------	.1-0.3	.0X	------	.000X	------	------	nd	.00X	------	------	.X	------	nd	nd	nd	------	.00X	------	.0X
195	.0X	------	.3-0.6	.X	------	------	------	------	nd	.0X	------	------	.X	------	nd	.005	nd	------	------	------	.X
196	.00X	.000X	1-3	.X	.00X	.00X	.00X	------	4-7	.0X	------	------	.X	------	nd	nd	nd	.0X	.0X	------	.0X
197	.00X	.000X	.1-0.3	.X	.00X	.0X	.00X	------	7-10	.00X	------	------	.X	------	nd	nd	nd	.00X	.00X	------	.0X
198	.0X	.00X	.X	.X	------	------	.03	------	nd	.00X	------	------	.X	------	nd	nd	nd	nd	.0X	------	.0X
199	.00X	.000X	.3-0.6	.0X	.00X	.000X	.00X	------	4-7	.0X	------	------	.X	------	nd	nd	nd	.00X	.00X	------	.0X
200	------	.00X	.3-0.6	.0X	------	.00X	------	------	nd	.0X	------	------	.X	------	nd	nd	nd	.00X	.00X	------	.0X
201	------	.0X	.3-0.6	.X	------	.000X	------	.000X	nd	.00X	------	------	.X	nd	nd	.002	nd	.00X	.00X	------	.0X
202	------	.0X	X0	.X	------	.00X	------	.00X	nd	.00X	------	------	.X	nd	nd	.003	nd	.00X	.00X	.X	.0X
203	------	.0X	.6-1	X	------	------	------	.000X	nd	.00X	------	------	.0X	nd	nd	------	nd	------	------	.0X	.00X
204	------	.0X	6-10	.X	.00X	.0X	------	.0X	nd	.00X	------	------	.0X	nd	nd	.001	nd	------	------	.X	.0X
205	.0X	.00X	6-10	X	------	.00X	------	.000X	nd	.0X	------	------	.X	nd	nd	.004	nd	.00X	.0X	------	.0X
206	------	.0X	X0	X	------	.00X	------	.000X	nd	.00X	------	------	.X	nd	nd	.002	nd	.00X	------	.0X	.00X
207	.0X	------	.6-1	.0X	.00X	.0X	------	.000X	nd	.X	------	------	.0X	nd	nd	.008	nd	.X	.0X	.0X	.0X
208	.0X	------	.6-1	.0X	.00X	.0X	------	.000X	nd	.X	------	------	.0X	nd	nd	.010	nd	.X	.0X	.0X	.0X
209	------	.0X	------	X	------	.00X	------	.00X	nd	------	------	------	.0X	nd	nd	------	nd	.0X	------	------	.00X
210	.0X	------	6-10	.X	------	.00X	------	.00X	nd	.00X	------	------	.X	nd	nd	.014	nd	.X	.0X	------	.0X
211	------	.0X	.1-0.3	.X	------	.00X	------	.0X	nd	------	------	.00X	.0X	nd	nd	.002	nd	.00X	.00X	.X	.0X
212	------	X	6-10	.X	------	.000X	------	.0X	nd	------	------	------	.0X	nd	nd	.001	nd	------	------	X0	------

TABLE 15.—*Spectrographic analyses, in percent, for other*

[Analysts, F, Janet D. Fletcher; M, K. J. Murata; C, A. A. Chodos. nd, not determined; leaders (----) looked

	Locality and sample	Analyst	BeO	Sb	As	Ba	Bi	B	Cd	CaO	Cr	Co	Cu	Ga	Ge	In	Fe_2O_3
	WYOMING (see fig. 46)																
	Carbon County, Hanna district:																
213	328-248	M	0.0003	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.002	----	nd	nd
	Sweetwater County, Superior district:																
214	328-245	M	.0004	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
	COLORADO (see fig. 49)																
	Boulder County, Lafayette area:																
215	328-357	M	----	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
216	358	M	.0003	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.003	----	nd	nd
	Chaffee County:																
	Monarch district:																
217	328-020	F	----	----	----	0.000X	----	----	----	X0	0.00X	0.000X	0.00X	0.00X	----	nd	X0
218	021	F	----	----	----	.00X	----	----	----	X0	.00X	.000X	.00X	.00X	----	nd	X0
	Sedalia mine:																
219	328-602	F	.0004	----	----	.0X	----	----	----	X0	.00X	----	.00X	.00X	----	nd	3-6
	Conejos County:																
	Platoro—Summitville district:																
220	328-594	F	----	----	----	.0X	----	----	0.0X	.6-1	.000X	.00X	.0X	----	----	nd	1-3
221	595	F	----	----	----	.X	----	----	----	.3-0.6	.00X	.000X	.0X	.00X	----	nd	3-6
222	597	F	----	----	----	.0X	0.00X	----	----	<.1	.00X	.00X	.X	.0X	----	nd	3-6
223	598	F	----	----	----	.X	.00X	----	----	<.1	.000X	----	.0X	.00X	----	nd	3-6
	Costilla County, La Veta area:																
224	328-164	M	*.0004	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
	Fremont County, Florence—Canon City area:																
225	328-171	M	*.0006	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
226	172	M	*.0002	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
	Garfield County, Rifle—Silt area:																
227	328-93	M	*.0009	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
228	94	M	*.0009	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.005	----	nd	nd
229	96	M	.0004	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.005	----	nd	nd
	Gunnison County:																
	Iron Hill:																
210	328-039	F	.000X	----	----	.0X	----	----	----	X0	.00X	.00X	.00X	.00X	----	nd	X0
211	043	F	.000X	----	----	.0X	----	----	----	X0	.000X	.00X	.00X	.00X	----	nd	10
212	044	F	.000X	----	----	.0X	----	----	----	X0	.000X	.00X	.00X	.00X	----	nd	X0
213	048	F	----	----	----	.0X	----	----	----	6-10	.000X	.00X	.00X	.00X	----	nd	X0
214	051	F	----	----	----	.X	----	----	----	3-6	.000X	.000X	.00X	.00X	----	nd	6-10
215	053	F	.000X	----	----	.X	----	----	----	1-3	.000X	.000X	.00X	.00X	----	nd	3-6
216	060	F	.000X	----	----	.00X	----	----	----	X0	.000X	.00X	.00X	.00X	----	nd	X0
217	064	F	.000X	----	----	.0X	----	----	----	X0	.00X	.00X	.0X	.00X	----	nd	X0
218	073	F	.004	----	----	.X	----	----	----	1-3	.0X	.00X	.0X	.00X	----	nd	X0
219	074	F	.001	----	----	.X	----	----	----	X0	.0X	.00X	.00X	.000X	----	nd	X0
220	500	F	----	----	----	.0X	----	----	----	X0	.000X	.00X	.0X	.00X	----	nd	nd
221	504	F	----	----	----	.0X	----	----	----	X0	----	.00X	.0X	.000X	----	nd	nd
222	505	F	----	----	----	.0X	----	----	----	X0	.000X	.00X	.0X	.00X	----	nd	nd
223	506	F	.0005	----	----	.0X	----	----	----	X0	.000X	.00X	.0X	.00X	----	nd	nd
224	508	F	.0005	----	----	.0X	----	----	----	8	.000X	.000X	.00X	.00X	----	nd	nd
225	510	F	----	----	----	.X	----	----	----	10	.000X	.00X	.0X	.00X	----	nd	nd
226	513	F	----	----	----	.0X	----	----	----	8	.000X	.00X	.0X	.00X	----	nd	nd
227	516	F	.001	----	----	.X	----	----	----	6-10	.0X	.00X	.00X	.00X	----	nd	nd
228	518	F	.001	----	----	.X	----	----	----	6-10	.0X	.00X	.0X	.00X	----	nd	3-6
229	520	F	.001	----	----	.0X	----	----	----	X0	.000X	.00X	.00X	.00X	----	nd	3-6
230	529	F	----	----	----	.X	----	----	----	X0	.000X	.000X	.00X	.00X	----	nd	3-6
231	535	F	.001	----	----	.0X	----	----	----	X0	.000X	.00X	.00X	.00X	----	nd	3-6
232	539	F	.002	----	----	.0X	----	----	----	X0	.00X	.00X	.0X	.00X	----	nd	3-6
233	545	F	.002	----	----	.0X	----	----	----	X0	.000X	.00X	.00X	.00X	----	nd	3-6
234	564	F	.002	----	----	.X	----	----	----	X0	.00X	.00X	.00X	.00X	----	nd	3-6
	Italian Mountain:																
235	328-082	F	----	----	----	.0X	----	0.0X	----	X0	.00X	----	.00X	.00X	----	nd	X0
	Snowmass Mountain:																
236	328-086	F	.001	----	----	.000X	----		----	X0	.000X	.00X	.00X	.000X	----	nd	X0
	Tomichi district:																
237	328-022	F	----	----	----	.00X	.00X	.00X	----	3-6	.000X	.00X	.0X	.00X	----	nd	X0
238	023	F	<.001	----	----	.00X	----	.00X	----	X0	.00X	.000X	.00X	.00X	----	nd	1-3
239	030	F	<.001	----	----	.00X	.0X	.00X	----	3-6	.00X	.00X	.X	.00X	----	nd	X0
	Hinsdale County, Lake City district:																
240	328-576	F	----	----	----	X	----	.00X	.0X	.3-0.6	.000X	----	.0X	----	----	nd	1-3
241	580	F	----	----	----	.0X	.0X	----	.0X	.1-0.3	.000X	.00X	X	----	----	nd	3-6

elements in samples analyzed for beryllium—Continued

for but not found; asterisk (*) percent of element rather than oxide. Major, more than 1 percent]

	La	Pb	MgO	Mn	Mo	Ni	Nb	Ag	Na_2O	Sr	Ta	Sn	Ti	W	U	eU	eU_3O_8	V	Y	Zn	Zr
213	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<0.001	nd	0.02	nd	nd	nd
214	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<.001	nd	.008	nd	nd	nd
215	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<.001	nd	.01	nd	nd	nd
216	nd	nd	nd	nd	nd	nd	nd	nd	ud	nd	nd	------	nd	nd	nd	<.001	nd	.01	nd	nd	nd
217	------	0.00X	1-3	0.X	------	0.00X	------	------	------	0.0X	------	------	0.X	nd	nd	nd	nd	.00X	0.00X	0.0X	0.00X
218	0.00X	.000X	1-3	.X	------	.00X	------	------	------	.0X	------	------	.X	nd	nd	nd	nd	.0X	.00X	.0X	.00X
219	.0X	.00X	6-10	.X	------	.00X	------	------	nd	.0X	------	------	.X	nd	nd	nd	nd	.00X	.0X	------	.0X
220	------	X	------	.X	------	------	------	0.00X	nd	.00X	------	------	.0X	nd	nd	nd	.001	------	------	X	.00X
221	.00X	.00X	1-3	.0X	------	.00X	------	.000X	nd	.00X	------	------	.X	nd	nd	nd	.002	.0X	.00X	------	.0X
222	------	.0X	1-3	.0X	------	.00X	------	.00X	nd	.X	------	------	.X	nd	nd	nd	.002	.0X	------	------	.0X
223	.00X	.0X	<.1	.0X	------	.000X	------	.00X	nd	.0X	------	------	.X	nd	nd	nd	.002	.00X	------	------	.0X
224	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<.001	nd	.01	nd	nd	nd
225	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.001	nd	.007	nd	nd	nd
226	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.001	nd	.001	nd	nd	nd
227	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<.001	nd	.02	nd	nd	nd
228	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.001	nd	.01	nd	nd	nd
229	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.002	nd	.008	nd	nd	nd
210	.0X	------	3-6	.X	------	.000X	0.0X	------	4-7	.X	------	------	X	nd	nd	nd	nd	.00X	.00X	.0X	.00X
211	.0X	------	6	.X	------	.000X	------	------	4-7	.X	------	------	.X	nd	nd	nd	nd	.00X	.00X	.0X	.0X
212	.0X	------	6	.X	------	.000X	.0X	------	2-4	.X	------	------	X	nd	nd	nd	nd	.0X	.00X	.0X	.00X
213	.0X	------	6	.X	------	.00X	.0X	------	<1	.0X	------	------	X	nd	nd	nd	nd	.0X	.00X	------	.0X
214	.00X	------	.1-0.3	.0X	------	.000X	------	------	4-7	.X	------	------	.X	nd	nd	nd	nd	.0X	.0X	------	.0X
215	.00X	------	.1-0.3	.0X	------	.000X	------	------	7	.0X	------	------	.X	nd	nd	nd	nd	.00X	------	------	.0X
216	.00X	------	6	.X	------	.000X	------	------	<1	.0X	------	------	.X	nd	nd	nd	nd	.0X	.0X	------	.0X
217	.0X	------	3-6	.X	------	.00X	.0X	------	<1	.X	------	------	X	nd	nd	nd	nd	.0X	.0X	------	.0X
218	.0X	.000X	.1-0.3	.0X	0.00X	.00X	.0X	------	1-2	.0X	------	------	X	nd	nd	nd	nd	.0X	.0X	------	.X
219	.0X	------	6-10	X	------	.0X	.0X	------	1-2	.0X	------	------	X	nd	nd	nd	nd	.0X	.00X	------	.0X
220	.0X	------	3-6	.X	------	.000X	.0X	------	nd	.X	------	------	X	nd	nd	nd	.003	.0X	------	------	.0X
221	.0X	------	3-6	.X	------	.000X	.0X	------	nd	.X	------	------	X	nd	nd	nd	.004	.0X	------	------	.0X
222	.0X	------	3-6	.X	------	.000X	.0X	------	nd	.0X	------	------	X	nd	nd	nd	.003	.0X	------	------	.0X
223	.00X	------	1-3	.X	------	.000X	.0X	------	nd	.0X	------	------	X	nd	nd	nd	.002	.0X	.00X	------	.0X
224	.00X	------	1-3	.X	------	------	.0X	------	nd	.0X	------	------	.X	nd	nd	nd	.002	.0X	------	------	.0X
225	.00X	------	1-3	.X	------	.00X	------	------	nd	.0X	------	------	.X	nd	nd	nd	.002	.0X	.00X	------	.0X
226	------	------	1-3	.X	------	.00X	------	------	nd	.00X	------	------	.X	nd	nd	nd	------	.0X	.00X	------	.0X
227	.0X	.000X	6-10	.X	.00X	.00X	.0X	------	nd	.0X	------	.00X	X	nd	nd	nd	------	.0X	.0X	------	.X
228	.0X	.000X	6-10	.0X	------	.00X	.0X	------	nd	.0X	------	------	X	nd	nd	nd	.005	.0X	.0X	------	.0X
229	.00X	------	3-6	.X	------	------	------	------	nd	.0X	------	------	X	nd	nd	nd	.002	.0X	.0X	------	.X
230	.0X	------	6-10	.X	------	------	.0X	------	nd	.X	------	------	.X	nd	nd	nd	.003	.0X	.00X	------	.0X
231	.0X	------	3-6	.0X	------	000X	.0X	------	nd	.X	------	------	X	nd	nd	nd	.001	.0X	.00X	------	.0X
232	.0X	.000X	3-6	.0X	------	.00X	.0X	------	nd	.X	------	------	X	nd	nd	nd	------	.0X	.00X	------	.0X
233	.0X	------	3-6	.0X	------	.00X	------	------	nd	.X	------	------	.X	nd	nd	nd	------	.0X	.0X	------	.0X
234	.0X	------	3-6	.X	------	.00X	.0X	------	nd	.X	------	.00X	.X	nd	nd	nd	.003	.0X	.00X	------	.00X
235	------	------	3-6	.X	------	.00X	------	------	<1.0	.0X	------	.00X	.X	nd	nd	nd	nd	.0X	.00X	------	.00X
236	------	------	1-3	.X	------	.00X	------	------	------	.00X	------	------	.0X	nd	nd	nd	nd	.00X	------	------	.00X
237	------	.00X	X0	.X	------	------	------	.00X	nd	------	------	------	.0X	nd	nd	nd	------	.00X	------	X	.00X
238	------	.000X	X0	.X	------	.00X	------	------	nd	.00X	------	------	.X	nd	nd	nd	.002	.0X	.00X	.X	.0X
239	.00X	.00X	1-3	.X	------	------	------	.00X	nd	.0X	------	------	.X	nd	nd	nd	.002	.0X	.00X	.0X	.00X
240	------	X	.3-0.6	X0	.0X	.000X	------	.00X	nd	.X	------	------	.X	nd	nd	nd	.002	.000X	------	X	.00X
241	------	X0	<.1	.0X	.00X	.000X	------	.0X	nd	------	------	------	.0X	nd	nd	nd	------	.00X	------	X	------

TABLE 15.—*Spectrographic analyses, in percent, for other*

[Analysts, F. Janet D. Fletcher; M. K. J. Murata; C. A. A. Chodes. nd, not determined; leaders (----) looked

	Locality and sample	Analyst	BeO	Sb	As	Ba	Bi	B	Cd	CaO	Cr	Co	Cu	Ga	Ge	In	Fe_2O_3
	COLORADO—Continued																
	Huerfano County, Walsenburg:																
242	329–251	F	0.002	----	----	0.0X	----	0.00X	----	6–10	0.0X	0.00X	0.0X	0.00X	----	nd	3
243	252	F	.0008	----	----	.X	----	.00X	----	6–10	.0X	.00X	.00X	.00X	----	nd	3
	La Plata County, Durango area:																
244	328–158	M	.0003	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	0.006	nd	nd
245	159	M	.0006	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.005	.007	nd	nd
246	161	M	----	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
247	163	M	.0003	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	.005	----	nd	nd
	Las Animas County, Morley area:																
248	329–254	F	----	----	----	.0X	----	.00X	----	3–6	.0X	.00X	.00X	.00X	----	nd	3
249	257	F	----	----	----	.0X	----	.00X	----	3–6	.0X	.000X	.00X	.00X	----	nd	1–3
	Mineral County, Creede district:																
250	328–590	F	.002	----	.X	.00X	----	----	0.0X	.1–0.3	.000X	----	.0X	----	----	nd	1–3
251	592	F	.002	----	.0X	.0X	----	----	----	.1–0.3	.000X	----	.0X	----	----	nd	6–1
	Park County, Tarryal district:																
252	328–603	F	.001	----	----	.0X	0.00X	----	----	6–10	.00X	.0X	.0X	.00X	----	nd	X0
253	608	F	.0004	----	----	.0X	----	----	----	X0	.0X	.000X	.0X	.00X	----	nd	3–6
254	612	F	.001	----	----	.0X	----	.00X	nd	.1–0.3	.0X	.00X	.00X	.00X	----	nd	3–6
255	614	F	----	----	----	.00X	----	----	nd	X0	.00X	----	.00X	.00X	----	nd	nd
	Pitkin County, Redstone area:																
256	328–092	M	*.0005	----	nd	nd	nd	nd	nd	nd	nd	nd	nd	.004	----	nd	nd
	Summit County, Breckenridge district:																
257	328–099	F	----	----	----	.0X	----	----	----	X0	.00X	.000X	.00X	.00X	----	nd	X0
	Tri-State lead-zinc district:																
258	328–325	F	----	----	----	.00X	----	nd	----	X0	.00X	----	.0X	----	----	nd	.3–0.6
259	327	F	----	----	----	.00X	----	nd	----	X0	.00X	----	.00X	----	----	nd	.3–0.6
	ARKANSAS																
	Hot Springs County, Magnet Cove:																
260	328–293	F	.01	----	----	.0X	----	.00X	----	X0	.00X	.000X	.00X	.000X	----	nd	3
261	299	F	.002	----	----	.X	----	----	----	X0	.000X	.00X	.000X	.000X	----	nd	X0
262	311	F	.001	----	----	.0X	----	----	----	X0	.00X	.00X	.00X	.00X	----	nd	X0
263	318	F	.001	----	----	.0X	----	----	----	.6–1	.00X	----	.000X	.00X	----	nd	1–3
	Saline County:																
264	329–842	C	*.00X	----	----	.00X	----	----	----	nd	----	----	----	.0X	----	----	nd
265	843	C	*.00X	----	----	.00X	----	----	----	nd	----	----	----	.0X	----	----	nd
266	844	C	*.000X	----	----	.00X	----	----	----	nd	----	----	.00X	.0X	----	----	nd
	NEW JERSEY																
	Sussex County:																
	Beemerville area:																
267	329–826	C	*.00X	----	----	.0X	----	----	----	nd	----	----	.000X	.00X	----	----	nd
268	827	C	.00X	----	----	.0X	----	----	----	nd	----	.00X	.000X	.0X	----	----	nd
269	828	C	.002	----	----	.0X	----	----	----	nd	----	----	.000X	.0X	----	----	nd
270	829	C	*.000X	----	----	.0X	----	----	----	nd	.00X	----	.000X	.0X	----	----	nd
271	830	C	*.000X	----	----	.0X	----	----	----	nd	----	----	.000X	.0X	----	----	nd
	Franklin district:																
272	329-819B	M	.01	----	----	.0X	----	----	----	X0	----	.00X	.000X	----	----	----	X0
273	832	C	.003	----	----	.00X	----	----	----	nd	----	----	.00X	----	----	----	3–6
274	837	C	.001	----	----	.00X	----	----	----	nd	----	.00X	.00X	----	----	----	3–6
	NEW HAMPSHIRE																
	Carroll County:																
	Bartlett mine:																
275	329-865	M	.0032	----	----	.00X	----	----	----	.X	----	----	----	.00X	----	----	X.0
	Red Hill area:																
276	329–812	C	.000X	----	----	.00X	----	----	----	nd	----	----	.000X	.00X	----	----	nd
277	813	C	----	----	----	.00X	----	----	----	nd	.000X	----	.000X	.00X	----	----	nd

elements in samples analyzed for beryllium—Continued

for but not found; asterisk (*) percent of element rather than oxide. Major, more than 1 percent]

	La	Pb	MgO	Mn	Mo	Ni	Nb	Ag	Na_2O	Sr	Ta	Sn	Ti	W	U	eU	eU_3O_8	V	Y	Zn	Zr
242	------	------	3-6	0.0X	------	0.00X	------	------	nd	0.0X	------	------	X	------	nd	0.001	nd	0.0X	------	------	0.0X
243	------	------	6-10	.0X	------	.0X	------	------	nd	.X	------	------	X	------	nd	.001	nd	.0X	------	------	.0X
244	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.001	nd	.02	nd	nd	nd
245	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<.001	nd	.01	nd	nd	nd
246	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	<.001	nd	.006	nd	nd	nd
247	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.001	nd	.008	nd	nd	nd
248	------	------	3-6	.0X	------	.0X	------	------	nd	.0X	------	nd	X	------	nd	------	nd	.0X	------	------	.00X
249	------	0.000X	.6-1	.0X	0.00X	.00X	------	------	nd	.X	------	nd	0.X	------	nd	.001	nd	.00X	------	------	.00X
250	------	X	<.1	.X	------	.000X	------	0.0X	nd	------	0.0X	------	.0X	nd	nd	------	nd	------	------	X	.00X
251	------	.X	<.1	.X	------	------	------	.00X	nd	.00X	------	------	.X	nd	nd	.002	nd	------	------	.X	.00X
252	------	------	6-10	.X	.00X	.00X	------	.000X	nd	.0X	------	------	.X	nd	nd	nd	nd	.0X	0.00X	------	.0X
253	------	------	X0	.X	.00X	.00X	------	------	nd	.0X	------	------	.X	nd	nd	nd	nd	.0X	------	------	.0X
254	0.0X	------	1-3	.0X	------	.00X	------	------	nd	.00X	------	------	.X	nd	nd	nd	nd	.0X	.00X	------	.0X
255	------	------	X0	.X	------	------	------	------	nd	.00X	------	------	.0X	nd	nd	nd	nd	.0X	------	------	.00X
256	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	------	nd	nd	nd	.001	nd	.02	nd	nd	nd
257	.00X	.000X	1-3	.X	------	.00X	------	------	2-4	.00X	------	------	.X	nd	nd	.002	nd	.00X	.00X	------	.0X
258	------	.0X	nd	.0X	------	------	------	------	nd	.00X	------	------	.0X	nd	nd	.001	nd	.00X	.00X	X	------
259	------	.000X	nd	.0X	------	------	------	------	nd	.00X	------	------	.00X	nd	nd	nd	nd	.00X	.00X	X	------
260	.0X	------	1-3	.0X	------	.00X	.0X	------	nd	.0X	------	------	.X	nd	nd	nd	nd	.0X	.0X	------	.0X
261	.0X	.000X	X0	.X	.00X	------	.00X	------	nd	.0X	------	------	.0X	nd	nd	nd	nd	.0X	.0X	------	.00X
262	------	------	1-3	.0X	.00X	.00X	------	------	nd	.0X	------	------	.X	nd	nd	nd	nd	.X	.0X	------	.0X
263	.00X	.000X	<.1	.0X	.00X	.00X	.0X	------	nd	.0X	------	------	.0X	nd	nd	nd	nd	.00X	.00X	------	.0X
264	.0X	.00X	nd	.X	------	------	nd	------	nd	.0X	nd	------	.X	------	nd	nd	nd	------	------	------	.X
265	.0X	.00X	nd	.X	.00X	------	nd	------	nd	.0X	nd	------	.X	------	nd	nd	nd	.0X	------	------	.X
265	.0X	------	nd	.X	------	------	nd	------	nd	.00X	nd	------	.X	------	nd	nd	nd	.0X	------	------	.X
267	.00X	------	nd	.X	------	------	nd	------	nd	.X	nd	------	.X	------	nd	nd	nd	------	------	------	.X
268	.0X	------	nd	.X	------	------	nd	------	nd	.X	nd	------	.X	------	nd	nd	nd	.0X	------	------	.X
269	.0X	------	nd	.X	------	------	.01	------	nd	.X	nd	------	.X	------	nd	nd	nd	.0X	------	------	.X
270	------	------	nd	.0X	------	------	nd	------	nd	.0X	nd	------	.X	------	nd	nd	nd	.0X	------	------	.0X
271	.0X	------	nd	.X	------	------	nd	------	nd	.X	nd	------	.X	------	nd	nd	nd	.0X	------	------	.0X
272	------	------	X.0	X0	------	.00X	nd	------	nd	.0X	------	------	.00X	------	nd	nd	nd	------	------	X	.00X
273	------	------	nd	X	.00X	.00X	nd	.00X	nd	.0X	nd	------	.0X	------	nd	nd	nd	------	------	X	.00X
274	.0X	------	nd	X	------	.00X	nd	.00X	nd	.0X	nd	------	.0X	------	nd	nd	nd	------	------	X	.00X
275	.0X	.00X	.0X	.0X	------	------	.02	------	nd	.000X	------	------	.X	------	nd	nd	nd	------	.0X	------	.0X
276	.00X	------	nd	.0X	------	------	nd	.000X	------	.00X	nd	------	.X	------	nd	nd	nd	------	------	------	.0X
277	.00X	------	nd	.0X	------	------	nd	------	nd	.00X	nd	------	.X	------	nd	nd	nd	------	------	------	.0X

TABLE 16.—*Other spectrographic analyses, in percent, from the files of the U. S. Geological Survey*

[Analyst, John C. Rabbitt, except for sample noted]

District and sample	Source of sample	Description	BeO	Sb_2O_3	Bi_2O_3	CdO	CoO	Ga_2O_3	GeO_2	In_2O_3	La_2O_3	HgO	MoO_3	NiO	Nb_2O_5	Ta_2O_5	Ti_2O_5	ThO_2	SnO	WO_3	eU[1]	V_2O_5	ZrO_2
Alabama:																							
Barbour County, Baker Hill lignite: 195-LC-1[2]	USBM, hole 3035 35-45 ft in drive pipe.	Lignitic clay	0.002				0.003				0.2			0.004								0.2	
Cherokee County, Rock Run district: 13-E-1	Emerson Mine tailings.	Manganese tailings.	.03				.2						0.008	.08					0.01		<0.003	.02	0.08
Arizona:																							
Mohave County, San Francisco district: 85-MC-3	Tyro, Portland, Minie, Arabian, Frisco mines.	Gold tailings	.03				.003						.002	.003							<.003	.01	
9	Goldroad mine	do	.006				.001						.002	.003							<.003	.02	
Arkansas:																							
Independence County, Batesville district: 14-ARK-2	Ayedelotte mine, stockpile grab sample.	High-grade manganese ore.	.01				.05	0.003					.04	.1					.08		<.003	.2	.06
2A	Ayedelotte mine, and others, stockpile.	do	.01				.08		0.005				.04	.1			0.001		.05		<.003	.1	.1
3	Bill Jim, Wildcat. Sec. 1-b, and others, stockpile.	do	.01				.08						.05	.1			.001		.06		<.003	.1	.08
3A	do	Low-grade manganese ore.	.01				.1		.004				.04	.1					.05		<.003	.1	.1
Pike County, Glenwood district: 14-ARK-1	North American mine.	Manganese concentrate.	.008		0.005		.3						.03	.2					.08		<.003	.05	.1
1A	do	Manganese tailings.	.01				.08						.002	.1					.005		<.003	.02	.05
Saline County: 396-AB-60-1[2]	Fletcher mine	Bauxite ore	.006					.01			.02		.003		0.03							.01	.1
Searcy County, St. Joe district: 25-ARK-E2	Excelsior mine	Zinc tailings	.002			0.002								.003							<.003		
E3	do	Zinc mill-run ore	.002			.05	.001		.001				.001	.004							<.003	.003	
California:																							
Riverside County: 133-E-1	Elsinore area	Lignitic oil shale	.004		.002									.001					.002		<.003	.04	
Amador County, Mother Lode district: 43-ARG-1	Argonaut mine	Gold tailings, 1936-42.	.002				.001							.01							<.003	.01	
2	do	do	.002				.001							.008							<.003	.02	
4	do	Gold tailings, 1917-36.	.002				.001							.008							<.003	.01	
5	do	do	.002											.008					.005		<.003	.01	

43-CE-1	Old Eureka mine	Gold tailings, 1933-42.	.002				.001							.008							<.003	.01	
2	do	do	.002				.001						.001	.01							<.003	.01	
4	do	do	.002				.001							.008							<.003	.01	
6	do	Gold tailings, before 1938.	.002				.001						.001	.01							<.003	.01	
7	do	do	.002				.001							.01							<.003	.01	
San Bernardino County, Providence Mts.:																							
12-SR1-6	Scheelite Ray shaft	Huebnerite ore	.01		.05								.03	.003					.005	.19	.003	.04	.08
12-SR2-7	do	do	.01		.05								.02	.003					.005	1.63	.003	.04	.02
Georgia:																							
Bartow County, Cartersville district:																							
76-AP-1A	Appalachian mine	Manganese tailings	.008				.04						.003	.02					.006		.003	.04	
1B	do	do	.008				.05						.002	.02					.008		.003	.03	
1C	do	do	.006				.05						.002	.02			.001		.02		.003	.04	
1D	do	do	.008				.05						.003	.02			.001		.02		.003	.04	
76-AU-9B	Aubrey mine	do	.006				.04						.002	.02			.001		.01		.003	.01	
9A	do	do	.007				.03						.002	.02			.001		.01		.003	.02	
7A	do	do	.008				.04						.003	.01			.001		.008		.003	.02	
7B	do	do	.008				.04						.002	.02			.001		.008		.003	.03	
7C	do	do	.008				.04						.002	.02			.001		.008		.003	.02	
7D	do	do	.008				.04						.003	.02			.001		.008		.003	.02	
7E	do	do	.008				.05						.003	.02			.001		.008		.003	.02	
7F	do	do	.008				.06						.003	.02					.01		.003	.02	
8A	do	do	.01				.07						.004	.04			.001		.02		.003	.02	
8B	do	do	.006				.04						.002	.02			.001		.02		.003	.01	
10	do	do	.01				.08						.006	.04			.001		.03		.003	.03	
11	do	do	.01				.08						.004	.03					.03		.003	.02	
12	do	do	.01				.05						.003	.03					.03		.003	.03	
76-Br-2	Blue Ridge mine	do	.006				.04						.003	.03			.001		.03		.003	.03	
76-D-6A	Dobbins mine	do	.006				.04						.002	.02			.001		.02		.003	.03	
6B	do	do	.007				.05						.003	.02			.001		.02		.003	.03	
76-PF-3-4	Pauper Farm mine	do	.01				.04						.002	.04					.02		.003	.04	
76-S-5	Satterfield mine	do	.01				.06						.003	.01					.03		.003	.03	
Polk County, Cave Springs district:																							
13-C-2	Callahan mine	do	.02				.2						.02	.1					.01		.003	.02	.08
Michigan:																							
Houghton district, Copper Range:																							
115-QUI-3	Quincy mine	Copper jig concentrate.	.002		.001		.002						.02						.001		<.003	.001	
Missouri:																							
Shannon County:																							
23-ROC-44	Rocky Creek mine	Manganese ore	.05	.08			.01	.002					.02	.005			.001		.05	.005	.003	.05	.01
Nevada:																							
Lincoln County, Tem-Piute district:																							
49-DGW-20	Tem-Piute mine	Scheelite and sulfide float tails.	.002		>1.0	.05	.01						.1	.01	.004		.003		.02	>1	.003	.008	
21	do	do	.003		>1.0	.06	.01		.002				.1	.01	.005		.003		03	>1	.003	.01	
22	do	Scheelite tailings	.01		.05	.001							.05	.001					.08	.03	.003	.04	
23	do	Scheelite conc	.001		.5	.003			.001				.3		.01	0.003	.002		.03	>1	.003	.08	

See footnotes at end of table.

TABLE 16.—*Other spectrographic analyses, in percent, from the files of the U. S. Geological Survey*—Continued

District and sample	Source of sample	Description	BeO	Sb_2O_3	Bi_2O_3	CdO	CoO	Ga_2O_3	GeO_2	In_2O_3	La_2O_3	HgO	MoO_3	NiO	Nb_2O_5	Ta_2O_5	Ti_2O_5	ThO_2	SnO	WO_3	eU_1	V_2O_5	ZrO_2
New Hampshire:																							
Grafton County:																							
Lyman Township:																							
82-OV-3	Orchard Vein (prospect).	Lead-zinc ore	0.006	0.005		0.3	0.01		0.005				0.008	0.02					0.01		0.003	0.005	
Warren Township:																							
82-OH-2	Ore Hill mine	Zinc-lead ore	0.006	.02	0.008	.2	.01		.003				.02	.02					.008		.003	.01	
North Carolina:																							
Vance County:																							
84-H-1	Hamme Tungsten mine.	Tungsten tailings.	.008		.008								.001							>1		.002	
2	do	do	.008		.008								.002							.03		.006	
3	do	do	.004		.008								.002							.04		.008	
South Dakota:																							
Pennington County, Keystone district:																							
10-KH-3	Holy Terror mine.	Gold tailings	.01				.01		.01				.01	.05							<.003	.05	0.05
Lawrence County, Maitland district:																							
10-M-1	Maitland mine	Gold tailings after roasting and cyanidation.	.02				.01						.01	.01							<.003	.08	.04
2	do	Heads, gold ore	.01				.02						.01	.02							<.003	.1	.03
Trojan district:																							
10-BM-1	Bald Mountain mine.	Gold tailings	.02				.01		.005				.01	.02							<.003	.05	.05
2	do	Heads, gold ore unoxidized.	.01				.03		.008				.01	.04							<.003	.05	.04
3	do	Heads, gold ore oxidized.	.02				.02		.006				.01	.03							.0072	.05	.05
Tennessee:																							
Unicoi County, Bumpass Cove:																							
16-EM-2	Embree mine	Zinc tailings	.06			.006	.004		.001	0.001				.04					.008		.003	.02	.05
3	do	Lead carbonate concentrates.	.01				.005	0.001		.001			.005	.02					.005		.003	.01	.03
4	do	Lead tailings (jig).	.08				.003						.004	.03					.01		.003	.03	.01
5	do	do	.01				.002						.003	.01							.003	.01	.04
6	do	Manganese concentrates.	.005				.1	.001					.008	.04			0.004		.05		.003	.06	.01
7	do	Manganese tailings (jig).	.01				.08						.006	.03			.001		.03		.003	.04	.01
8	do	Manganese concentrate (low-grade).	.02				.08						.006	.02			.001		.03		.003	.03	.02
9	do	Manganese-lead-zinc tailings.	.03				.05						.005	.02			.001		.01		.003	.03	.02
Hickman County:																							
116-TP-2	Phosphatic shale	Tan clay	.002				.006						.008	.008					.002		.0039	.005	
3		Hardin sandstone member of Chattanooga shale.	.002				.007						.01	.008							.0098	.006	
4		Chattanooga shale.	.002				.008						.01	.01							.0115	.008	
5		do	.003				.006						.01	.02							.0126	.04	

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6		Phosphatic shale	.002				.004						.01	.03							<.003	.04	
11		Meridian-Maury shale.	.004				.004						.003	.008							.0206	.01	
Jackson County:																							
154-S100-2 [4]	Oil shale	Sandstone, brown; lower part clayey.	.004										.01	.02							.010 U	.05	
6 [5]	do	Shale, brown	.003				.006						.01	.04							.012 U	.06	
15 [6]	do	Clay, green, sandy.	.002				.003						.01	.02					.003			.05	
Texas:																							
Brewster County, Terlingua district:																							
9-SB-1	Study Butte mine.	Collector dust, flue dust.	.005									0.008	.02	.001							<.003	.02	.2
Utah:																							
Emery County:																							
293-P4-44 [7]	Southern Temple Mountain.	Sandstone above basal shale zone.	.004											.004				0.03			.195	.3	
Virginia:																							
Bland County, Appalachian district:																							
13-RM-3	Round Mountain mine.	Manganese concentrates.	.01				.3	.004					.03	.1					.02		<.003	.08	.08
15-BI-1	Manganese concentrate from residual clay.	Manganese concentrates (jig).	.005				.2	.004					.02	.08					.03		<.003	.1	.1
15-CM-2	do	do	.006				.2	.001					.01	.1					.03		<.003	.1	.1
Smyth County, Southwest Virginia district:																							
7-GMC-1	Glade Mountain mine.	Manganese concentrates.	.02				.4						.005	.03					.05		<.003	.005	.03
2	do	do	.01				.1							.02					.001		<.003	.001	.01

[1] Equivalent uranium is based on measurement of radioactivity wherein it is assumed that all of the radioactivity of a sample arises from uranium and its disintegration products, and that none of the radioactivity arises from the thorium series or from potassium; it is assumed, furthermore, that the uranium is in radioactive equilibrium with all of its disintegration products wherein each radioactive product in the series is disintegrating at exactly the same rate at which it is being formed.

[2] Also CeO_2 (0.3); Nd_2O_3 (0.2); Y_2O_3 (0.7).

[3] Analysts K. J. Murata and E. W. Cloffy. Also BaO 0.02; Cr_2O_3 0.006; CuO and PbO 0.004; SrO 0.06; Ti_2O 0.3; Y_2O_3 0.01.

[4] Also CuO 0.005; Cr_2O_3 0.01; PbO 0.005.

[5] Also CuO 0.006; Cr_2O_3 0.01; PbO 0.006.

[6] Also CuO 0.007; Cr_2O_3 0.01; PbO 0.005.

[7] Also CuO 0.01; Cr_2O_3 0.07; PbO 0.006.

GENESIS OF BERYLLIUM DEPOSITS

The physicochemical conditions under which the beryllium-bearing minerals originate have not been determined, with few exceptions. However, some idea of the conditions may be surmised from the relative abundance of these minerals in certain geologic environments and their virtual absence in others. The preceding discussions emphasize that with few exceptions beryllium minerals occur in silicic and alkalic igneous rocks, especially pegmatites, in pyrometasomatic deposits, and in high- to medium-temperature veins. Beryllium deposits thus are mainly the products of igneous activity, rather than of sedimentary and metamorphic processes. Figure 3 shows the distribution

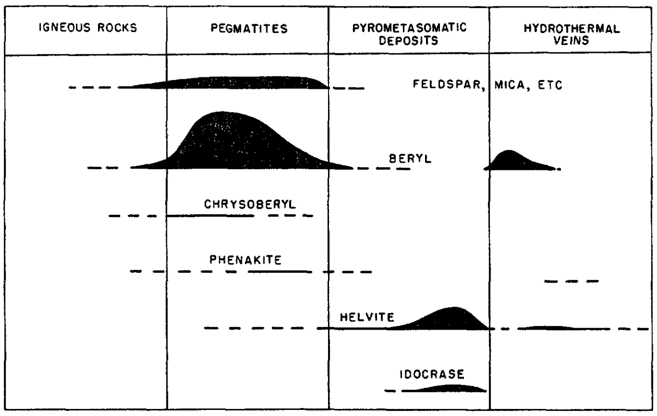


FIGURE 3.—Schematic diagram showing occurrence and distribution of principal beryllium-bearing minerals.

of the common beryllium-bearing minerals among the various types of major occurrence. Such a diagram cannot, of course, be quantitative with regard to the amount of any mineral; thus, the arrangement of columns is not necessarily significant.

Theoretical considerations discussed by Osborn (1950) lead to the conclusion that beryllium should be concentrated in the late aqueo-igneous residue of a magma, as a result of fractional crystallization, along with Si, F, Li, Na, K, and rare earths. These elements, together with water, generally are not removed in proportion to their abundance in the magma during the crystallization of olivine, pyroxene, amphibole, and plagioclase, which constitute the bulk of earlier minerals in igneous rocks. Their proportions in the remaining liquid, therefore, tend to increase progressively with crystallization, which is controlled largely by the concentration and stereochemical properties of the ions. Temperature is regarded as more important than pressure.

Distribution of beryllium in igneous rocks and mineral deposits suggests that much of it is deposited in beryl and helvite during the transition from magmatic to hydrothermal conditions. Except for local occurrences in granite, beryllium minerals are rare in igneous rocks other than pegmatites; probably most of the beryllium in such rocks is contained in silicate structures as a guest ion. This tendency appears to be particularly marked in the feldspathoidal intrusive rocks, which do not as a rule give rise to extensive pegmatites and ore deposits. Most veins containing beryllium minerals are of high-temperature origin and may form about the same time as pegmatites and pyrometasomatic deposits.

The reasons for deposition of beryllium in pegmatites or veins at some localities and in pyrometasomatic deposits at others are not clear. In the Victorio Mountains, N. Mex., beryl crystallized in an open vein about the same time that helvite replaced limestone nearby. Most pyrometasomatic deposits do not have any direct relation to pegmatites or even to neighboring igneous rocks. In pyrometasomatism the ease and pervasiveness of replacement implies high concentration of water and other volatiles. Although a moderate concentration of volatiles appears necessary for the growth of large crystals in pegmatites, detailed studies of their structure and composition suggest that they are formed from an equivalent body of magmatic material, with only minor and later hydrothermal alteration (Cameron and others, 1949, p. 97–106). According to this view, preexisting fissures are required for emplacement of pegmatites, whereas pyrometasomatism may be accomplished through rock pores without recourse to larger openings. Veins are regarded usually as fissure fillings. In a general way, structural conditions may thus influence to some extent the modal occurrence of beryllium in that commonly beryl appears to prefer fissure deposits and helvite to favor replacement bodies. Structural features presumably have little to do, however, with the presence or absence of beryllium in the deposits.

Whether beryllium appears at a given locality primarily in pegmatites, in veins, or in pyrometasomatic deposits is concerned also with relations of the pegmatite melt and the hydrothermal fluid. Petrologists do not agree on whether the two fluids exist as separate phases in the rest magma or are parts of a single water-silicate system. Objections by Morey (1949) to the hypothesis of immiscible fluids as postulated from theoretical studies by Neumann (1948) and the qualitative experiments of Smith (1948), seem to have been removed by recent quantitative experiments proving immiscibility in systems similar to magmas (Tuttle and Friedman, 1948). It remains to be proved that such immiscibility did in fact exist in the natural processes of pegmatite and vein formation.

In practice, the distinction between quartz-rich pegmatites and quartz veins is actually somewhat arbitrary; in this investigation those bodies with an appreciable amount of feldspar were considered as pegmatites. Many examples of gradation between the two have been described (see compilations by Tolman, 1931, and Furnival, 1939) and the beryl-bearing veins of Mount Antero, Colo., Hill City, S. Dak., Irish Creek, Va., and several foreign localities are all described as being closely related to neighboring pegmatites. Fersman (1940, p. 37–39) emphasized the genetic relation of many quartz veins to pegmatites, and recent structural studies of pegmatites have shown that many quartz-rich (and sometimes beryl-bearing) fracture fillings are continuous and contemporaneous with the quartz core or other inner zone of the associated pegmatite (Cameron and others, 1949, p. 70–83, 105–106). These associations suggest that some beryl-bearing quartz veins have an origin similar to pegmatites, if they are not actually continuations of neighboring pegmatites. They were probably formed at high temperatures from "magma-like liquid" (Jahns, 1948).

The temperatures of formation of pegmatites, pyrometasomatic deposits, and hypothermal veins probably are similar. The prevalence of helvite and idocrase in pyrometasomatic deposits in contrast to beryl in pegmatites and veins is, therefore, probably due to chemical environment rather than to temperature. In syenitic pegmatites, helvite or rare aluminum-poor beryllium minerals occur, whereas, in pyrometasomatic deposits in aluminous schists the mineral is beryl. Such occurrences are rare, however, as most pegmatites are granitic and most pyrometasomatism is in calcareous rocks. Where the ratio of aluminum to calcium, sodium, and potassium, is greater than one, some aluminum is available to form beryl; otherwise helvite may form (Holser, 1953, p. 608).

A somewhat wider range in temperature of formation is noted for helvite than for beryl. In pyrometasomatic deposits helvite is generally late in the mineral sequence, often lining vugs. The manganese-rich veins in which it occurs apparently formed at a lower temperature than the beryl-bearing quartz-tungsten veins. The association of a nearly pure manganoan member of the helvite series with sphalerite in veinlike deposits in the Carpenter district, New Mexico, in contrast to the occurrence of zinc-rich genthelvite in the pegmatites at St. Peters Dome, Colo. (Genth, 1892), suggests that at least this helvite-bearing vein was formed at a temperature far enough below that of pegmatites to decrease considerably the solubility of zinc in the helvite lattice.

The thesis that beryllium tends to be concentrated in the late silicic and alkalic differentiates of igneous magmas is based on averages of many analyses rather than on specific examples. In some igneous rock series whose trace elements have been analyzed in detail (Nockolds and Mitchell, 1948; Wager and Mitchell, 1943), the amount of beryllium concentrated in the final differentiates (granophyre and aplite) is too small to be detected by qualitative spectrography. Although analytical data indicate that granitic and syenitic rocks are on the average richer in beryllium than mafic rocks, some granodiorites and other intermediate types contain appreciable quantities of beryllium. These discrepancies may be due, of course, to differences in beryllium content of the magmas involved, but it is not certain that beryllium is inevitably concentrated in the late magmatic products.

At Mount Antero, Colo., and Bagdad, Ariz., rather complete gradation is found from a granite so rich in beryllium that it occurs as grains of beryl, through beryl-bearing schlieren, vugs, and small veins to conventional pegmatites. Such deposits have not been sufficiently studied to determine the relations between beryl and other rock minerals. However, in the Sheeprock Mountains, Utah, beryl replaces feldspar in an albite granite and appears to have been introduced in connection with albitization of the granite.

The concentration of beryllium in pegmatites may have been exaggerated. Moderately rich beryl pegmatite ore contains only about 1 percent beryl, or about 0.1 percent BeO (Hanley and others, 1950, p. 11). This does not take into account beryl that is too fine grained for hand sorting or that lies in unmined zones. If one considers that only a small percentage of pegmatites contain enough beryl to be mineable, it is apparent that the overall average beryllium content of pegmatites may not be appreciably higher than that of the average granitic or feldspathoidal rock.

Many sedimentary rocks and residual deposits contain some beryllium and beryllium shows some tendency to follow aluminum in sedimentary processes. For the most part, however, beryllium probably tends more to be dissipated than concentrated by processes of weathering and sedimentation. Little information is available concerning the beryllium content of metamorphic rocks, but there is no indication that beryllium tends to be concentrated by processes of dynamic and regional metamorphism.

COMMERCIAL POSSIBILITIES AND SUGGESTIONS FOR PROSPECTING

The deposits of beryllium in nonpegmatite rocks that are most likely to be of commercial interest fall into two categories: beryl in high-temperature veins and igneous rocks, and helvite in pyrometasomatic deposits. Beryllian idocrase commonly occurs with helvite, though it is probably never high enough in beryllium content to make its separation profitable. Its effect, therefore, is to make some of the beryllium contained in the deposit economically unrecoverable. Other silicates which contain beryllium, such as garnet and epidote in pyrometasomatic deposits, and micas and feldspars in igneous rocks, have a similar but lesser effect.

The best nonpegmatite beryllium deposit yet discovered is that at Iron Mountain, N. Mex., where a small tonnage of high-grade tactite ranges from 0.5 to 3.5 percent BeO, with an average of less than 1.0 percent, mostly in helvite. The low-grade material ranges from 0.1 to 0.85 percent BeO, with an average of 0.3 percent, but only a small part of this beryllium occurs in helvite (Jahns, 1944a, p. 59). Vein deposits in Arizona and New Mexico contain from 0.01 to 0.1 percent BeO, presumably all in beryl. These grades compare very favorably with those of beryl pegmatites, where the zones mined for beryl range from 2 percent down to less than 0.1 percent beryl, or about 0.2 to 0.01 percent BeO.

Despite the fact that several thousand tons of high-grade material are indicated at Iron Mountain, the deposit has not been mined, principally because it is fine grained. In inner pegmatite zones, some of the beryl crystals which are several feet long are easily hand sorted, or selectively mined, to give a concentrate above the marketable minimum of 8 percent BeO. Such treatment is impossible with the fine-grained material of all nonpegmatite beryllium deposits. Flotation of both beryl and helvite ores has been moderately successful on a laboratory scale (Lamb, 1947; Sneddon and Gibbs, 1947; Kennedy and O'Meara, 1948). However, when metallurgical concentration becomes widely applied to fine-grained beryl, the nonpegmatite deposits that could be worked would still have to compete with pegmatite deposits, many of which also contain beryl too fine grained for recovery by sorting.

In the Black Hills pegmatites, no deposits have been mined exclusively for beryl, it having been recovered as a byproduct of mica, feldspar, or lithium-mineral mining (Page and others, 1953, p. 52). Similarly, byproduct recovery of fluorite and magnetite may make it possible to mine the Iron Mountain tactite at a profit. Prospecting for nonpegmatite beryllium should be only part of a general prospecting program, as the beryllium can probably be recovered only in conjunction with some other metal or mineral. Actually the greatest hope is probably in byproduct recovery of beryllium from high-temperature veins or pyrometasomatic deposits that are presently producing a large tonnage of ore for tungsten, gold, lead, or other metals. The possibility is indicated by recovery at Climax, Colo., of cassiterite from molybdenum ore containing only a trace of tin (Gustavson and Umhau, 1951, p. 1195).

Where a large proportion of the beryllium is disseminated in minor amounts through the principal rock minerals, instead of occurring as beryl or helvite, the problems are much greater. High temperatures or very strong acids are required to decompose silicates such as idocrase, nepheline, and garnet and release their beryllium. Recovery of beryllium from such minerals does not seem likely at present. Even for minerals more susceptible to chemical treatment, such as the cryptomelane of Golconda, Nev., recovery would be relatively expensive. Traces of beryllium in minerals might be recovered as a byproduct in smelting to release other metals. However, most smelters treat mainly sulfide ores, which are unlikely to contain beryllium. Sampling of many zinc, lead, and copper smelters by the Mine, Mill, and Smelter Survey showed no beryllium in any of the products. Nonsulfide ores, such as bauxite, have a remote possibility of producing beryllium, but bauxites from the United States apparently contain very little.

The lack of a reliable method of beryllium analysis, with the attendant problem of separating ore from waste during mining, is an important economic factor. Although some pegmatite beryl is difficult to recognize, the problem is greatly increased when the material is fine grained. At Iron Mountain, N. Mex., much of the helvite-danalite cannot be distinguished from garnet except by a stain test. Some or all of the beryllium indicated by chemical or spectographic analyses may be contained in rock minerals as a guest element rather than in beryllium minerals. Microscopic mineralogical analysis is therefore recommended as offering the most realistic estimate of recoverable beryllium. Occasional control determinations of total beryllium content might be made by spectrography.

The importance of nonpegmatite beryllium deposits is exemplified in the Soviet Union. According to Scherbakov (1936) the Izumrudnie (emerald) mines of the Southern Urals have greater possibilities than all the other regions of the Soviet Union as a source of beryllium. Although associated with berylliferous pegmatites, the principal deposits are in the surrounding schists and slates. The second most important are the Sherlovoi Mountain deposits in Zabaikal, where beryl occurs in quartz veins and greisen zones in granite. Although none of the deposits thus far discovered in the United States is exactly analogous to these, the possibilities for discovery are not exhausted.

Most prospecting for nonpegmatite beryllium probably will be confined to pyrometasomatic deposits and high-temperature veins. The relationship of beryllium and fluorine minerals has been noted in many of these deposits, and the association of idocrase and fluorite in pyrometasomatic deposits is thought to be a reliable guide to beryllium occurrence. A similar relation between beryllium and tungsten is suggested by the widespread occurrence of beryllium in tungsten-bearing tactites and veins.

In general, mineralogical criteria appear to be somewhat more reliable than structural features, though the latter may also be clues to beryllium occurrence. Some beryllium-bearing tactites show a peculiar banded structure, called "ribbon rock" at Iron Mountain, N. Mex. Material of this type was not found during the present investigation in any of the beryllium-bearing tactites. Similar banded magnetites were completely free of beryllium. The absence of this structure, therefore, does not preclude the possibility of the occurrence of beryllium in tactites; that all "ribbon rock" contains beryllium remains to be proved. Most pyrometasomatic deposits that contain beryllium are found near the contact of limestone and granodiorite or granite. However, beryllium-bearing tactites, like other pyrometasomatic deposits, commonly being controlled by fractures or high-porosity limestone, may not be closely related to contacts. At Iron Mountain and Victorio Mountains, N. Mex., intrusive rocks are relatively inconspicuous.

As beryllium comes into greater use and the present resources are exhausted, it will become increasingly necessary to find new resources by scientific means. For this purpose a really basic understanding of the geochemistry of beryllium is necessary, especially an understanding of the relations among beryllium-bearing minerals, and the physical and chemical conditions of their deposition. Further investigations of the natural occurrences should be supplemented by experiments under controlled laboratory conditions.

DESCRIPTION OF LOCALITIES

NEVADA AND CALIFORNIA

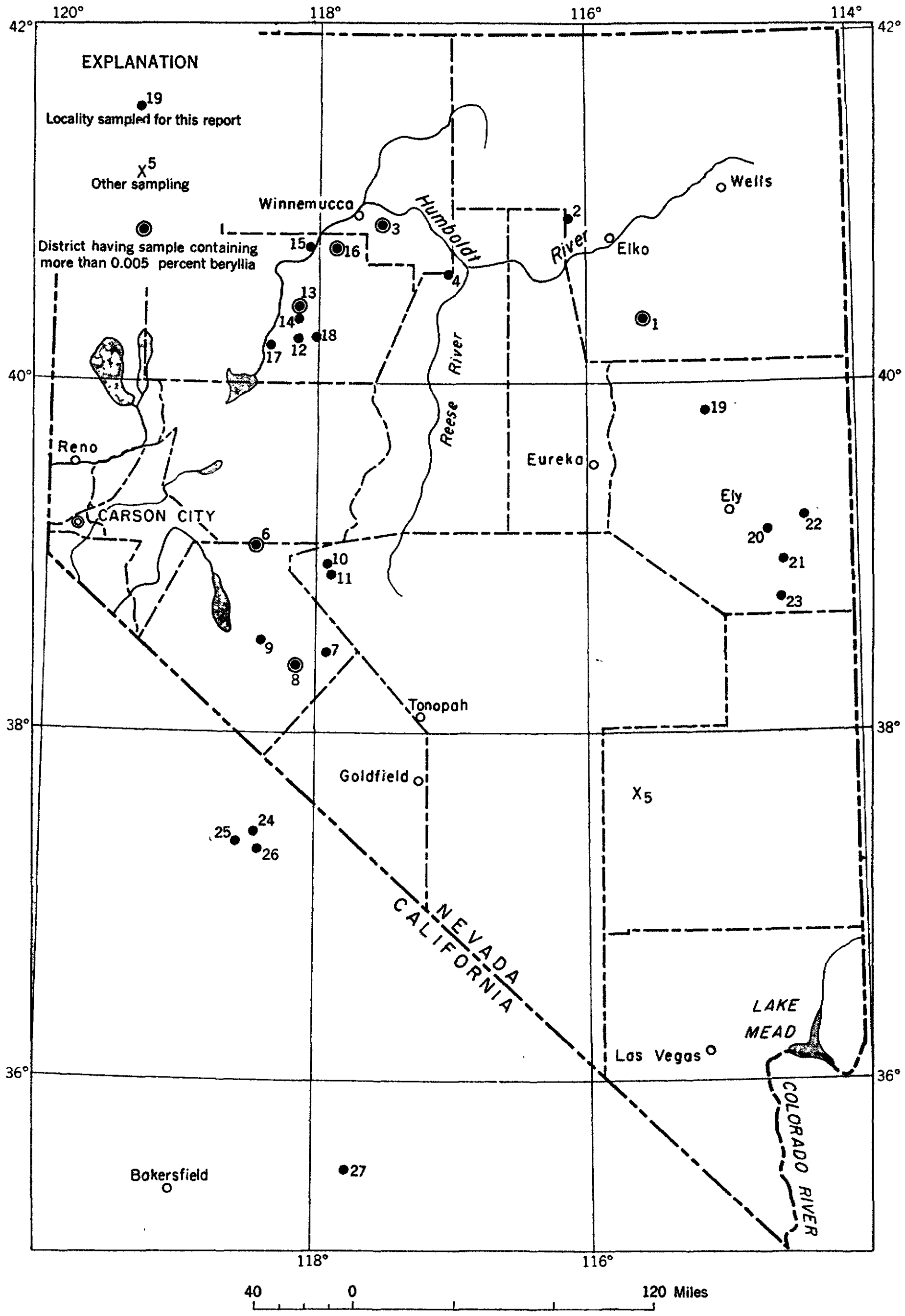
By E. N. Cameron and L. A. Warner

Sampling of nonpegmatite rocks and mineral deposits in Nevada and central California was undertaken by Cameron, assisted by J. H. McLeod, during July and August 1949. In the short time available only a few of the many mining districts of the region could be examined. Locations of the 27 districts and areas selected for investigation are shown on figure 4. One of these, the Tem Piute district, had been sampled by the Geological Survey in 1943 and was not revisited. Cameron found it necessary to return to other work before completion of the laboratory investigations. The analytical data were compiled by Warner, who also wrote parts of the descriptions. The descriptions of deposits are based partly on observations made during the sampling, but free use was made of information in the literature and of unpublished reports and maps compiled by various geologists of the U. S. Geological Survey during World War II.

Of the more than 300 samples that were collected and analyzed spectrographically for BeO, the larger number are from tungsten deposits in which scheelite is the dominant tungsten mineral. The field itinerary, therefore, conforms in a general way to the tungsten arcs in the Basin and Range province as shown by Kerr (1946a, pl. 1). A variety of other materials, however, was sampled in Nevada, including the manganese and tungsten-bearing hot-spring deposits at Golconda and Sodaville, the barite deposits at Good Hope and near Battle Mountain, andalusite deposits near Thorne, brucite-magnesite deposits at Gabbs, and a dumortierite deposit near Oreana. Samples of igneous rocks and contact-metamorphosed sedimentary rocks in and adjacent to the ore deposits were obtained in nearly all districts visited in which contact metamorphic tungsten deposits occur.

The analytical results suggest that in this region beryllium occurs in greater concentrations in the tungsten-bearing tactite than in the other deposits sampled. Of the 4 samples containing more than 0.01 percent BeO, 3 were from tactite deposits at the Star, Victory, and Rose Creek mines; they contained 0.056 percent, 0.044 percent, and 0.024 percent of BeO, respectively. Samples containing more than 0.001 percent BeO were obtained from all tactite deposits, though the average for some deposits—particularly at the Desert, Gunmetal, and Ragged Top mines and deposits in the Pawhide district—is considerably less than this amount. The BeO content of samples from tactite in the Mill City district, Nevada, and the Tungsten Hills district, California, were relatively low in comparison to the importance of these districts as tungsten producers. In general there is no apparent correlation between the amounts of tungsten and beryllium in the tactite deposits.

The beryllium content of the tungsten-bearing tactite is in marked contrast to that of associated hornfels, marble, and quartzite. Though many samples of these rocks were obtained, none contained BeO in excess of 0.001 percent. The beryllium contents of igneous rocks associated with the tactite is also low, the few exceptions being for samples obtained adjacent to con-



NEVADA

Elko County

1. Star mine, Harrison Pass
2. Good Hope mine

Humboldt County

3. Golconda deposit

Lander County

4. Battle Mountain barite deposits

Lincoln County

5. Tem Piute district

Mineral County

6. Rawhide district
7. Desert Scheelite and Gunmetal mines
8. Sodaville district
9. Thorne andalusite deposits

Nye County

10. Victory Tungsten deposits
11. Gabbs magnesite and brucite

Pershing County

12. Limerick Canyon area
13. Panther Canyon area
14. Rocky Canyon-Wrights Canyon area
15. Tungsten area
16. Rose Creek mine
17. Ragged Top mine
18. Champion dumortierite mine

White Pine County

19. Cherry Creek district
20. Sacramento Pass mine
21. Dirty Shirt mine
22. San Pedro mine
23. Minerva district

CALIFORNIA

Inyo County

24. Tungsten Hills district
25. Pine Creek district
26. Yaney prospect

San Bernardino and Kern Counties

27. Atolia district

FIGURE 4.—Index map showing localities sampled in Nevada and California.

tacts with tactite, where endomorphism might be expected. These relations imply that beryllium was introduced by ore-forming solutions which gave rise to the tungsten-bearing tactites, the two metals being derived from a common magmatic source.

Several scheelite vein deposits were sampled in the Snake Range and Cherry Creek district, Nevada, and in the Atolia district, California. None of the samples contained more than 0.001 percent BeO and most contained less than 0.0001 percent. The paucity of beryllium in these veins, in contrast to its relative abundance in pyrometasomatic deposits nearby, apparently is more marked in the Basin and Range province than in other areas where beryl is not uncommon in quartz-tungsten veins. The beryllium-bearing hot-spring deposits of Pleistocene age at Golconda and Sodaville, Nev., must be regarded as extraordinary. These are ocherous deposits containing relatively large amounts of manganese and tungsten. A sample from the deposit at Golconda contained 0.016 percent BeO, and one from Sodaville contained 0.0075 percent.

NEVADA

ELKO COUNTY

STAR MINE, HARRISON PASS

The deposits of the Star mine are in the Ruby Range on both sides of Harrison Pass Creek Canyon, about 2 miles east of the pass. They are readily accessible by road from Elko by way of Jiggs, thence by the road over Harrison Pass. The area is described briefly by Hess and Larsen (1921, p. 305); the deposits were mapped by M. R. Klepper and P. Joralemon of the U. S. Geological Survey in 1943.

The Ruby Range consists largely of a stock of biotite granite and quartz monzonite that intrudes limestone and quartzite of Paleozoic age. The contact east of Harrison Pass is very irregular; and many dikes and apophyses of aplitic granite cut the sediments, which have been metamorphosed to silicated marble and hornfels. Scheelite-bearing tactite occurs intermittently along the contact. Four ore bodies have been mined on the property of the Star mine and several others have been prospected. The principal workings, which are in the Main, North, and South ore lodes, were inaccessible in 1949. The No. 7 ore body and the ore bodies in the North opencut and the South shaft were examined briefly.

The North opencut exposes a tactite body along the irregular boundary between granite and marble. The body is 1 inch to 30 inches thick, not more than 20 feet long, and probably contains no more than 200 tons of rock. The tactite consists of garnet, diopside, epidote, quartz, and calcite.

The South shaft ore body is a tactite mass about 200 feet in strike length and 1 to 4 feet wide. A vertical shaft, 43 feet deep, has been sunk near the middle of the outcrop. From the bottom of the shaft a drift extends along the base of two stopes; the south stope is blind, the north stope extends to the surface. The tactite body appears to be cut off at depth either by a fault or by a change in strike of the contact of the granite and marble. Reserves are no more than a few hundred tons.

A belt about 1,500 feet wide along the irregular eastern margin of the granite stock consists of marble, silicate-bearing marble, and calc-silicate hornfels. The beds range from fractions of an inch to 3 feet in thickness. Garnet, diopside, and epidote are the principal minerals, but actinolite, idocrase, and tremolite characterize some beds.

Samples were taken of the metamorphosed rocks of the contact aureole, as well as of the tactite deposits. Sample descriptions and analytical results are given in the table 17.

TABLE 17.—*Beryllia in samples from Harrison Pass area*

Sample	Description	BeO (percent)
	NORTH OPEN CUT	
329–1039	Chip sample of aplitic granite 10 to 30 ft from tactite	0.0002
1040	Chip sample of tactite	.0044
1041	Chip sample altered aplitic granite immediately adjacent to tactite	.0098
1042	Silicated marble 0 to 3 ft from tactite	<.0001
	SOUTH SHAFT ORE BODY	
329–1043	Chip sample of tactite body, north end of south stope at its base	.029
1044	Chip sample from tactite body, top of south stope	.056
1045	Chip sample of silicated marble adjacent to tactite, bottom of north stope	<.0001
1046	Chip sample of silicated marble adjacent to tactite, base of shaft	<.0001
1047	Chip sample of granite outcrop adjacent to tactite, north of shaft	.0078
	CONTACT-METAMORPHOSED ROCKS	
329–1048	Chip sample of recrystallized marble, 0 to 15 ft from contact	<.0001
1049	Chip sample of blue and gray marble, partly silicified, 15 to 70 ft from contact	<.0001
1051	Chip sample of blue and gray silicified limestone, 150 to 170 ft from contact	<.0001
329–1054	Chip sample across beds of idocrase-bearing(?) marble, 345 to 365 ft along road from contact	<.0001
1055	Chip sample of interbedded pure and silicated marble, 656 to 681 ft from contact	<.0001
1057	Chip sample across beds of bluish-gray, fine- to medium-grained marble, 1,053 to 1,233 ft along road from contact	.0008
1059	Chip sample across beds of blue-black limestone, 1,520 to 1,540 ft along road from contact	.0008
1061	Chip sample of silicated marble and hornfels, south slope of Harrison Pass Creek Canyon, between No. 7 ore body and Main ore body	<.0001
1063	Chip sample of porphyritic granite, summit of Harrison Pass	<.0001

The analytical data clearly indicate that beryllium is contained in the tactite bodies and in the granite immediately adjacent to them. It appears to be lacking in the other rocks of the contact aureole and in the interior of the granite stock. Presumably the solutions that formed the tactite bodies and related tungsten ores were those which brought in beryllium. The beryllium-bearing mineral or minerals have not been identified. If most of the beryllium is in helvite, some byproduct recovery may be possible in connection with future mining of tungsten in the area.

GOOD HOPE BARITE MINE, TUSCARORA RANGE

The Good Hope mine is on one of a series of barite vein deposits in the Tuscarora Range. The mine is reached by a road leading north to Lynn from U. S. Highway 40 at Carlin, Nev. At 7.4 miles from U. S. 40 and just south of the mouth of Maggie Creek Canyon, a mine road turns westward. The mine is about 1.3 miles from this point on the northeast side of a small canyon.

The deposit, as exposed in the main and upper working, is an irregular vein of massive, fine- to coarse-grained, white barite that apparently occupies a shattered zone in partly silicified interbedded limestone, shale, and sandstone. The vein strikes N. 38° W. and dips 70° to 80° E. The lower working consists of a 41-foot drift along the vein, which is 4 to 5 feet wide, and an adit that extends northward from the mouth of the drift. A chip sample (329–1071) of the vein from the upper working contain 0.0007 percent BeO.

HUMBOLDT COUNTY

GOLCONDA MANGANESE-TUNGSTEN DEPOSIT

The Golconda manganese-tungsten deposit is in the Edna Mountains about 3 miles east of Golconda. The mine is a short distance north of U. S. Highway 40 and immediately east of the road to the Getchell mine. The deposit has been described by Kerr (1940; 1946a, p. 171–173). It was mined for manganese during World War I and for tungsten during World War II. The deposit consists of layers of manganiferous ocher and calcareous tufa, with some rubble derived from underlying Triassic sedimentary rocks, and is capped by tufa and fanglomerate. The ore bodies extend northward along the slopes for about a mile. Toward the east they rest directly on the beveled edges of the Triassic sedimentary rocks, but toward the west an increasing thickness of sedimentary rocks intervenes between the deposits and the bedrock surface. A typical pediment-alluvial fan relation is indicated. The tungsten-bearing manganese oxides and ferruginous ocher, together with the tufa, were deposited by hot springs thought to have been most active during the Pleistocene epoch. Fissure veins in the underlying Triassic sedimentary rocks contain ore material similar to that in the overlying ocherous deposits.

For the present purpose the workings are divided into two groups: the north workings, which consist largely of opencuts and stopes, and the south workings, which are a series of large opencuts.

NORTH WORKINGS

The workings of this group may be subdivided into the northwest workings, which are a series of adits that lead to gently inclined stopes, and the Bed Springs Hill workings, which consist of opencuts around the eastern end of the hill and underground workings of unknown extent.

In the northwest workings, two parts of the stopes were sampled. The section exposed in the stopes is as follows, from top to bottom:

4. Thin layer of gravels.
3. Coarse rubble (fanglomerate?) cemented by calcareous tufa; as thick as 6 feet. This is the cap of the deposit.
2. Rubble tufa with manganese oxides and ocher, 1 to 3 feet thick. Apparently this zone was mined for manganese.
1. Rubble poorly cemented by tufa. Thickness more than 3 feet; bottom is not exposed. Contains some manganese oxides and ocher, but much less than zone 2.

At Bed Springs Hill, in the opencuts near the north end, the beds dip gently westward and are as follows, from top to bottom:

5. Thin layer of gravels.
4. Calcareous tufa caprock, as thick as 5 feet. The lower 12 inches in places is manganese rich.
3. Layer rich in manganese oxide and ocher, ranging along strike from iron-rich to manganese-rich; 9 to 18 inches thick.
2. Gray shale rubble as much as 2 feet thick. Low in manganese and iron content.
1. Soft shale of Triassic age, forming the surface upon which zones 2 to 5 were laid down. Manganiferous and ferruginous. This material has been mined to a depth of at least 10 feet in the opencut.

Descriptions and analytical data for samples from the north workings are given in table 18.

TABLE 18.—*Beryllia in samples from north workings, Golconda manganese-tungsten deposit*

Sample	*Description*	BeO (*percent*)
	BED SPRINGS HILL	
329–1073	Chip sample, calcareous tufa, zone 4	0.0008
1074	Chip sample, manganese-rich material, base of zone 4	.0026
1075	Channel sample, manganese-rich material, zone 3	.0045
1076	Channel sample, ocher-rich material, zone 3	.0037
1077	Channel sample, zone 1	.0016
1078	Chip sample, small lens of ocherous tufa in zone 1	.0058
	NORTHWEST WORKINGS	
329–1079	Chip sample, zone 3	.0007
1080	Channel sample, zone 2	.0058
1081	Channel sample, zone 1	.001

SOUTH WORKINGS

The south workings consist of three large opencuts arranged roughly along a line trending northeast for about 2,000 feet. The northeastern cut is about 600 feet long and 200 feet in maximum width; the middle one measures about 700 feet by 700 feet. The southeastern cut was not measured. It is the largest and deepest of the three cuts, but its walls are not accessible for sampling.

In the northeastern cut the section is as follows, from the top down:

4. Tufa cap, more than 3 feet thick.
3. Manganese-rich layer, thickness greater than 4 feet; bottom not exposed. Mined in underground workings of unknown extent.
2. Shale rubble, at least 4 feet in maximum thickness. This material is highly variable. In part it appears nearly barren of iron and manganese oxides, in part it is rich in one or the other.
1. Shales of Triassic age containing manganese and iron oxides.

In the middle cut samples were obtained from the east wall and the southwest wall. Along the east wall the section is as follows, from the top downward:

4. Fanglomerate, 6 to 8 feet thick; rests on the uneven top of of a layer of compact calcereous tufa.
3. Calcareous tufa, 3 to 7 feet thick, bottom gently undulating.
2. Manganifereous fanglomerate, 9 inches to 2½ feet thick.
1. Ferruginous fanglomerate, thickness more than 4 feet; bottom concealed.

Along the southwest wall the section is as follows:

5. Fanglomerate, a maximum of 4 feet in thickness.
4. Manganese-bearing, fractured tufa, 3 to 4 feet thick.
3. Manganese-rich tufa, 2 to 3 feet thick, forming a series of lenses in the tufa cap. The largest lens is about 30 feet long.
2. Manganese-free tufa, 4 to 4½ feet thick.
1. Crossbedded green and brown gravels, containing ocherous layers and manganiferous layers as thick as 2 inches.

Data for samples from the south workings are given in table 19.

TABLE 19.—*Beryllia in samples from south workings, Golconda manganese-tungsten deposit*

Sample	*Description*	BeO (*percent*)
	NORTHEASTERN CUT	
329–1084	Channel sample, zone 3	0.0023
1085	Channel sample, manganese-rich rubble, zone 2, southeast wall of cut	.0023
1087	Chip sample, ocherous material overlying shale rubble of zone 2, southeast wall of cut	.016
1086	Composite channel sample, zone 1	.0024
	MIDDLE CUT, EAST WALL	
329–1088	Chip sample, zone 3	<.0001
1089	Composite channel sample, zone 2	.0035
1099	Composite channel sample, zone 1	.0002
	MIDDLE CUT, SOUTHWEST WALL	
329–1092	Chip sample, zone 4	.0027
1094	Chip sample, zone 1	.005

OCCURRENCE AND DISTRIBUTION OF BERYLLIUM

Analytical data indicate that beryllium in the Golconda deposit is contained mainly in the manganiferous ocher, which has been mined for its tungsten content, rather than in the tufa caprock or the underlying Triassic sediments. Presumably, the beryllium is genetically related to solutions which deposited the tungsten-bearing material. According to Kerr (1940, p. 1385–1387), warm spring waters rose along fissures in the Triassic rocks, the outflow resulting in beds of calcareous tufa, together with tungsten-bearing limonitic and manganiferous material. He concludes that iron and manganese were precipitated as gel products, which adsorbed tungstic oxide from the solutions, a process which could just as well result in the presence of beryllium. Tungsten occurs in hydrated ferric oxide, psilomelane, and hollandite; the beryllium-bearing minerals are not known.

The thickness and composition of the layers in the Golconda deposits are extremely variable along strike and dip. Only detailed exploration and sampling would serve as a basis for estimating reserves.

LANDER COUNTY

BARITE DEPOSITS, BATTLE MOUNTAIN AREA

Many barite deposits, some of commercial importance, are found in northern Lander County, northern Eureka County, and west-central Elko County, especially in the Tuscarora and Shoshone Ranges. The barite deposits are of two general types: vein deposits of white barite, in some areas associated with metalliferous deposits; and bedded gray barite generally considered to have formed by replacement of limestone. The veins have supplied small tonnages of barite, some of exceptional purity. The bedded deposits contain large tonnages of barite ranging from 80 to 93 percent barium sulfate and are the main producers. Samples from deposits of the latter type were obtained from mines of the California-Nevada Barite Co. and the Barium Products Corp., Ltd.

CALIFORNIA-NEVADA BARITE CO. MINE

The California-Nevada Barite Co. mine is reached by about 2 miles of steep but well-graded gravel road that turns south from U. S. Highway 40 at a point 12.9 miles east of the junction of U. S. Highway 40 and State Highway 8A. The mine is near the crest of the northwest spur of the Shoshone Range.

The workings are a series of opencuts extending for about 2,200 feet along the eastern side of the ridge. The principal workings are in the southern 900 feet and consist of five opencuts and several minor openings. The workings are in a belt 300 feet wide that trends about N. 20° W. The mine is owned and operated by the California-Nevada Barite Co., subsidiary of the Glidden Co.

The deposit consists of beds of barite, with an aggregate thickness of at least 40 feet, interbedded with thin beds of chert, silicified limestone, and shale. The barite beds mostly range from an inch to a foot in thickness and appear to be thickest and least interrupted by chert partings in the southern 900 feet. The structure of the deposit is highly complex. The barite beds in general appear to be dipping to the east at moderate angles, but there is local folding and much faulting. Table 20 gives the beryllia content of samples.

TABLE 20.—*Beryllia in samples from the California-Nevada Barite Co. mine*

Sample	*Description*	BeO (*percent*)
329–1064	Chip sample, bed by bed of about 15 ft of chert beds immediately above main barite zone	<0. 0001
1065	Chip sample, bed by bed across main barite zone; represents about 30 ft of beds	<. 0001
1066	Chip sample, bed by bed, of 5 ft of interbedded barite and chert immediately beneath footwall of main barite zone	. 001

BARIUM PRODUCTS CORP., LTD., MINE

The Barium Products Corp., Ltd., mine is 26 miles south of Battle Mountain in Lander County, by way of State Highway 8A. A good gravel road leads from the highway about a mile to the mine. The workings consist of an opencut about 260 feet long, 210 feet wide, and 20 feet in maximum depth. The deposit is a warped and moderately faulted westward-dipping sheet that extends from the crest of a low hill down the northwest slope for about 280 feet. The deposit is probably about 375 feet in strike length.

The barite is similar to that at the California-Nevada Barite Co.'s mine. It overlies thin-bedded chert. The overlying beds are not exposed.

A bed-by-bed chip sample (329–1072) taken across a 20-foot thickness of barite, beginning a few feet above the footwall contains 0.0007 percent BeO.

LINCOLN COUNTY

TEM PIUTE DISTRICT

Scheelite-bearing tactite deposits occur at the north end of the Tem Piute Range in the west-central part of Lincoln County, Nev., about 85 miles west of Caliente. The district is reached by 40 miles of desert road from U. S. Highway 93 at Crystal, near Hiko. The principal mines of the district are the Lincoln and the Schofield, the former accounting for most of the production. A mill at Hiko processes the ore. The deposits were explored by the U. S. Bureau of Mines in 1942 and 1944 (Binyon, Holmes, and Johnson, 1950), and were mapped and described by D. W. Lemmon (written communication).

The district comprises steeply dipping limestone, shales, and sandstones of Paleozoic age which have been intruded by two small granite stocks and several narrow basalt dikes. For a distance of 700 feet from the granite contacts the limestone is bleached and in places recrystallized. Shales are altered to hornfels and sandstones to quartzite. West of the south stock are thick tactite bodies in bands parallel to the bedding; little tactite has been found near the north stock.

Minerals observed in the tactite and listed in approximate order of abundance are: garnet, quartz, actinolite, calcite, fluorite, pyrite, pyrrhotite, diopside, sphalerite, scheelite, chlorite, hematite, clinozoisite, epidote, molybdenite, and powellite. Most of the scheelite occurs in garnet tactite but some rich deposits have been found in small masses of calcite-fluorite-sphalerite rock formed in marble remnants adjoining tactite bodies.

Products of the mill at Hiko were sampled for the Mine, Mill and Smelter Survey in 1943. Data for these samples are given in table 21.

TABLE 21.—*Beryllia in mill products from the Tem Piute district*

Sample	*Description*	BeO (*percent*)
49–DGW–20	Grab sample of scheelite tailings, and sulfide float tails (1942–43 production)	0. 002
21	Same (1940–42 production)	. 003
22	Grab sample of test run on scheelite mill tailings	. 001
23	Scheelite concentrate (composite of samples collected by company)	. 001

MINERAL COUNTY

RAWHIDE DISTRICT

Tactite deposits containing scheelite occur in the southern part of the Sand Springs Range about 4 miles east of the old mining camp of Rawhide. The deposits are in secs. 1 and 12, T. 13 N., R. 32 E., near the south border of the Carson Sink quadrangle. The deposits can be reached by a graded road that turns off U. S. Highway 50 about 35 miles east of Fallon, on the east slope of the Sand Springs Range just below the summit, or by graded roads leading northeasterly for about 45 miles from the town of Hawthorne. The deposits were mapped by R. F. Stopper and others of the U. S. Geological Survey in 1944. The geology of the area and locations of the mines are shown on figure 5. The Nevada Scheelite, Hooper No. 2 and Yankee Girl mines were visited and sampled.

The tungsten deposits are tactite bodies in metamorphosed limestone and hornfels at or near the margins of a body of granite about a mile wide in outcrop. The limestone is part of a thick sequence of folded and faulted sediments and metavolcanic rocks that were intruded by granite. The main limestone unit is estimated by Stopper (written communication) to be 400 to 750 feet thick. Other limestone units are thin beds included in hornfels that overlies the main limestone unit. The productive deposits are along the west and north margins of the granite where for some thousands

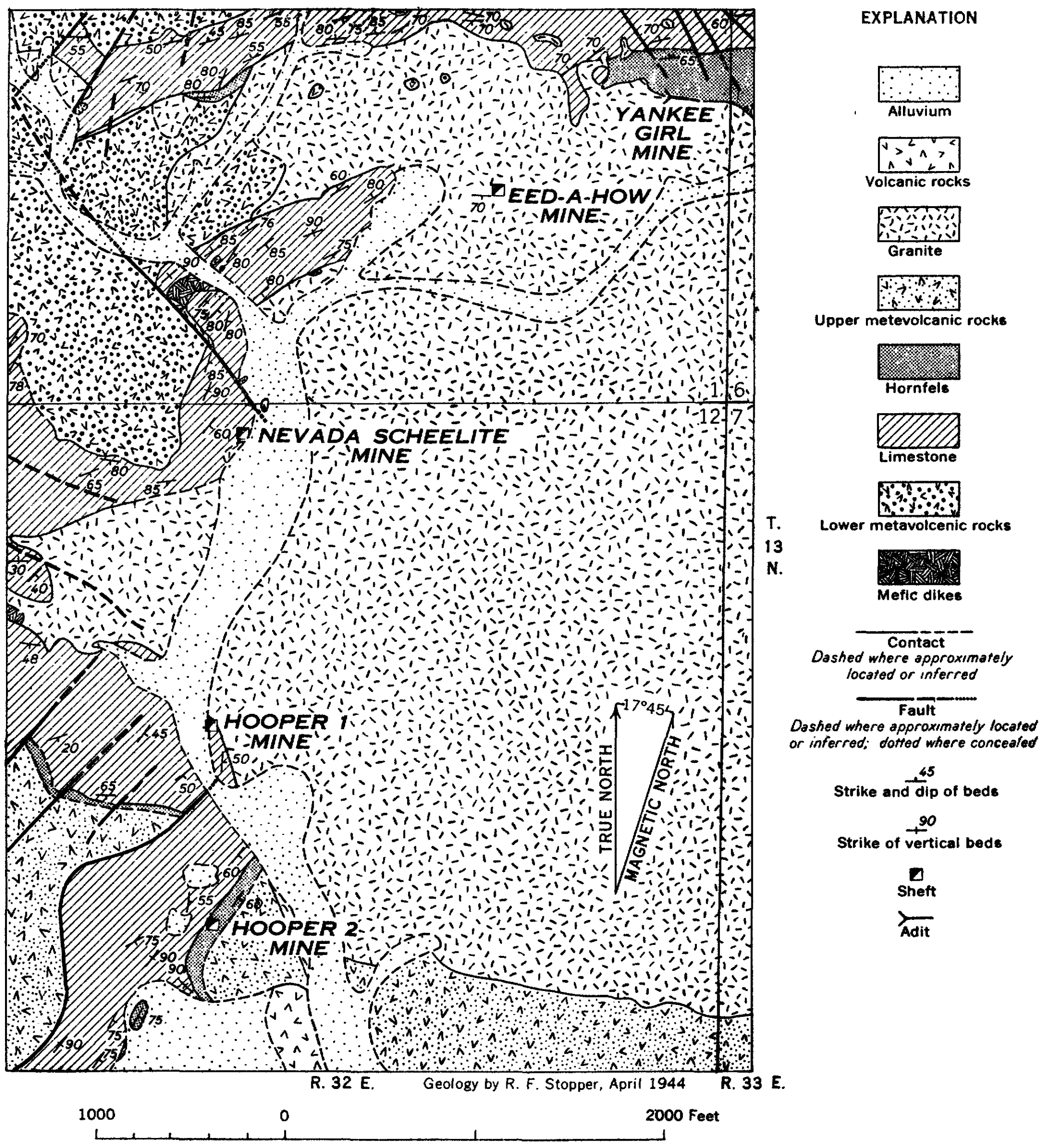


FIGURE 5.—Geologic map of part of the Rawhide district, Mineral County, Nev.

of feet it is in contact with the main limestone or with the overlying hornfels. Tactite bodies, however, occur only at intervals along the contact; elsewhere limestone or marble is directly against the granite. The tactite bodies range in thickness from a few inches to 50 feet. The fresh tactite consists of andradite garnet with various proportions of calcite, quartz, amphibole, epidote, pyroxene, wollastonite, pyrite, magnetite, scheelite, and chalcopyrite.

NEVADA SCHEELITE MINE

The Nevada Scheelite mine consists of an inclined shaft leading to levels at 100, 200, and 300 feet, together with a series of stopes between the levels. The mine is on the west side of the granite stock near a sharp bend in the contact (see fig. 5). The limestone beds at the mine strike northeast and dip from vertical to steeply southeast. A tactite body 2 to 50 feet wide occurs along the contact in an irregular zone about 1,800 feet long. In the northern and southern parts of the zone, the contact between limestone and granite is nearly vertical and mainly concordant with bedding in the limestone. In the middle part of the zone, the contact strikes northwest and dips 30° to 40° NE., cutting sharply across the bedding. This part of the contact is believed by Stopper to follow a pregranite fault along which the beds northeast of the fault have been offset about 350 feet to the northwest. The tactite body is thickest along the middle part of the contact and is absent in places to the north and south, granite being directly against marble. The tactite in this mine is in large part oxidized. Oxidation is marked on the 200- and 100-foot levels and extends in places below the 300-foot level, which is probably about its lower limit.

Samples of tactite, granite, and marble were obtained. No systematic variation in any of these rocks was noted. The marble is in marked contrast to that associated with tactite in other contact metamorphic deposits sampled, because it contains few silicate minerals representing lower grades of metamorphism. The change from tactite to marble commonly is abrupt, there being no clearly defined light-colored silicated marble zone. Table 22 gives beryllia contents.

TABLE 22.—*Beryllia in samples from the Nevada Scheelite mine*

Sample	*Description*	BeO (*percent*)
329–1189	Chip sample across 15-ft thickness of marble beds adjoining granite, north end of drift on 300-ft level, about 540 ft north of shaft. (No tactite zone present here.)	0. 0008
1190	Chip sample of granite in contact with marble, north end of drift on 300-ft level, 500 to 520 ft north of shaft	. 0007
1191	Chip sample across full width (5 ft) of tactite zone at intersection of headings about 460 ft north of shaft, 300-ft level	. 0028
1192	Chip sample across full width (30 ft) of tactite zone, stope 390, 24 to 30 ft above 300-ft level	. 0024
1194	Chip sample across 15-ft thickness of marble beds in west drift of 200-ft level, 200 ft northeast of shaft	. 0004
1195	Chip sample of marble, in part silicated (thickness, 7 ft), northeast end of main drift, 200-ft level	<. 0001
1228	Chip sample of granite taken at intervals along face of drift, 100 to 150 ft south of shaft, 200-ft level	<. 0001

HOOPER NO. 2 MINE

The Hooper No. 2 mine consists of an inclined shaft 110 feet deep, a drift extending 140 feet northeast from the shaft, and a 16-foot winze that extends downward from the shaft and leads to a 20-foot drift. The workings follow a tactite layer in thin-bedded andalusite-biotite hornfels. The tactite layer is about 20 feet stratigraphically above the main limestone formation. Three samples taken at the mine are described in table 23.

TABLE 23.—*Beryllia in samples from the Hooper No. 2 mine*

Sample	*Description*	BeO (*percent*)
329–1225	Chip sample across 3-ft thickness of hornfels immediately overlying tactite, main level, north end	<0. 0001
1226	Chip sample across full width (5 ft) of tactite pillar on main level	<. 0001
1227	Chip sample across 5-ft thickness of hornfels overlying tactite, mouth of winze	<. 0001

YANKEE GIRL MINE

At the Yankee Girl mine a 40-foot adit leads to two drifts, one extending about 65 feet northeasterly, the other extending about 90 feet east-southeast. Each of the drifts is connected with the surface by a shaft. A 25-foot inclined winze leads from the floor of the east-southeast drift to a small stope.

The mine is along the contact of the granite with the hornfels that overlies the main limestone unit. Inclusions of limestone that have been metamorphosed to tactite and marble are exposed in the workings. Hornfels is in contact with granite at several places in the mine. Sampling data are given in table 24.

TABLE 24.—*Beryllia in samples from the Yankee Girl mine*

Sample	*Description*	BeO (*percent*)
329–1229	Chip sample of hornfels 6 in. to 12 in. from contact with granite, near end of northeast drift	<0. 0001
1230	Chip sample of granite 6 in. to 12 in. from contact with hornfels of sample 329–1229	<. 0001
1231	Chip sample across 5-ft thickness of hornfels at end of northeast drift	<. 0001
1232	Chip sample across silicated marble beds at and near bottom of winze	<. 0001
1233	Chip sample across tactite zone, 31 ft from end of northeast drift	<. 0001
1234	Chips from various outcrops of fresh granite from lower part of gulch below mine	<. 0001

DESERT SCHEELITE AND GUNMETAL MINES, PILOT MOUNTAINS

The Desert Scheelite and Gunmetal mines are on the east slope of the Pilot Mountains, in Mineral County. The Desert Scheelite mine is 2.4 miles S. 22° E. of Graham Spring (Tonopah quadrangle). The Gunmetal mine is about 2 miles S. 10° W. of Graham Spring. Both deposits are reached by a graded gravel road extending east from Mina across the mountains. A short distance east of the summit a desert road leads southward past Graham Spring and connects with the mine access roads.

DESERT SCHEELITE MINE

The workings at the Desert Scheelite mine consist of two opencuts, a 50-foot inclined shaft with a small stope at the bottom, a 65-foot vertical shaft, and several trenches and short adits. The workings are in an east-trending belt of interbedded gray and white marble and silicated marble. This belt contains a tabular body of tactite (see fig. 6). The rocks dip 45° to 80° N. The tactite body extends westward for 700 feet from the 65-foot vertical shaft (shaft A) and probably connects beneath covered ground with the tactite zone exposed at the surface and in the 50-foot inclined shaft (shaft B). The total length of the tactite body therefore may be more than 1,400 feet. It consists of tactite beds with irregular blocks and partings of marble and silicated marble. Tactite formation is controlled primarily by bedding, but in part its distribution is related to cross fractures cutting the marble beds. The thickness of the tactite varies markedly from place to place.

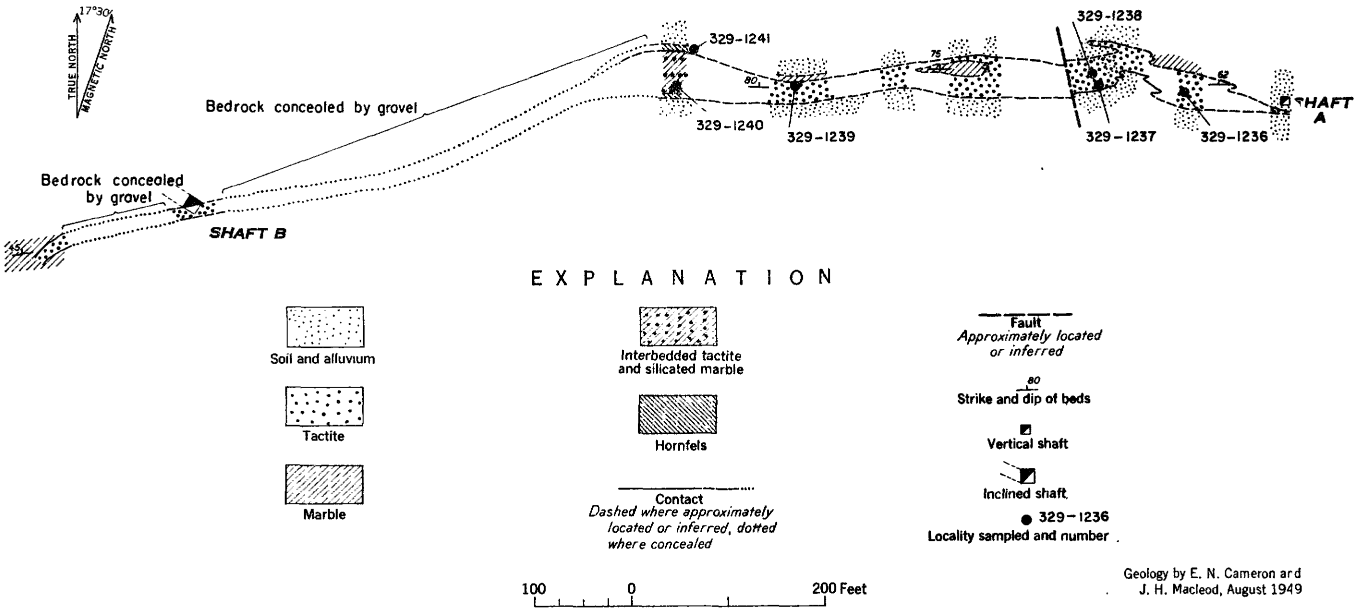


FIGURE 6.—Geologic map of part of the Desert Scheelite mine, Mineral County, Nev.

The tactite is fine- to coarse-grained, massive to layered rock consisting of garnet with some quartz, carbonates, and epidote. The color of the garnet ranges from red to greenish brown or yellowish brown. The mineral proportions vary locally and in places the tactite is rich in epidote. The silicated marble is mainly a thin-bedded fine-grained rock of indeterminate composition. The marbles are gray to white, and fine grained to medium grained. The white marble evidently formed along bedding and cross fractures by recrystallization of gray marble. The gray marble was derived from blue-black fine-grained limestone similar to that exposed outside the tactite zone. Samples were taken as listed in table 25 and shown on figure 6.

TABLE 25.—*Beryllia in samples from the Desert Scheelite mine*

Sample	*Description*	BeO (*percent*)
329–1236	Chip sample across full width of tactite	<0. 0001
1237	Chip sample, bed by bed, across 15-ft thickness of marble and silicated marble directly underlying tactite, south wall of opencut	<. 0001
1238	Chip sample across full width of tactite (includes 4 ft of interbedded tactite and light silicate rock)	<. 0001
1239	Chip sample across full width of tactite	<. 0001
1240	Chip sample across lower 10 ft of tactite	<. 0014
1241	Chip sample across 5-ft thickness of dense thin-bedded green hornfels immediately overlying tactite	<. 0001

GUNMETAL MINE

The Gunmetal mine is in gently dipping tactite layers interbedded with marble and silicated marble along the contact of the beds with quartz-monzonite. The tactite beds extend as much as 100 feet from the contact. The main working consists of two adits that lead to stopes on three levels. The tactite is prevailingly garnet-rich but contains also quartz, calcite, epidote, and scheelite.

A chip sample (329–1242) was taken across the lowest tactite layer exposed in an old foundation excavation north of the adits leading to the main workings. This layer is exposed for 60 feet along the strike and averages 3 feet in thickness. A second sample (329–1243) was taken across the main tactite bed exposed in a wall between the mouths of two adits in the first stope of the main workings. The samples showed no BeO, the limit of sensitivity being 0.0001 percent.

MANGANESE-TUNGSTEN DEPOSIT AT SODAVILLE

The Sodaville manganese-tungsten deposit, also known as the Black Jack claim, is on a pediment about half a mile west of U. S. Highway 95 opposite the former railroad station at Sodaville. The deposits are mostly on the crests and flanks of two small knobs that rise above the pediment. They have been described by Kerr (1946a, p. 178).

The deposits are veins in two steeply dipping north- to northeast-trending fracture zones cutting cherty rock that forms the knobs and underlies the pediment. The richest veins are on the eastern knob and the adjacent part of the pediment. They range from less than 1 inch to 2 feet in width and are as much as 20 feet in length. The veins consist largely of tungsten-bearing psilomelane, with varying amounts of pyrolusite, wad, iron oxides, calcite, gypsum, quartz, and chalcedony. The tungsten content of the psilomelane is reported to be 4.88 percent (Kerr, 1946a). Reserves are small, and operations at the deposits have never gone beyond the prospecting stage.

For comparison with the larger deposit at Golconda, a chip sample (329–1235) of high-grade manganese-tungsten ore was taken from blocks on various small ore piles. It contained 0.0075 percent of BeO.

ANDALUSITE DEPOSITS NEAR THORNE

The andalusite deposits that are exposed on both edges of the Soda Spring Valley a few miles east of Thorne, Mineral County, occur in a belt about 7 miles long that traverses the lower foothills of the Gillis Range (Hawthorne quadrangle). Another andalusite deposit is exposed at the Deep mine, a prospect on the southeast side of a prominent knoll immediately south of Highway 95, about 8 miles east-southeast along the highway from the center of Hawthorne.

Two deposits on the south edge of the Gillis Range, the Green Talc mine and a mine of unknown name about 0.4 mile west-northwest of the Green Talc mine, were visited and sampled.

GREEN TALC MINE

The Green Talc mine is on the lower southeast end of a spur of the Gillis Range. The mine consists of three opencuts and a series of prospect pits scattered over an area about 500 feet long and 125 feet wide, trending northeast across the spur. The main working, near the southwest end of the area, is an opencut 100 feet long, 90 feet wide, and about 40 feet in maximum depth. At the northeast end of the area is a second opencut about 45 feet long, 45 feet wide, and 25 feet in maximum depth. A third, small opencut is immediately north of the main opencut.

The principal body of andalusite-bearing rock appears to be the one exposed in the main working. The core of this body strikes N. 5° W. across the opencut and is more than 125 feet in exposed length and 10 to 15 feet thick. It is exposed to a maximum depth of about 12 feet and appears to dip steeply east. The core consists principally of 10 to 50 percent andalusite in blue to lavender crystals and clusters of crystals ⅛ inch to 1 inch in diameter and ½ inch to 4 inches long, set in a green to brownish-green matrix of pyrophyllite. The andalusite crystals are stout, rounded prisms apparently showing marginal alteration to pyrophyllite. In places a brownish granular material, possibly a carbonate, is present in the greenish matrix, and locally this is the dominant constituent. Enveloping the andalusite-bearing rock is a variety of altered volcanic rocks.

The northeast cut exposes dark volcanic rocks irregularly altered to pyrophyllite, with varying amounts of the brown granular mineral. Irregular bodies of similar pyrophyllitic rocks are scattered over the crest of the hill between the northeast opencut and the main working. The largest of these bodies appears to be about 50 feet long and 20 feet wide.

Samples taken at the Green Talc mine are described in table 26.

TABLE 26.—*Beryllia in samples from the Green Talc mine*

Sample	*Description*	BeO (*percent*)
329–1197	Chip sample across 10-ft thickness of pyrophyllite-carbonate(?) rock, northeast wall of lower part of northeast opencut, above layer of dark, altered volcanic rock	<0.0001
1198	Chip sample across 10-ft layer of dark altered volcanic rock, underlying rock of sample 329–1197	<.0001
1199	Chip sample across full width (8–10 ft) of andalusite-bearing core rock. Small opencut north of main working	<.0001
1200	Chip sample across full width (15 ft) of andalusite-bearing core rock, north wall of main working	<.0001

MINE NEAR GREEN TALC MINE

An unnamed mine 0.4 mile west-northwest of the Green Talc mine consists of a glory hole about 60 feet in diameter and about 60 feet in maximum depth. On the southeast side of the pit there is a vertical shaft reported to be about 75 feet deep.

The mine is in a lens of andalusite-pyrophyllite rock that strikes N. 65° E. and is nearly vertical. The lens is about 40 feet in maximum width and its strike length is probably not much more than 60 feet. On its northwest side the lens appears to grade irregularly into altered volcanic rock, and on its southwest side it is cut off by a steeply southeast-dipping, gouge-filled fault zone.

Chip sample 329–1224 was taken across an andalusite-bearing lens exposed in the southwest wall near the bottom of the glory hole. It showed no BeO, the limit of sensitivity being 0.0001 percent.

NYE COUNTY

GABBS AREA

We spent one day near Gabbs, Nev., sampling deposits of scheelite, magnesite, and brucite. The main purpose of the visit was to sample the scheelite-leuchtenbergite vein in the Paradise Range described by Kerr and Callaghan (1935). Examination revealed, however, that the vein is poorly exposed and probably of small tonnage; consequently no samples were taken. The newly developed Victory tungsten deposits were examined and sampled. A few samples were taken at the mine of the Sierra Magnesite Co. and from the brucite deposits at Gabbs.

VICTORY TUNGSTEN DEPOSITS

The Victory tungsten deposits are in the northwestern part of the Tonopah quadrangle and on the southwest slope of the Mammoth Range about 3 miles west-southwest of Marble. They are in the north part of sec. 22, T. 13 N., R. 36 E., and are accessible by a dirt road that turns northeast off State Highway 23 at a point about 1 mile northwest of the Gabbs airport entrance road. The deposits are on the crest and northeast side of a spur and are at the west border of a northward-trending body of granodiorite. The granodiorite mass is probably more than a mile long and is at least a quarter-mile wide. The deposits are of two types: disseminated scheelite in granodiorite, and scheelite-bearing contact-metamorphosed calcareous rocks.

Deposits of the first type are exposed in a series of 5 trenches 30 to 75 feet in length. The surface slopes 22° E. and the trenches extend for about 250 feet along a line that trends northwest. The trenches are excavated in a medium- to coarse-grained biotite granodiorite locally containing streaks and patches of quartz. Examination by ultraviolet light shows that scheelite is disseminated through the rock, but the content varies markedly from place to place. A chip composite sample (329–1248) was taken along 57 feet of the second trench (counting from north to south along the line of trenches) and 37 feet of the third trench. Spectrographic analysis showed 0.0034 percent BeO in the sample.

The second type of deposit is exposed west of the first, in a series of trenches at and near the crest of the same spur. The trenches are 15 to 30 feet in length and are spaced at intervals along a line trending northeast for at least 200 feet. They expose an undulating contact of granite with limestone and quartzite. At the crest of the spur the contact is nearly horizontal, but it appears to dip west where exposed on the west side of the spur. Along parts of the contact where limestone abuts against granite, a zone of silicated marble 6 inches to 2 feet thick is present. The minerals present include biotite, chlorite, and possibly amphibole and pyroxene.

In the two southernmost trenches a well-exposed contact zone, according to local report, contains the best showing of tungsten along the west contact of the granodiorite. A chip sample (329–1249) of the contact-metamorphosed material was taken along the 25-foot length of the southernmost trench and was found to contain 0.014 percent BeO. In view of the relatively high beryllium content of this sample, further study of the deposit seems advisable.

BRUCITE AND MAGNESITE DEPOSITS

The brucite deposits at Gabbs are on the west slope of the Paradise Range, east of town. They are being worked by the Basic Refractories Co. The workings consist of two series of large irregular opencuts, one in an upper deposit, the other in a lower one. The workings visited are in the upper deposit. They have a maximum depth of more than 350 feet and extend along the strike of the deposit for about 800 feet.

The deposits are in a thick series of magnesite and dolomite beds along the contacts of a northward-projecting prong of a granodiorite stock. The brucite formed by hydrothermal alteration of the carbonate rocks. Irregular masses of dolomite and magnesite in various stages of alteration are contained in the brucite. The deposits are capped by blankets of supergene hydromagnesite that are as much as 50 feet thick. The whole assemblage of dolomite, magnesite, and brucite is cut by an intricate network of granodiorite dikes, each bordered by serpentine. The high-grade brucite is compact and appears soapy. It grades into rock locally called "limy brucite" that contains much dolomite and calcite.

Two grab samples of the brucite were obtained from the lower level workings of the east (upper) ore body. Sample 329–1245, high-grade brucite, contained less than 0.0001 percent BeO; sample 329–1246, limy brucite, contained 0.0014 percent BeO.

The extensive deposits of magnesite in this area have been described by Rubey and Callaghan (Hewett and others, 1936, p. 142–143). A sample (329–1244) of raw magnesite obtained from the crusher at the mine of the Sierra Magnesite Co. contained less than 0.0001 percent BeO.

PERSHING COUNTY

ROCKS IN THE WEST HUMBOLDT RANGE

The West Humboldt Range is noteworthy for the association of scheelite and beryl in two deposits on the west slope of the range—the Humboldt Canyon beryl-scheelite prospect and the Oreana tungsten mine. With the idea that these deposits might indicate the presence of an unusual amount of beryllium in one or more of the several types of granitic intruded rocks exposed in the range or in the contact-metamorphic rocks bordering them, a fairly extensive program of sampling was undertaken.

LIMERICK CANYON AREA

Large masses of aplite have been described by Knopf (1924, p. 33) and Jenney (1935, p. 34, 35) from the Rochester mining district and the area immediately north of it. The aplite is a fine-grained massive rock that, according to Jenney, consists mainly of quartz, orthoclase, and albite, with traces of magnetite, sphene, tourmaline, zircon, and biotite.

No exhaustive study of the aplite was attempted, but two samples were taken from exposures in Limerick Canyon (see fig. 7), as follows:

329–1126. Chip sample from various exposures on the north side of Limerick Canyon (0.0007 percent BeO).

1127. Chip sample from various exposures on the south side of Limerick Canyon (0.0011 percent BeO).

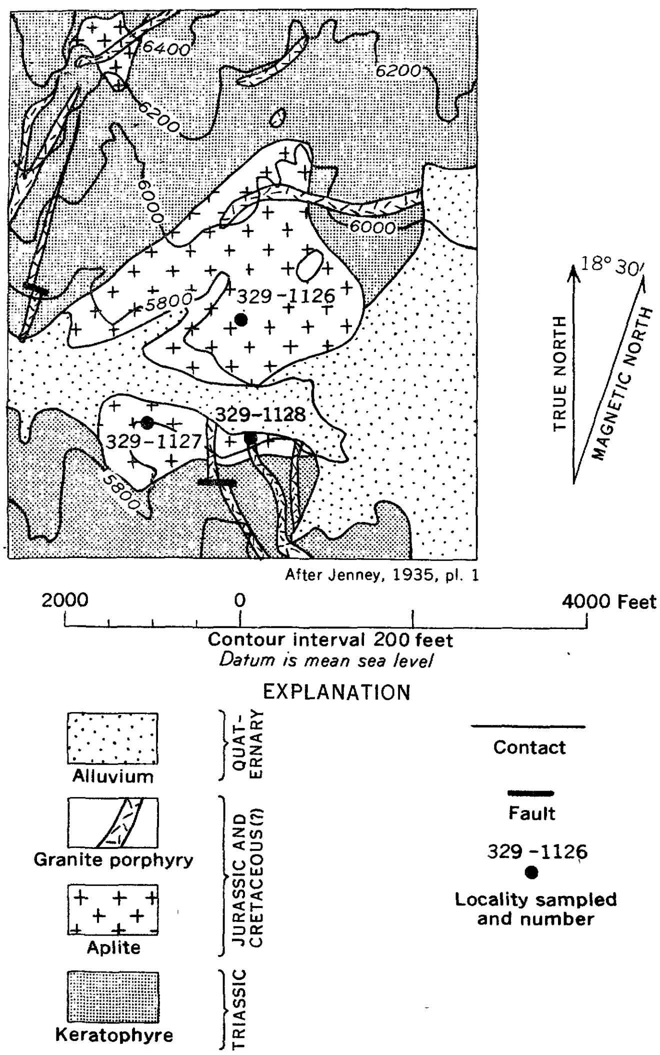


FIGURE 7.—Geologic map of part of Limerick Canyon, West Humboldt Range, Pershing County, Nev.

Dikes of granite porphyry cut aplite on the south side of Limerick Canyon (fig. 7). Sample 329–1128 consisted of chips from various exposures of five dikes. The BeO content proved to be less than 0.0001 percent. This same rock forms large bodies in the area extending north from the Rochester mining district toward Unionville Canyon.

PANTHER CANYON AREA

The Panther Canyon area has been described by Vitaliano (1944). In Rye Patch Agnes Canyon quartz monzonite underlies an area of 20 acres, and contact-metamorphosed rocks associated with it underlie large parts of an area 2,400 feet by 3,200 feet, extending from the south side of Rye Patch Agnes Canyon across Panther Canyon (see fig. 8). Because Vitaliano's report includes detailed maps of both the intrusive body and the associated contact aureole, the area appeared to offer excellent ground for sampling.

The quartz monzonite is a light-gray medium-grained massive rock reported by Vitaliano to consist mainly of quartz, feldspar, and mica, with accessory sphene, apatite, magnetite, and pyrite, and traces of epidote, calcite, hematite, chlorite, and zircon. It is finer grained than the granite in Rocky Canyon (fig. 11) and contains more plagioclase. The quartz monzonite shows little variation. At a few places it grades into aplite.

Outcrops of the quartz monzonite along Rye Patch Agnes Canyon were carefully examined, for beryl and for indications of uncommon minerals. A chip sample of granite (329–1124) was taken from outcrops at 15-foot intervals along the bottom of Rye Patch Agnes Canyon, from the east contact nearly to the midpoint of the granite body. The sample contained 0.0016 percent BeO.

Two principal groups of rocks have been affected by contact metamorphism in the Panther Canyon area: calcareous argillite, now represented by hornfels layers; and limestones, ranging from pure to argillaceous and including thin layers of argillite.

The hornfels is mainly represented by three layers of a brownish (limonitic) sugary textured rock from 6 to 50 feet in width. The easternmost layer was sampled (329–1123) on the north side of Rye Patch Agnes Canyon just above the canyon bottom. At this point it is about 45 feet thick. The rock consists largely of quartz and orthoclase, with subordinate amounts of diopside, epidote, and other minerals. The sample contained 0.0008 percent BeO.

The limestone layers are an extremely varied assemblage, ranging from blue-black, fine-grained marble that apparently has undergone recrystallization but little silicification, through blue-black marble containing streaks and patches that range from white marble and silicated marble to tactite. Metamorphosed limestone occurs mainly in two zones: an inner zone immediately contiguous to the quartz monzonite in Rye Patch Agnes Canyon, and an outer zone east of this body and, extending roughly north from the south side of Rye Patch Agnes Canyon across the south fork of Panther Canyon (see fig. 8).

In the inner zone, silicification of the limestone series is only locally complete and the rocks consist largely of blue-black marble with streaks, patches, lenses, and lay-

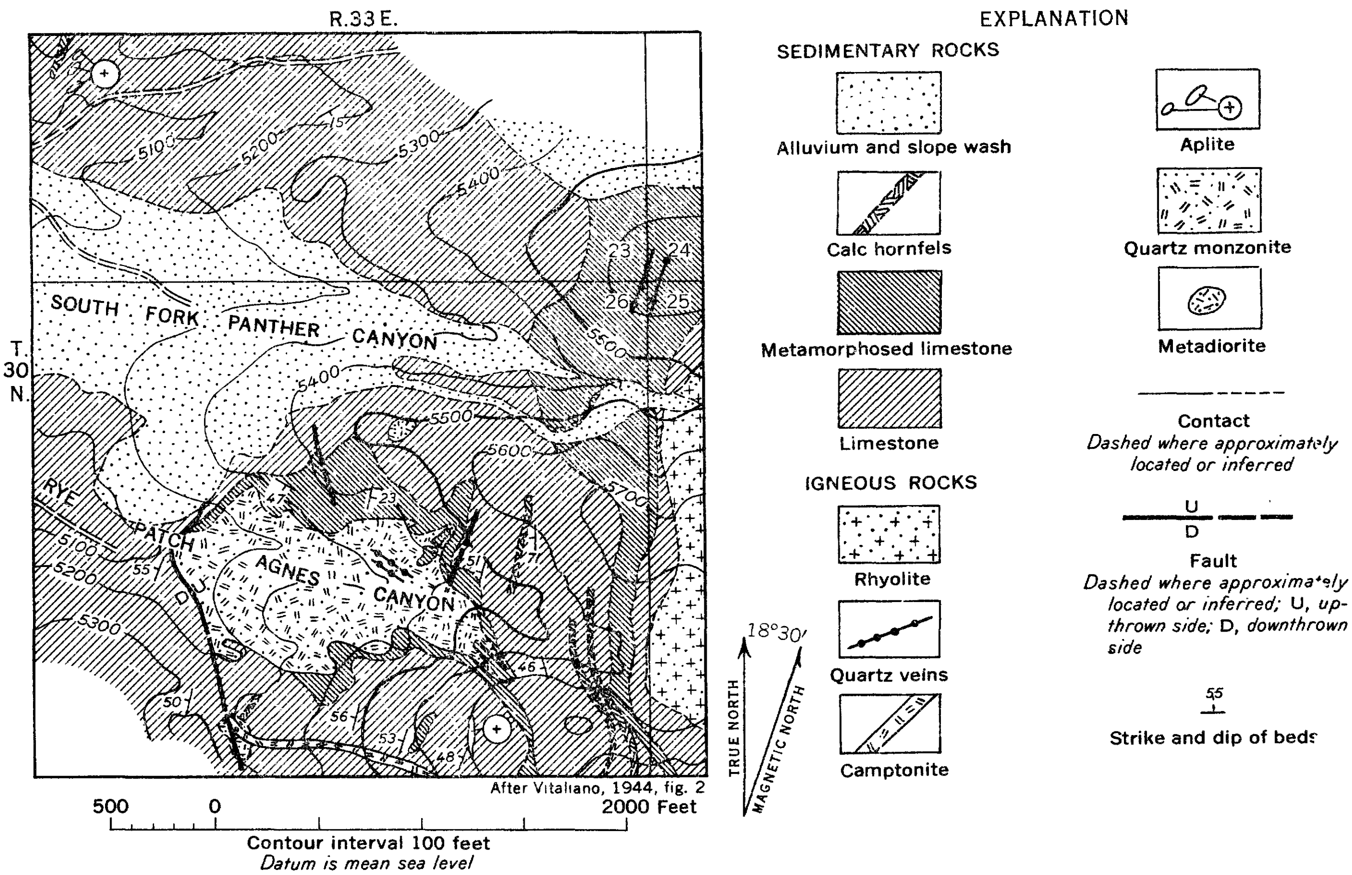


FIGURE 8.—Geologic map of a part of Panther Canyon area, Rye Patch, Nev.

ers of white marble and silicated marble. Samples taken and analyzed for BeO are described in table 27.

TABLE 27.—*Beryllia in samples from inner contact zone, Panther Canyon area*

Sample	*Description*	BeO (*percent*)
329–1111	Chip sample taken at intervals across a series of thin layers of silicated marble intercalated with marble. Zone is 40 ft across strike and 200 ft long	< 0.0001
1112	Chip samples across zone of interbedded gray, white, and blue-black marble containing layers of silicated marble. Total thickness of zone is 54 ft; 18 ft is silicated marble (329–1112) and 36 ft is marble (329–1113)	.0078
1113	do	.0013
1122	Grab sample of tremolite marble from limestone area north of quartz monzonite	.0013
1125	Chip sample from various outcrops of blue-black marble containing patches of white marble and veins of silicates	.0016

The outer contact-metamorphic zone includes rocks that are thoroughly silicated. These rocks range from hornfels and silicated marble to tactite and can best be seen in the ridges separating the North and South forks of Panther Canyon. The section exposed on the north wall of the south fork is typical (fig. 9). The structure of the outer zone is complicated by a steeply dipping fault that marks the eastern margin of the zone, at least between the North and South Forks of Panther Canyon (fig. 10), and there may also be one or more faults along the bottom of the south fork of the

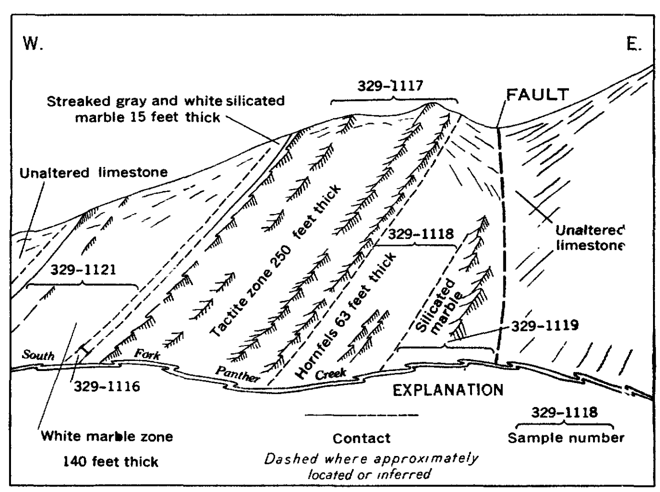


FIGURE 9.—Sketch of part of north wall, South Fork Panther Canyon, Pershing County, Nev.

canyon. Sampling was restricted largely to the north wall of South Fork Panther Canyon, west of the fault; sampling data are given in table 28.

TABLE 28.—*Beryllia in samples [1] from outer contact zone, Panther Canyon area*

Sample	*Description*	BeO (*percent*)
329–1115	Chip sample across belt of silicated marble, north side Rye Patch Agnes Canyon	0.0007
1116	Chip sample across beds approximately 15 ft thick in lower part of section of silicated marble	.0009
1117	Chip sample across tactite zone, taken along crest of ridge	.0037
1118	Chip sample across beds of hornfels	.0026
1119	Chip sample across 15-ft thick zone of silicated marble	.0029
1121	Chip sample across 140-ft thickness of beds, mostly marble	.0036

[1] Samples 329–1116 to 329–1121 are from the section on north side of South Fork of Panther Canyon. See figure 9 for locations.

ROCKY CANYON-WRIGHTS CANYON AREA

The area extending from Rocky Canyon to Wrights Canyon includes the Oreana tungsten mine, described by Kerr (1938; 1946a, p. 189–192), where scheelite and beryl occur in pegmatite. The general geology of the area is shown in figure 10, and detailed geology in the vicinity of the Oreana mine is shown in figure 11. The rocks sampled include limestone in various stages of recrystallization and silicification, hornfels, granite and aplite. Locations of samples are shown on figures 10 and 11, and sampling data are given in table 29.

TABLE 29.—*Beryllia in samples from the Rocky Canyon-Wrights Canyon area*

Sample	*Description*	BeO (*percent*)
	ROCKY CANYON AREA	
329–1130	Chip sample across pegmatite-aplite dike, north side of canyon	0.0001
1131	Chip sample of aplite from composite dike on south side of canyon	.0011
1132	Chip sample of granite; chips taken at 150-ft intervals for 4,000 ft up canyon from mouth	.0011
1133	Composite sample of six pegmatite-aplite dikes, north side of canyon	.0007
1135	Chip sample of granite; chips taken at intervals along ridge south of canyon	.001
	WRIGHTS CANYON (OREANA) AREA	
329–1137	Chip sample across aplite dike	.0011
1138	Chip sample across hornfels layer	.0008
1139	Chip sample across aplite dike or sill	.0015
1140	Chip sample across lens of silicated marble and tactite between aplite dikes	.0031
1141	Chip sample across silicated marble	.0015
1142	Chip sample across aplite dike, north side Wrights Canyon	.001

The granite is exposed in the gorge forming the lower part of Rocky Canyon. It is a medium- to course-grained massive biotite granite. Apart from patches of biotite-rich material present locally, particularly near the mouth of the gorge, it appears homogeneous.

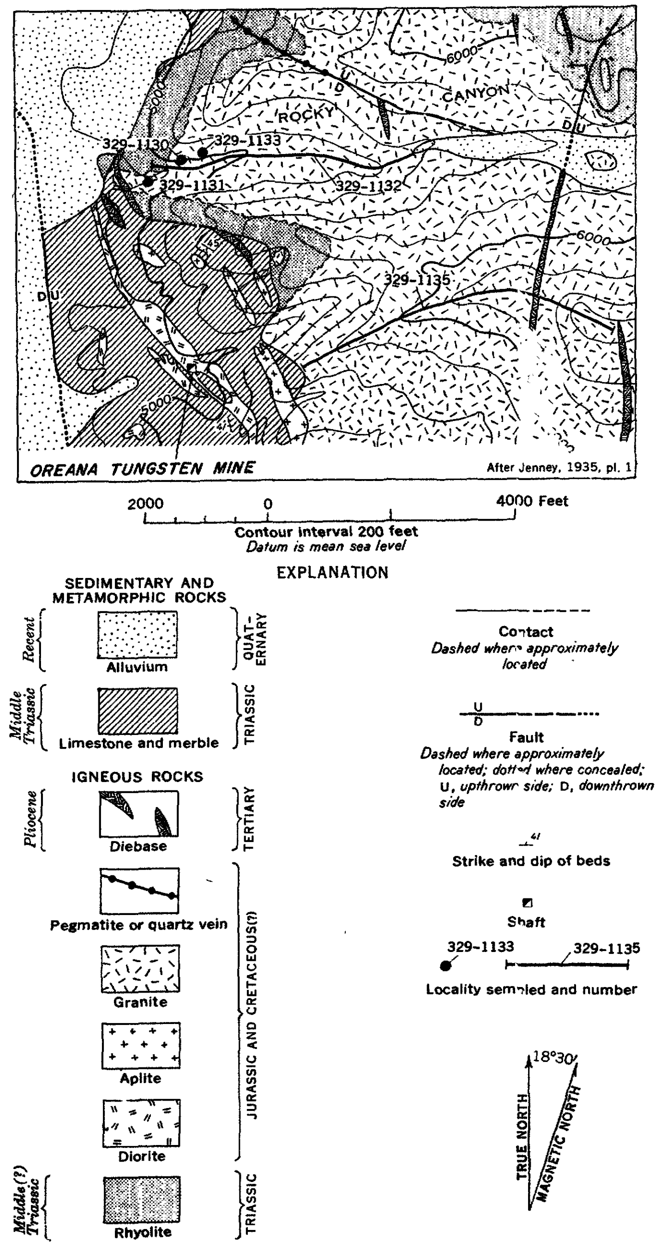


FIGURE 10.—Geologic map of part of Rocky Canyon and vicinity, West Humboldt Range, Pershing County, Nev.

The granite was examined for beryl, but none was found.

Aplite-pegmatite dikes are found in great profusion. Proportions of aplite and pegmatite material in the dikes vary markedly, even from place to place within the same dike, but the aplite fraction predominates. In general the dikes strike N. 30° to 45° W. and dip 35° to 50° NE.; some strike northeast and are vertical. They range from a few inches to many feet in width, and some are exposed for hundreds of feet along strike or dip. Apparently, they are of several generations and some of the older are sill-like bodies in rhyolite

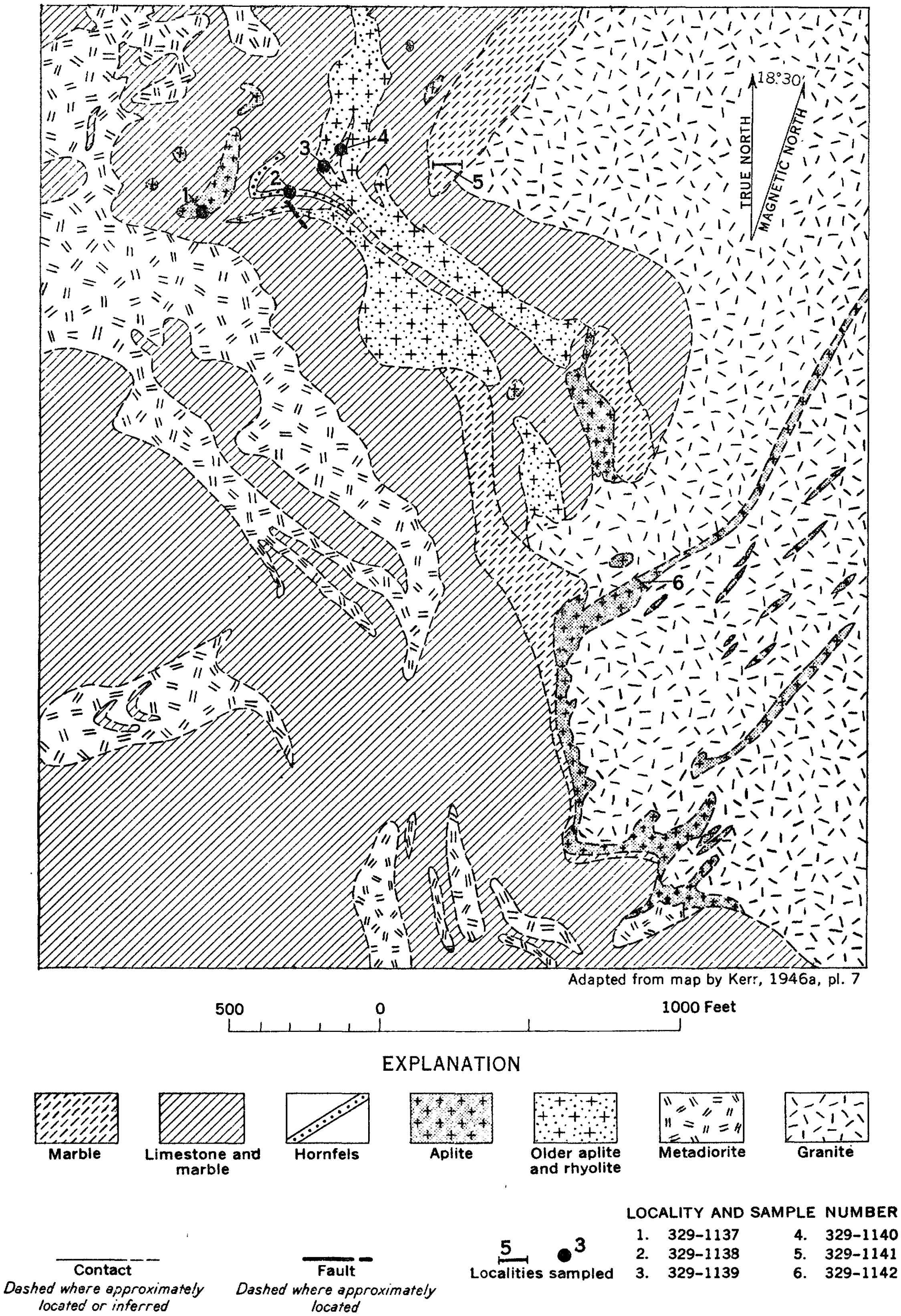


FIGURE 11.—Geologic map of vicinity of Oreana tungsten mine, Pershing County, Nev.

(Kerr, 1946a, p. 189–190, pl. 7). Beryl was not found in the dikes examined.

In the area east of the Oreana mine, contact-metamorphosed rocks consisting of blue-black limestone and marble, silicated marble, tactite, and hornfels were sampled. These rocks are in contact with metadiorite on the west and granite on the east (see fig. 11).

RESULTS OF SAMPLING

In view of the occurrence of beryl in scheelite deposits in the West Humboldt Range, analytical results of the rock samples collected in this region are disappointing. Of the 27 samples of all rock types that were analyzed spectrographically, only 1 (329–1112) contained more than 0.005 percent BeO, and only 3 others contained more than 0.003 percent. The average BeO content of the other 23 samples is less than 0.002 percent.

Sample 329–1112, containing 0.0078 percent BeO, represents material which might some day be of commercial interest, though the tonnage probably is small. The sample is from a zone of silicated marble adjacent to the intrusive quartz monzonite in Rye Patch Agnes Canyon. The zone is more than 50 feet wide and persists for at least 200 feet along the strike. It is estimated to contain about 3,500 tons for each 10 feet of depth. The beryllium-bearing mineral is not known, and there is no assurance that the beryllium is recoverable.

In evaluating results of the sampling, it should be emphasized that the metasedimentary rocks at each of the localities sampled in the Humboldt Range are of extremely diverse composition. Hundreds of samples, each taken from a single bed, would be needed to determine the exact distribution of beryllium. Considerable contamination is inherent in the present sampling; thus further investigation might reveal material of much higher beryllium content than that indicated by the analyses given above. However, the present work gives no indication of large individual deposits of relatively high-grade beryllium-bearing material.

TUNGSTEN AREA, MILL CITY DISTRICT

The tungsten deposits at Tungsten, near Mill City, Nev., are among the most important of the tactite type in the United States. The deposits, which are worked by the Nevada-Massachusetts Co., are on the southeast slopes of the Eugene Range, in Pershing County. They have been described by Kerr (1946a, p. 182–188).

At Tungsten three steep-sided stocks of granodiorite cut a series of calcareous strata interbedded with hornfels. In general the beds strike nearly north and dip steeply east or west. The beds are offset by both pre- and post-mineralization faults. The deposits are in parts of the calcareous beds that have been converted to tactite and impregnated with scheelite. Scheelite-bearing tactite has been found in some of the beds for distances as great as 2,000 feet from the nearest intrusive body, and the deepest workings have reached 1,700 feet without sign of bottoming of the beds against granite.

No one of the calcareous beds is uniformly mineralized. In general, a bed traced along dip or strike will be found to show four facies, as follows:

1. Tactite, consisting chiefly of garnet, epidote, diopside, and quartz in various proportions.
2. Silicated marble, with pale-green silicates and pale garnet.
3. White marble, commonly with some light-colored silicates and grading in places into silicated marble.
4. Blue-black fine-grained marble grading into limestone. Certain beds contain partings or lenses of hornfels.

The number of calcareous beds is large and the workings are extensive; no attempt at overall sampling could be made. Two groups of beds, known locally as the Sutton beds and the George beds, were selected for the major part of the sampling, because each was easily accessible in several opencuts. A few samples were also taken from beds on Humboldt Hill and Stank Hill. The various ore-bearing beds and surface workings are shown on figure 12.

None of the samples from this area contains sufficient beryllium to be of commercial interest at present. In view of the large number of samples taken and the variety of rock types represented, the prospect that substantial quantities of higher grade material is present seems unlikely.

SUTTON BEDS OF LOCAL USAGE

The rocks known locally as the Sutton beds consist of two calcareous layers separated by about 40 feet of hornfels. Samples were taken from these beds in the Baker workings, the workings immediately north of the Springer stock, and the south opencut of the Sutton mine. The samples are described in table 30.

TABLE 30.—*Beryllia in samples from the Sutton beds of local usage*

Sample	Description	BeO (percent)
EAST SUTTON OPENCUT; EXPOSURES IN LOWER PART OF HEADWALL (NORTH WALL)		
329–1143	Chip sample, layer by layer, across east ore bed, thickness 9 to 9.5 ft. Interbanded tactite, white marble, silicated marble, quartz, and hornfels. Tactite includes both garnet-rich and epidote-rich material	<0.0001
1144	Chip sample of west ore bed, 8.5 ft thick. Garnet-epidote-quartz-calcite tactite with minor hornfels layers	.0017
1145	Chip sample of blue-black and gray hornfels from 40-ft thickness of beds separating the two ore beds	.0016
1146	Chip sample from same beds as 329–1145 but consisting of hornfels altered along layering and cross fractures to a green fine-grained rock	.0012

TABLE 30.—*Beryllia in samples from the Sutton beds of local usage*—Continued

Sample	Description	BeO (percent)
EAST SUTTON OPENCUT; EXPOSURES IN LOWER PART OF HEADWALL (NORTH WALL)—continued		
329-1147	Chip sample across 6 ft of hornfels immediately overlying the west ore bed	0.0018
1148	Chip sample of 4 ft of hornfels immediately underlying the east ore bed	< .0001
SOUTH SUTTON OPENCUT; EXPOSURES IN LOWER PART OF HEADWALL (SOUTH WALL)		
329-1149	Chip sample across east ore bed, 44 in. thick at base of cut. Mostly marble and silicated marble, with some tactite	.0025
1150	Chip sample of hornfels separating the two ore beds; thickness about 41 ft	.001
1151	Chip sample across west ore bed, 9 ft thick at base of cut; gray marble, and silicated marble, with inclusions of blue-black marble, garnet-rich and epidote-rich tactite	.0032
1152	Chip sample across 6 ft of hornfels immediately overlying (west of) the west ore bed	.0013
1153	Chip sample across 4 ft of hornfels immediately beneath (east of) the east ore bed	.0013
1154	Grab sample of the blue-black marble from broken material near the north end of the opencut	.0006
OPENCUT EAST OF BAKER WORKINGS; EXPOSURES AT BASE OF HEADWALL. (THE CORRELATION OF THESE BEDS WITH THE SUTTON BEDS OF LOCAL USAGE IS UNCERTAIN.)		
329-1155	Chip sample across west ore bed, about 5.5 ft thick. Consists mostly of silicated marble containing garnet. Includes 2 ft of blue-black marble and gray marble	.004
329-1156	Chip sample across east ore bed, about 15 ft thick. Upper half mostly diopside-epidote rock and garnet rock. Lower half mostly fine-grained to medium-grained marble	.0029
BAKER WORKINGS; EXPOSURES IN ENTRANCE CUT AND SOUTH WALL OF OPENCUT		
329-1157	Chip sample across west ore bed, 125 ft thick. Consists mostly of dense, light-green calc-silicate rock. Upper 2 ft is garnet marble	.0027
1158	Chip sample across 6 ft of hornfels immediately adjacent to west (hanging) wall of west ore bed	.0023
1159	Chip sample across east ore bed, 5 ft thick. Mostly epidote-rich tactite veined by quartz	.0026
1160	Chip sample across 4-ft thickness of hornfels forming east (foot) wall of the east ore body	.002
1161	Chip sample across an aplite dike cutting the ore beds and enclosing hornfels in the south part of the opencut. The dike strikes N. 55° W. and dips 77° SW. It is 6 to 15 ft thick and at least 100 ft long	.0008
1162	Chip sample across 40-ft thickness of hornfels separating the two ore beds	.0012
OPENCUT NORTH OF THE BAKER WORKINGS; EXPOSURES IN SOUTH END OF OPENCUT		
329-1163	Chip sample across east ore bed, 2½ ft thick. White and blue-black marble, silicated marble, and epidote-garnet-quartz tactite	.0022
1164	Chip sample across west ore bed, 26 in. thick. Epidote-quartz and garnet-quartz tactite	.003

GEORGE BEDS OF LOCAL USAGE

The rocks known locally as the George beds are a varied assemblage of layers of marble, calc-silicate rocks, and tactite composed of diopside, garnet, and epidote in various proportions. In part the diopside-garnet rocks appear to have been formed by alteration of dark-gray hornfels, not of limestone. This is clearly shown in workings 2,000 feet north-northwest of the summit of Humboldt Hill. Here the George beds are about 19 feet thick and nearly vertical. They consist of garnet-diopside tactite, grading into hornfels, and blue-black marble partly recrystallized to white marble. Samples from the George beds are described in table 31.

TABLE 31.—*Beryllia in samples from the George beds of local usage*

Sample	Description	BeO (percent)
SHALLOW CUT ON SADDLE NORTHWEST OF SUMMIT OF HUMBOLDT HILL		
329-1165	Chip sample across lower (east) part of beds, consisting, from east to west, of (1) garnet-quartz-epidote tactite 14-21 in. thick; (2) interlayered gray-green calc-silicate rock, hornfels, and fine-grained tactite, 32-40 in. thick; (3) interlayered hornfels and calc-silicate rock 32 in. thick; (4) garnet-rich and epidote-rich tactite 71 in. thick	0.003
1166	Chip sample of beds overlying beds of 329-1165: (1) white marble, in part silicated, containing blocks of blue-gray marble, 85 in. thick; (2) garnet tactite 3-12 in. thick; and (3) white and blue-black marble	.0008
1167	Chip sample of upper beds, comprising (1) garnet and garnet-epidote tactite, 33 in. thick; (2) garnet and garnet-epidote tactite interbanded with gray-green calc-silicate rock, 12-16 in. thick; (3) garnet and garnet-epidote tactite, 30 in. thick, and (4) fine-grained green calc-silicate rock, 12 in. thick	.0013
OPENCUT IN GULCH ABOUT 1,500 FEET WEST OF SUMMIT OF HUMBOLDT HILL; EXPOSURES IN LOWER PART OF SOUTH FACE OF CUT		
329-1172	Chip sample across (1) 21 in. of interbanded gray hornfels and diopside(?) hornfels, with a few thin garnet bands; (2) 25 in. of interbanded diopside(?) and garnet tactite, and (3) 9 in. of dense green calc-silicate rock	.0021
1173	Chip sample across 3.5-ft thickness of blue-black marble in large part converted to white marble, partly silicated	.0007
1174	Chip sample across 6.5 ft of diopside and diopside-quartz rock, with thin garnet layers and lenses	.0026
1175	Chip sample across 6 ft of hornfels immediately east of the George beds of local usage	.0016

OTHER ROCKS SAMPLED

The Humboldt beds of local usage were sampled in the opencut near the summit of Humboldt Hill where they have a total thickness of about 13 feet. The beds comprise epidote-quartz and garnet-quartz tactite, sili-

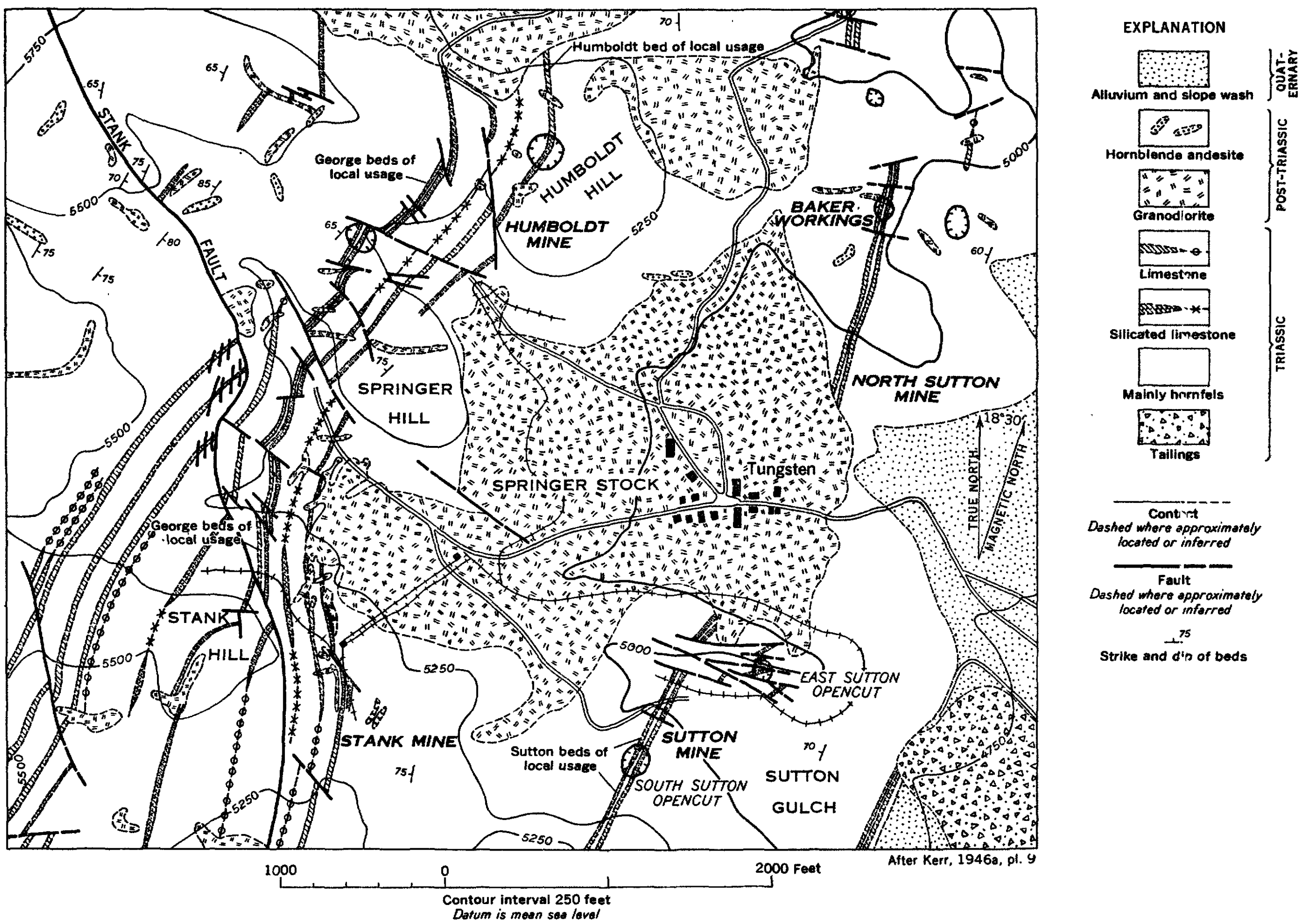


FIGURE 12.—Geologic map of part of Tungsten area near Mill City, Pershing County, Nev.

cated marble, white marble, and blue-black marble. The beds on the west side of Stank Hill were sampled in the hope of getting representative material from the outer fringes of the mineralized area. Samples from these localities are described in table 32.

TABLE 32.—*Beryllia in samples from Humboldt Hill and Stank Hill*

Sample	*Description*	BeO (*percent*)
	HUMBOLDT BEDS OF LOCAL USAGE; OPENCUT ON HUMBOLDT HILL	
329–1168	Chip sample across the full width of the beds	0.0033
1169	Chip sample of 5-ft thickness of hornfels immediately beneath (east of) the ore beds	.0014
1170	Chip sample from various layers of garnet tactite	.0036
1171	Chip sample of white marble having abundant pale garnet	.0022
	BEDS WEST OF STANK HILL	
329–1176	Chip sample of 6-ft thickness of argillite immediately east of (overlying) the ore beds	0.0023
1177	Chip sample across 32 in. of silicated marble and 30 in. of interbanded diopside and garnet tactite. These beds form the top (east) part of the main zone of calcareous strata	.0016
1178	Chip sample across 6-ft thickness of blue-black and white marble and silicated marble forming the middle part of the main zone of calcareous strata	.0005
1180	Chip sample across 4½-ft thickness of hornfels overlying (east of) the main zone of calcareous strata and separating them from 2.5 ft of blue-black and white marble	.0014

A composite (329–1181) of granodiorite from various outcrops in the southwestern part of the Springer stock had a BeO content less than 0.0001 percent.

ROSE CREEK MINE

The Rose Creek tungsten mine is in the northeastern part of the East Range, 11 miles south-southwest of Winnemucca. A detailed study of the deposit was made by R. J. Roberts (1943). Rocks of the area include dolomite, limestone, argillite, and quartzite which have been cut by a small granite body (see fig. 13). Argillite next to the granite has been altered to hornfels, and tactite has formed in the limestone.

The main, or upper, workings consist of an adit that extends westerly for about 400 feet and connects with a series of drifts, raises, and stopes (see fig. 14). An inclined winze extends down the ore bed to the northwest. A lower adit was driven westerly from a point 370 feet northeast of, and 117 feet lower than, the portal of the upper adit to intersect the winze (fig. 13). This adit was flooded at the time of the present investigation. A sublevel consisting of a few short drifts was excavated after Roberts' survey. It joins the winze about 35 feet vertically below the upper adit.

The deposit is a bed of scheelite-bearing tactite enclosed in interbedded quartzite and hornfels. The bed is 2 to 4 feet thick, averaging about 2½ feet. The average thickness of the parts of the bed remaining in the underground workings is probably 1½ to 2 feet. The bed strikes northeasterly and dips northwesterly at a moderate angle. It is offset by a number of postmineralization faults, mostly of small displacement, and is cut by preore lamprophyre dikes and postore diabase dikes. Mining has been confined to the richer and thicker parts of the bed.

The tactite is fine grained and is composed chiefly of

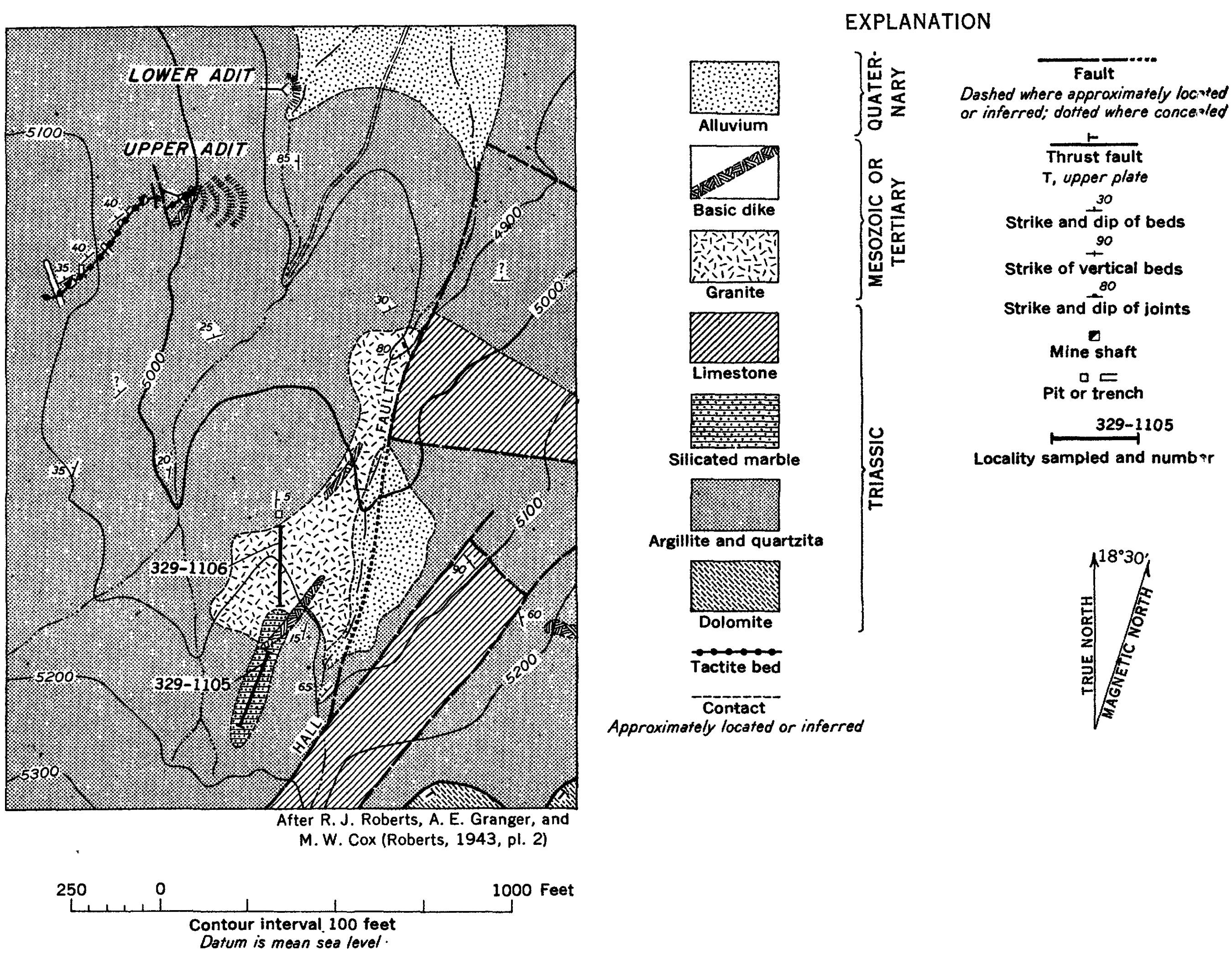


FIGURE 13.—Geologic map of the Rose Creek mine and vicinity, Pershing County, Nev.

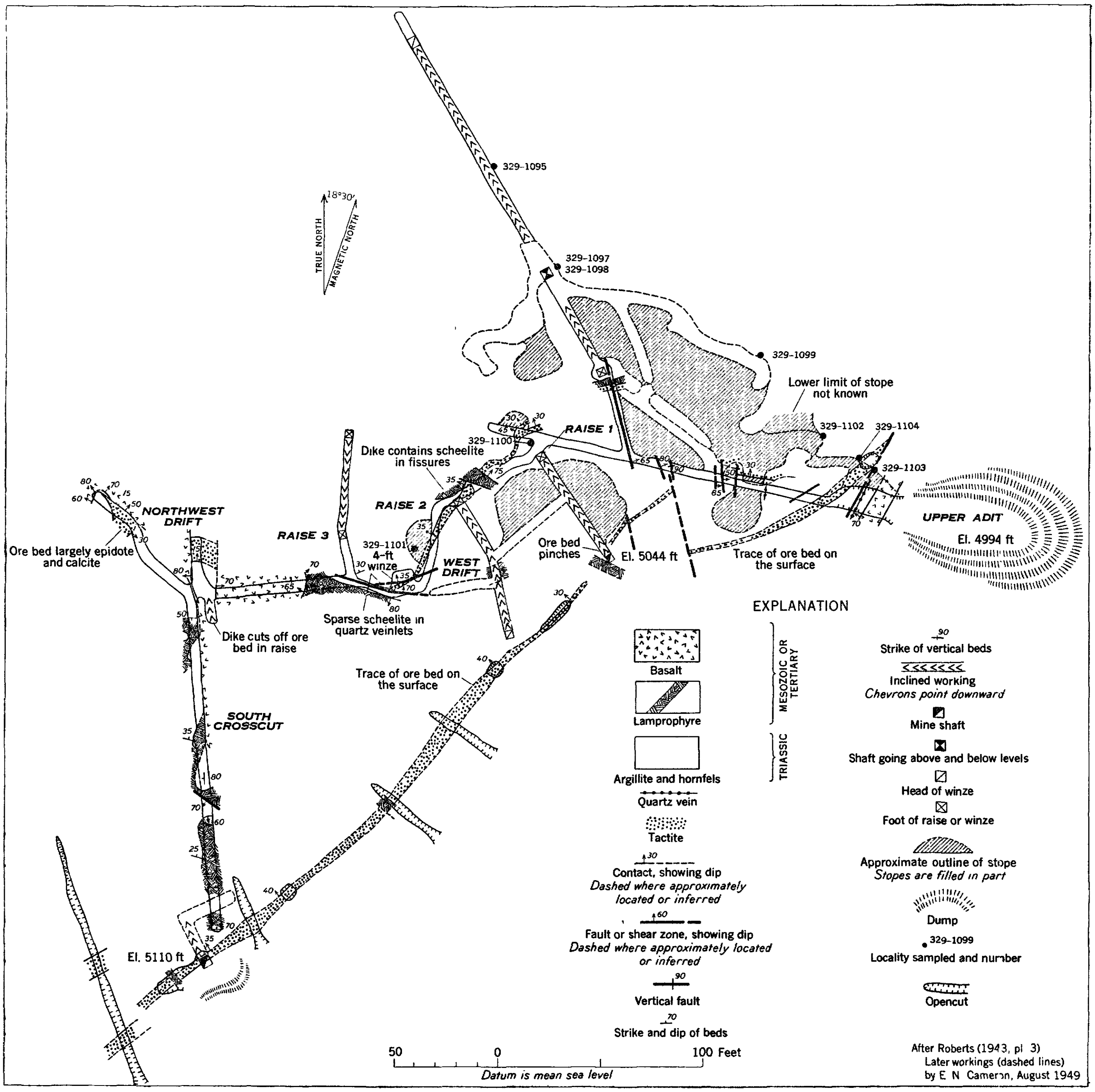


FIGURE 14.—Geologic map of the Rose Creek mine workings, Pershing County, Nev.

diopside, actinolite, feldspar, quartz, calcite, epidote, and zoisite in varying proportions. Minor amounts of other minerals, including sulfides, are present in quartz veins or disseminated through the tactite. Pyrite and chalcopyrite are the common sulfides. The absence of garnet and prominence of pyroxene and amphibole distinguish this deposit from the ordinary tungsten-bearing tactite of the region.

Sampling was done mainly in the underground workings, because surface exposures are poor. One sample each of silicated marble and granite was obtained from surface outcrops. Sampling data are given in table 33; locations of samples are shown on figures 13 and 14.

Analytical results of the sampling show that parts of the tactite bed contain beryllium in abnormal amounts, but that its distribution in the tactite is quite irregular. For the six tactite samples analyzed the range in BeO content is from 0.0032 percent to 0.024 percent, the average being about 0.007 percent. The average BeO content of the rocks may, of course, differ markedly from this in view of the small number of samples taken. The beryllium-bearing mineral is not known.

TABLE 33.—*Beryllia in samples from the Rose Creek mine*

Sample	*Description*	BeO (*percent*)
329–1095	Chip sample across full width of tactite (21–32 in.), northeast wall of winze, 80–85 ft above bottom	0.0033
1097	Chip sample across full width of tactite (16–29 in.), intersection of sublevel and winze	.024
1098	Chip sample of 3-ft thickness of quartzite overlying tactite at locality of 329–1097	.0015
1099	Chip sample across full width of tactite (15 in.) at east end of sublevel	.0074
1100	Chip sample across full width of tactite (13 in.), junction of upper adit and raise No. 1	.0042
1101	Chip sample across full width of tactite (13 in.), underhand stope, upper adit level, 25 ft southwest of raise No. 2	.0047
1102	Chip sample across full width of tactite (2.5 ft), east end of stope extending down from upper adit level, 45 ft inside portal	.0032
1103	Chip sample of 5-ft thickness of gray hornfels, footwall of tactite, portal of upper adit	.0013
1104	Chip sample of black hornfels overlying tactite, opencut at portal of upper adit	<.0001
1105	Chip sample of silicated marble from ridge southeast of tungsten mine	.0012
1106	Chip sample from granite outcrops southeast of tungsten mine	.0015

Roberts (1943, p. 13) estimated the amount of ore in the mine to be about 6,000 tons but a large part of the ore between the sublevel and the surface appears to have been subsequently removed. It is doubtful that more than a few thousand tons of tactite remains in the mine. That much larger reserves might be disclosed by further development seems unlikely.

RAGGED TOP AREA

The Ragged Top tungsten mine is on the west side of the Trinity Range, in sec. 11, T. 25 N., R. 28 E., Lovelock quadrangle. It is accessible from U. S. highway 40 by about 8 miles of gravel road leading west from Toulon. The mine consists of a series of small shafts, opencuts, adits, and test pits excavated to explore scheelite-bearing tactite deposits along the contacts of limestone and granodiorite.

The mine is described briefly by Kerr (1946a, p. 192) and was mapped during World War II by Ward C. Smith of the U. S. Geological Survey. It is near the southeast edge of an area of granodiorite containing inclusions or pendants of limestone. The limestone patches are contact-metamorphosed, along their margins where in places tactite containing scheelite is formed. Most of the tactite bodies are small but one about 1,000 feet northwest of the mine has a strike length of more than 1,000 feet (fig. 15).

Since Smith's map was made, a series of shallow cuts and trenches has been excavated along the length of the tactite body. These excavations indicate that the body is more complex than was supposed. In trench A (fig. 15) it consists of two principal southeastward-dipping layers of garnet and garnet-diopside tactite separated by a limestone parting. The lower layer of tactite is probably about 15 feet thick, and the limestone parting probably has roughly the same thickness. The upper layer may be as much as 35 feet thick, but this figure includes a few feet of limestone. The lower layer is exposed in trench B, but its thickness of southeastward-dipping beds abutting against granodiorite includes about 4 to 5 feet of tactite in two layers separated by 5 to 6 feet of limestone. The bottom of the lower layer is not exposed, but it probably is not more than a few feet thick. Trench C exposes a single zone of tactite, 18 to 25 feet wide, containing blocks of silicated marble. In cut E a width of 62 feet of tactite is exposed, but the mass appears to be dipping gently to the southeast and may bottom on granodiorite at shallow depth. At the head of the cut it contains a mass of blue limestone and silicated marble. North of this cut the width of tactite decreases and it finally pinches out, though small pods of tactite are present here and there along the granodiorite-marble contact for some distance. Samples taken from the tactite body are described in table 34.

TABLE 34.—*Beryllia in samples from the Ragged Top area*

Sample	*Description*	BeO (*percent*)
329–1182	Chip sample along 110 ft from upper tactite layer (which includes limestone parting) to east edge of trench A	<0.0001
1183	Chip sample covering 8 ft along western end of trench A, from upper part of lower tactite layer	.0016
1184	Chip sample, full width of lower tactite layer, trench B	.0014
1185	Chip sample of silicated marble forming parting 4.5 ft thick between tactite layers trench D	.0005
1186	Chip sample across full width of tactite layer, cut E	.0016
1187	Grab sample of granodiorite from chunks of rock on dump of Ragged Top mine	.0013
1188	Chip sample of tactite from low knoll east of mine road 2,300 ft N. 10° E. of north end of tactite body shown on figure 15	.0019

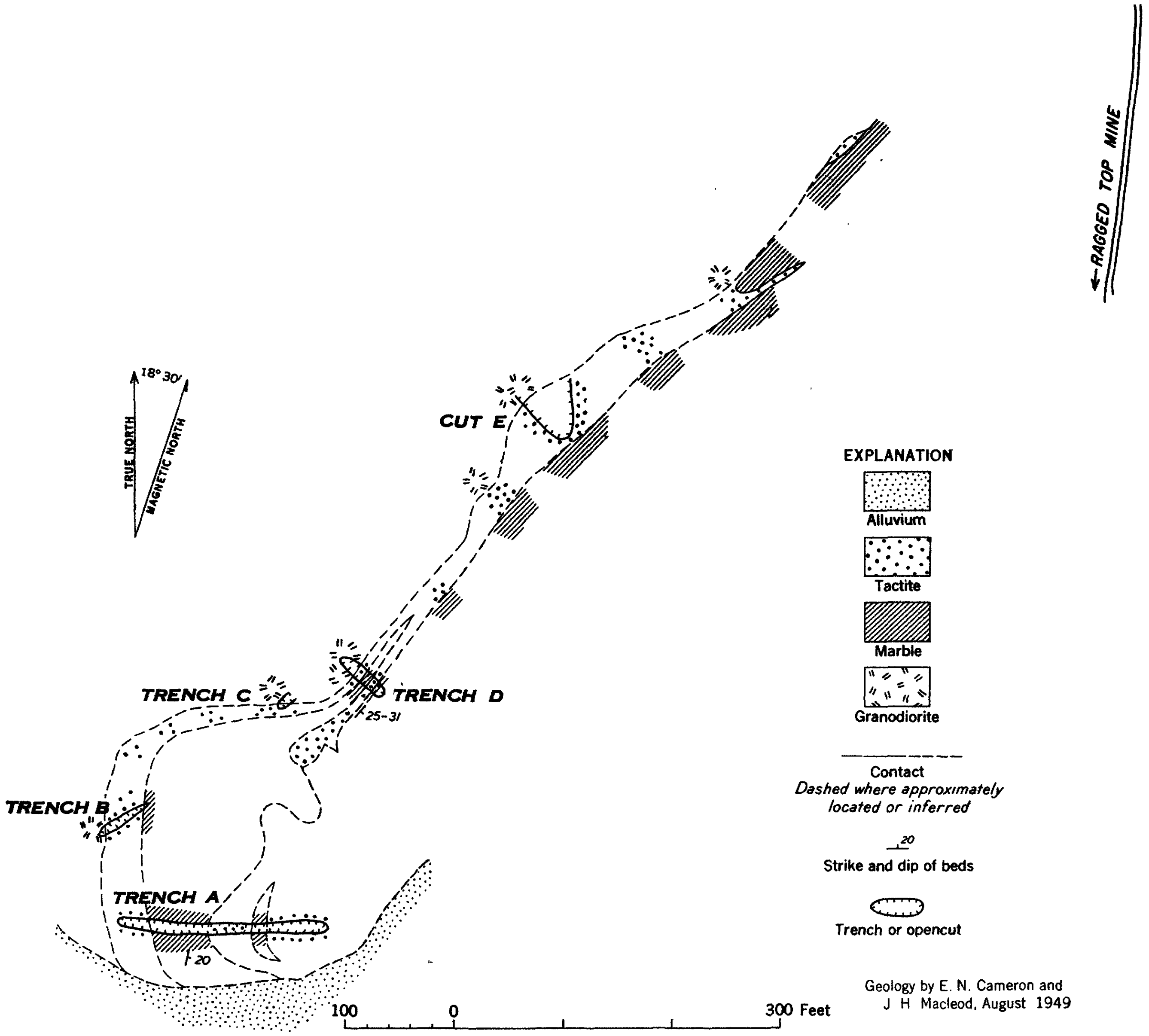


FIGURE 15.—Geologic map of tactite body near Ragged Top mine, Pershing County, Nev.

CHAMPION DUMORTIERITE MINE

The dumortierite mine of Champion Sillimanite, Inc., is near the head of Humboldt Queen Canyon, on the west side of the Humboldt Range, about 5 miles east of Oreana, Nev. A gravel road branching northeastward from the Oreana-Limerick Canyon road gives access to the mine. Geology at the mine has been described by Kerr and Jenny (1935).

Dumortierite occurs in two zones of andalusite-quartz-albite-sericite rock. These rocks are most abundant on the north side of Humboldt Queen Canyon. The zones are about 225 feet apart, stratigraphically; they strike N. 10° to 20° E. and have an average dip of about 40° W. The rocks of the two zones have been described as schists, but they are mostly gneisses with subordinate mica.

According to Kerr and Jenney (1935), the andalusite was formed by replacement of tuffaceous schist and the dumortierite by replacement of andalusite. Dumortierite in the western zone is largely in veinlets, some of which contain quartz. A small amount of prospecting in this zone has failed to discover sizable bodies of dumortierite.

The mine workings are in the eastern zone, which is roughly 60 feet thick. They extend from the canyon bottom up the north side of the canyon for about 1,000 feet, through a vertical distance of about 600 feet. The lower part of the workings, extending from the canyon floor upward through a vertical distance of about 270 feet, appear to have furnished all the production. The workings, which consist of opencuts and, at various levels adits leading to inclined stopes, extend as much as 600 feet into the canyon wall. Most of the stopes are inaccessible.

Owing to the poor condition of the workings and the lack of satisfactory cross-sectional exposures, systematic sampling was not attempted. The samples collected and analyzed are described in table 35.

TABLE 35.—*Beryllia in samples from the Champion mine*

Sample	*Description*	BeO (*percent*)
329–1108	Chips from various blocks of lavender dumortierite-bearing rock on the dumps, main workings	0.0011
1109	Chips from various blocks of andalusite-bearing rocks on the dumps, main workings	.0006
1110	Chips from various blocks of pink dumortierite-bearing rock on the dumps, main workings	.0013
1129	Chip sample across full width of the east zone, from exposures above the uppermost stope and its connected opencut	<.0001

WHITE PINE COUNTY

CHERRY CREEK DISTRICT

The tungsten deposits of the Cherry Creek district are in the Egan Range, west and northwest of the town of Cherry Creek. They are in a northeastward-trending belt extending more than 2½ miles southwestward from a point northeast of the Ticup mine. The main part of the belt, which is in the vicinity of the Ticup mine, has been mapped and described briefly by M. R. Klepper (1943, fig. 3).

The belt is underlain by northwestward-dipping interbedded limestone and shale resting on quartzite. In the Ticup mine area, the mineralized parts of the belt lie mostly northwest of a northeast-trending silicified fault zone. Tungsten mineralization appears to be related both to the fault zone and to certain shattered limestone units. The mineralized beds and the fault zone converge southwestward toward the Ticup mine area, where the principal tungsten deposits are located.

HAPPY CLAIMS

The Happy claims are in limestone southwest of the area mapped by Klepper, presumably in the same general mineralized belt. In 1949 they were being explored and mined on a small scale by the Cherry Creek Tungsten Mining Corp. The claims lie between the Cherry Creek-Arthur road and the Ticup mine area and are accessible by a good mine road that turns northeastward from the Cherry Creek-Arthur road a few hundred yards southeast of the pass over the Egan Range.

The deposits on the Happy claims are in a shattered zone in westward-dipping blue-black limestone; the zone trends roughly north and is traceable for at least 400 feet along the axis of the ridge in which the mine workings lie. The limestones are irregularly mineralized with quartz, calcite, and minor amounts of scheelite. The ore bodies apparently consist of more heavily mineralized parts of the zone that contain scheelite in minable amounts and are large enough to warrant exploration.

There are two ore bodies, both near the south end of the crest of the ridge. The west ore body, reportedly worked during World War I, was mined by an irregular opencut 30 feet long. The ore consisted of extremely coarse calcite with quartz and scheelite. Little ore remains, and the deposit was not sampled.

The ore body being mined in 1949 is northeast of the west ore body and appears to be connected with it by small irregular stringers of calcite and quartz. Mining is chiefly from an opencut 60 feet long. At its north end the cut leads to an inclined stope trending northwest. The ore body dips steeply eastward and appears to have been highly irregular in outline. In the inclined stope it is a more regular veinlike body striking N. 5° W. and dipping 42° E. It consists of quartz, calcite, and accessory scheelite. The average grade of ore in the stope is reported to be about 1.5 percent WO_3. Sampling data for the Happy claims are shown in table 36.

TABLE 36.—*Beryllia in samples from the Happy claims*

Sample	*Description*	BeO (*percent*)
329–1024	Chip sample of ore from walls of inclined stope	0.0009
1025	Fines scooped up from floor of stope	<.0001
1035	Sample of table concentrates from about 400 tons of ore	<.0001
1038	Sample of tailings from about 400 tons of ore	<.0001

CHERRY CREEK MINE

The Cherry Creek mine consists of workings south and southeast of the Ticup mine. Three types of scheelite ore bodies have been mined, and they are known as the "A" ore body, the "B" ore body, and the quartzite ore body. The "A" body is a pipe-shaped ore shoot reported to contain from 1 percent to 3 percent WO_3. The shoot lies along the contact between dense, light-gray limestone and blue-black limestone. The ore consists of varying proportions of coarse calcite, quartz, and scheelite, cementing silicified limestone. The pipe apparently formed at the intersection of northwest-trending fissures with a shattered zone in the limestones. The shoot is surrounded by an envelope of low-grade ore of unknown thickness reported to contain about 0.5 percent WO_3. A dump sample (329–1034) of this ore contained less than 0.0001 percent BeO.

The "B" ore body consists of a series of podlike lenses of shattered and mineralized blue-black limestone. Two lenses were examined and sampled. These are the southernmost body shown on Klepper's map and an adjacent body to the northwest that did not crop out. One sample of ore-bearing limestone was obtained from each of the lenses (samples 329–1028 and –1029). Each contained 0.0007 percent BeO.

The quartzite ore body is mostly on the northwest side of the silicified fault zone that extends southwestward from the Ticup mine area. The hanging wall of the body is of limestone and the footwall is of quartzite. The ore body is reported to have been traced for more than 3,000 feet on the surface, and the ore is largely low grade, containing about 0.5 percent WO_3. A sample (329–1031) of fines from the floor of a stope in the quartzite ore body continued less than 0.0001 percent BeO.

A considerable tonnage of tailings has been settled in various parts of the valley below the company's mill in Cherry Creek Canyon. Two samples of tailings (329–1036 and –1037) representing large tonnages of ore from the "A" and "B" ore bodies were taken. They did not contain as much as 0.0001 percent BeO.

SNAKE RANGE

SACRAMENTO PASS MINE

The Sacramento Pass mine is in sec. 18, T. 15 N., R. 68 E., one-fourth of a mile south of U. S. Highway 6, and 2.5 miles west of Sacramento Pass. The deposit consists of two shattered beds of limestone of Cambrian age that dip 20° to 25° W. The shattered parts of the beds have been cemented by a varying mixture of quartz and calcite, with small amounts of scheelite. In the more markedly mineralized parts of the beds, fragments of limestone have been silicified to varying degrees. A small tonnage of scheelite has been recovered. Scheelite occurs as coarse crystals in quartz, with which coarse calcite is assocated, and in adjacent silicified limestone. The mineralization was highly erratic, and there is no well-defined ore body.

The workings consist of an inclined stope and a small irregular cut near the north end of a ridge. Prospect pits have been dug on the ridge crest south of the workings, and an adit and at least two shafts enter the west slope of the hill. The adit and a connecting shaft were accessible but showed only stringers of quartz and carbonate. The principal scheelite ore body, and apparently the only one at all productive, is in the inclined stope, which is probably in the upper of the two limestone beds.

A single chip sample (329–1000) was taken of various types of vein material at a number of points along the face of the inclined stope. A piece of altered limestone was included. The sample contained 0.001 percent BeO.

DIRTY SHIRT MINE

The Dirty Shirt mine is on the west slope of the Snake Range, one-fourth of a mile north of Mary Ann Canyon in sec. 24, T. 14 N., R. 67 E., southeast of Osceola, Nev. In 1941–43, about 120 units of WO_3 were produced from 100 tons of ore. The workings consist of an incline nearly parallel to the dip of the vein, with a small stope southwest for about 50 feet from the upper part of the incline, and small extensions northwest from the incline at two places. At 70 feet below the collar of the incline a drift about 40 feet long has been run southward, and 120 feet below the collar a second drift has been run southward for about 80 feet.

The deposit is a vein that strikes about N. 47° E. and dips about 45° SE. It cuts westerly dipping quartzite, and in places a dark greenish rock locally called "metadolerite" forms the hanging wall. The full thickness of the vein could be seen only at one place, where it is about 10 feet. The vein consists of quartz with varying amounts of calcite, feldspar (probably plagioclase), and minor amounts of scheelite, galena, and possibly various other sulfides. The vein is everywhere partly oxidized; so the original sulfide content may have been somewhat higher than is now apparent.

An adit 650 feet long, driven at a point several hundred feet north of the incline and about 200 feet lower, is considered to be on the same vein. A brief inspection indicated that the vein in this adit ranges from a few inches to at least 6 feet in thickness and is partly in quartzite, partly in "metadolerite." Much of the variation in thickness is due to postmineralization movement along the vein walls, whereby the vein has been pinched out in places. The vein consists of quartz with minor amounts of plagioclase. It appears to contain little if any carbonate, scheelite, or sulfides, and is thus in marked contrast to the vein exposed in the main working.

Chip samples were taken at various places across the exposed parts of the vein in the incline and stopes. As mining centered on the footwall part of the vein and the hanging-wall side was accessible at only one place, the 6 to 8 feet of the vein from the footwall upward is better represented. Sampling data are given in table 37.

TABLE 37.—*Beryllia in samples from the Dirty Shirt mine*

Sample	Description	BeO (percent)
329–1005	Chip sample of parts of vein next to footwall below scheelite ore shoot	0.0008
1008	do	.0006
1007	Same as 1005 but from hanging-wall side	.0008
1009	Chip sample across vein, north wall of incline	<.0001
1010	Chip sample across scheelite ore body	<.0001
1011	Chip sample across vein in pillar separating main stope from incline	<.0001

SAN PEDRO MINE

The San Pedro gold mine is about 2 miles northeast of Sacramento Pass and is reached by a road that branches to the north off Highway 6 at a point a few hundred yards east of the Sacramento Inn. About a mile north of the main highway a road leads northwest up a canyon to the mine.

The workings include adits at three levels. The upper adit is just below the ridge crest and is about 275 feet long. Inclined stopes extend at intervals upward 5 to 30 feet from the adit, and downward for as much as 85 feet. The middle adit is 75 feet lower and intersects the lower parts of the stopes. The third adit which is about 100 feet below the second, was not fully explored, but it appears to be connected by raises to the level above. Surface workings consist of a series of shallow pits, trenches, and shafts.

The mine workings are chiefly in a mineralized zone in fractured quartzite. The zone is more than 900 feet long and at least 180 feet in maximum width. The quartzite dips westerly and is overlain by quartzitic conglomerate, which appears to mark the effective limit of mineralization. Part of the lowest working is in phylite, which may underlie the quartzite, but exposures in the vicinity suggest that the structure of the beds may be far from simple.

The mineralized zone is in fractured quartzite. Quartz veins fractions of an inch to several feet thick have formed along the major fractures that strike N. 55° E. and dip 45° SE. These veins are in places intricately connected by cross veins; thus the mineralized zone ranges from a sheeted lode to a stockwork. There is much variation from place to place in the spacing of the veins. The workings that constitute the gold mine are along what apparently is the thickest and most persistent vein in the zone. The vein ranges from a few inches to 6 feet or more in thickness and in most places it has no sharp contacts but appears to grade outward into shattered quartzite. The veins, so far as accessible, consist solely of quartz.

Chip sample 329–1003 was taken across the main vein from a pillar in the upper adit level. Sample 329–1004 consisted of chips taken at intervals across 40 feet of mineralized zone exposed east of the mouth of the upper adit. Neither contained as much as 0.0001 percent BeO.

MINERVA DISTRICT

The deposits of the Minerva tungsten district are southeast and east of Shoshone, Nev., on the west slope of the Snake Range. Studies by R. F. Stopper [5] and others during world War II indicated that the district has seven principal veins. The veins are thought to occupy normal faults that strike east and dip 45° to 70° N. The fault zones range in width from a few inches to 30 feet and in length from 1,000 to 4,000 feet. Scheelite ore shoots form where a favorable bed, locally called the "upper white limestone," is intersected by the vein. The shoots plunge gently westward. They are of small vertical extent but have pitch lengths as great as 900 feet.

The veins consist of quartz and carbonates (iron-bearing in part) with minor amounts of scheelite and traces of other minerals. Horses and fragments of limestone in various stages of silicification are numerous. Scheelite occurs mostly in the veins but small quantities are found in the enclosing wall rocks. It is closely associated with quartz. The carbonates mainly formed late, occurring along fractures in the other minerals. All veins of the district are offset by postmineralization faults. Sampling data for the three veins examined by Cameron—the Chief, Oriole, and Everit—are shown in table 38.

TABLE 38.—*Beryllia in samples from the Minerva district* [1]

Sample	Description	BeO (percent)
329–1015	Chip sample across full width of Chief vein	0.0008
1019	do	<.0001
1020	Chip sample of mineralized limestone from footwall of Chief vein	<.0001
1021	Chip sample across full width of Oriole vein, lower level	.0007
1022	Same as 1021 but from upper level	.0017
1023	Chip sample across full width of vein, upper level, East Everit mine	<.0001
1016	Tailings, Minerva mill, from mixed ores of Canary Yellow and Chief mines	.0006

[1] Chip samples taken by R. F. Stopper, then manager, Minerva Scheelite Mining Co.

CALIFORNIA

INYO COUNTY

TUNGSTEN HILLS DISTRICT

A series of tungsten deposits of the tactite type occurs in the Tungsten Hills at the east base of the Sierra Nevada about 10 miles west of Bishop, Calif. The deposits have been worked periodically for tungsten since about 1916, and have been described by Knopf (1917), Hess and Larsen (1921, p. 268–274),

[5] Manager of Minerva Scheelite Mining Co. at time of our visit.

Lemmon (1941a), Kerr (1946a, p. 143–145), and Bateman and others (1950, p. 23–42). An investigation of the Mount Goddard and adjoining quadrangles, being completed by Paul C. Bateman, has included remapping and further study of the tungsten deposits, and much information obtained from him is included in the following discussion.

The Tungsten Hills are underlain chiefly by complex intrusive bodies consisting of aplite, aplitic granite, granite, and quartz monzonite. Within this complex are small areas underlain by metamorphic rocks, remnants of the country rocks that were intruded. In the Round Valley, in the northern part of the hills, the metasediments are in contact with granite, but in the Deep Canyon area they lie within areas of darker rocks ranging from quartz diorite to hornblende gabbro.

The metasediments were originally limestones, shales, and sandstones. The limestones have been progressively metamorphosed to gray granular marble, white granular marble, silicated marble, calc-silicate rock, and tactite. The larger areas of metamorphic rocks commonly show all members of the series. The tungsten deposits are in tactite, which forms irregular zones along the contacts of granite and marble, or extends outward along certain beds that were evidently more susceptible to intense silication. Parts of some deposits show interbedded tactite, marble, and calc-silicate rock. The tactites appear to consist mainly of garnet, diopside, quartz, calcite, and epidote in varying proportions; garnet-rich and diopside-rich tactite rocks are the most common types. In places, amphibole, apatite, sphene, and sulfides are found. Scheelite is present in disseminated grains and in veinlets with quartz or quartz and garnet. The calc-silicate rocks are mostly fine grained, and their mineralogy is for the most part uncertain, but apparently similar to that of the tactite; some beds contain idocrase. The shales have been metamorphosed to hornfels and the sandstones to quartzite.

The tactite deposits and associated metasedimentary rocks are found in two principal areas: the Deep Canyon area in the south-central part of the hills, and the Round Valley area at the northwest edges of the hills.

DEEP CANYON AREA

In the Deep Canyon area there are two groups of deposits, one is along the north fork of Deep Canyon in the northern part of sec. 12, T. 7 S., R. 31 E., and the second lies partly in sections 11, 12, 13, and 14 (Lemmon, 1941a, pl. 73). The principal group of tungsten deposits is in the southern group, which occupies an area about a mile long and 1,000 to 2,000 feet wide. The long axis of the area trends east. It includes the Lucky Strike, Little Sister, and Aeroplane (Moonlight) mines, and the Tiptop claims. The tungsten workings are in metasedimentary bodies ranging from 35 feet to more than 1,000 feet in maximum dimension. These bodies Bateman regards as inclusions. Most of the inclusions are in an irregular belt of diorite and gabbro extending from the Lucky Strike mine at the west end of the area to the Aeroplane mine at the east end. The rock north and south of this belt is quartz monzonite.

Little Sister mine.—The main working at the Little Sister mine is a glory hole about 300 feet long, 180 feet in maximum width, and 150 feet in maximum depth. An adit at a level about 40 feet below the bottom of the glory hole leads to a series of drifts and a winze. Raises from the drifts have been used to draw the ore mined from the glory hole.

The workings explore a body of tactite, marble, and calc-silicate rock. According to Lemmon's plan of the mine (1941a, pl. 75), this body is 1,270 feet long and 230 feet in maximum width at the surface, but it narrows downward and at adit level is only 200 feet in length and 180 feet in maximum width. The underground workings indicate that it is completely surrounded by diorite at adit level. The southeast contact is a fault. The diorite around the inclusion is a coarse-grained biotite-hornblende-plagioclase rock. In places it is rich in epidote for distances of a few inches to a few feet from the contact.

The rock mined in the glory hole and explored by the underground workings is mainly tactite. The beds strike northwest and are nearly vertical. Garnet-rich tactite is the predominant type, but some layers are rich in quartz, diopside, and epidote. One lens of calc-silicate rock was noted. Sampling was done along a northeast line extending from the inner end of the short tunnel in the east wall of the working across the glory

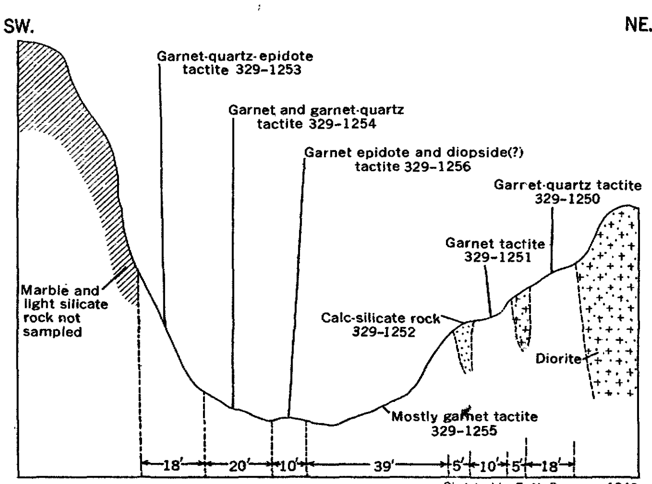


FIGURE 16.—Sketch cross section of glory hole, Little Sister mine, Tungsten Hills, Calif., showing rock units sampled.

hole approximately at right angles to its length. The rocks were subdivided into units as shown in figure 16; sampling data are given in table 39.

TABLE 39.—*Beryllia in samples from the Little Sister mine*

Sample	Description	BeO (percent)
329-1250	Chip sample across 18-ft thickness of garnet-quartz and garnet-quartz-epidote tactite	0. 0024
1251	Chip sample across 10-ft layer of garnet tactite	. 0019
1252	Chip sample across layer of calc-silicate rock 5 ft in maximum thickness	. 0017
1253	Chip sample across quartz-garnet and quartz-epidote tactite, 18 ft thick	. 0019
1254	Chip sample across garnet and garnet-quartz tactite, 20 ft thick. Sample includes only 10 ft of this thickness; remainder inaccessible	. 0021
1255	Chip sample across garnet tactite, 39 ft thick	. 0036
1256	Chip sample across 10-ft thickness of garnet, epidote, and diopside(?) tactite	. 0022
1257	Chip sample across lens of silicated marble in central part of glory hole, north of line of section (about 15 ft thick and 30 ft long)	<. 0001
1305	Chip sample of epidotized quartz diorite from east margin of inclusion at east edge of glory hole	<. 0002
1306	Chip sample of unaltered quartz diorite from tunnel in east wall of glory hole	<. 0001

Aeroplane (*Moonlight*) *mine*.—The Aeroplane mine is near the summit of the ridge on the southeast side of the south fork of Deep Canyon. It is in a crescent-shaped northeast-trending inclusion of metasedimentary rocks that is bounded on the west and northwest by gabbro and diorite, on the northeast and southwest by quartz monzonite, and on the southeast by a body of aplitic granite and aplite. The main working is a north-trending glory hole about 175 feet long, 35 to 50 feet wide, and more than 100 feet in depth. An 80-foot adit driven from the west slope of the hill intersects the west wall of the glory hole about 30 feet below the rim, and a 440-foot adit has been driven southeastward beneath the glory hole at a level about 170 feet below the rim. An inclined raise from this adit to the glory hole evidently was used to draw ore.

Lemmon's cross section of the Aeroplane mine (1941a, fig. 72) shows the main body of tactite as a layer 30 to 35 feet thick enclosed in feldspathic rock that resembles quartzite. Contacts between these units strike north and dip steeply west. In the upper adit a second body of tactite is exposed for about 25 feet inward from the entrance, where it is in fault contact with the quartzite overlying the main tactite body. The quartzite is more than 100 feet thick at the level of the upper adit, but in the lower adit the quartzite is cut off by quartz diorite about 20 feet west of the main tactite body. As exposed in the lower adit, the quartzite is mostly a fine- to medium-grained rock composed principally of biotite, quartz, and plagioclase.

Because the tactite body at the main workings is largely inaccessible, no attempt was made to sample the full thickness. A few feet inside the west margin of the tactite body in the lower adit, a 6-foot thickness of calc-silicate rock, including 2 feet of alternating layers of wollastonite-rich and garnet-rich rock, is exposed. A sample was taken for comparison with silicated limestones obtained at other localities. Sampling data for the Aeroplane mine are given in table 40.

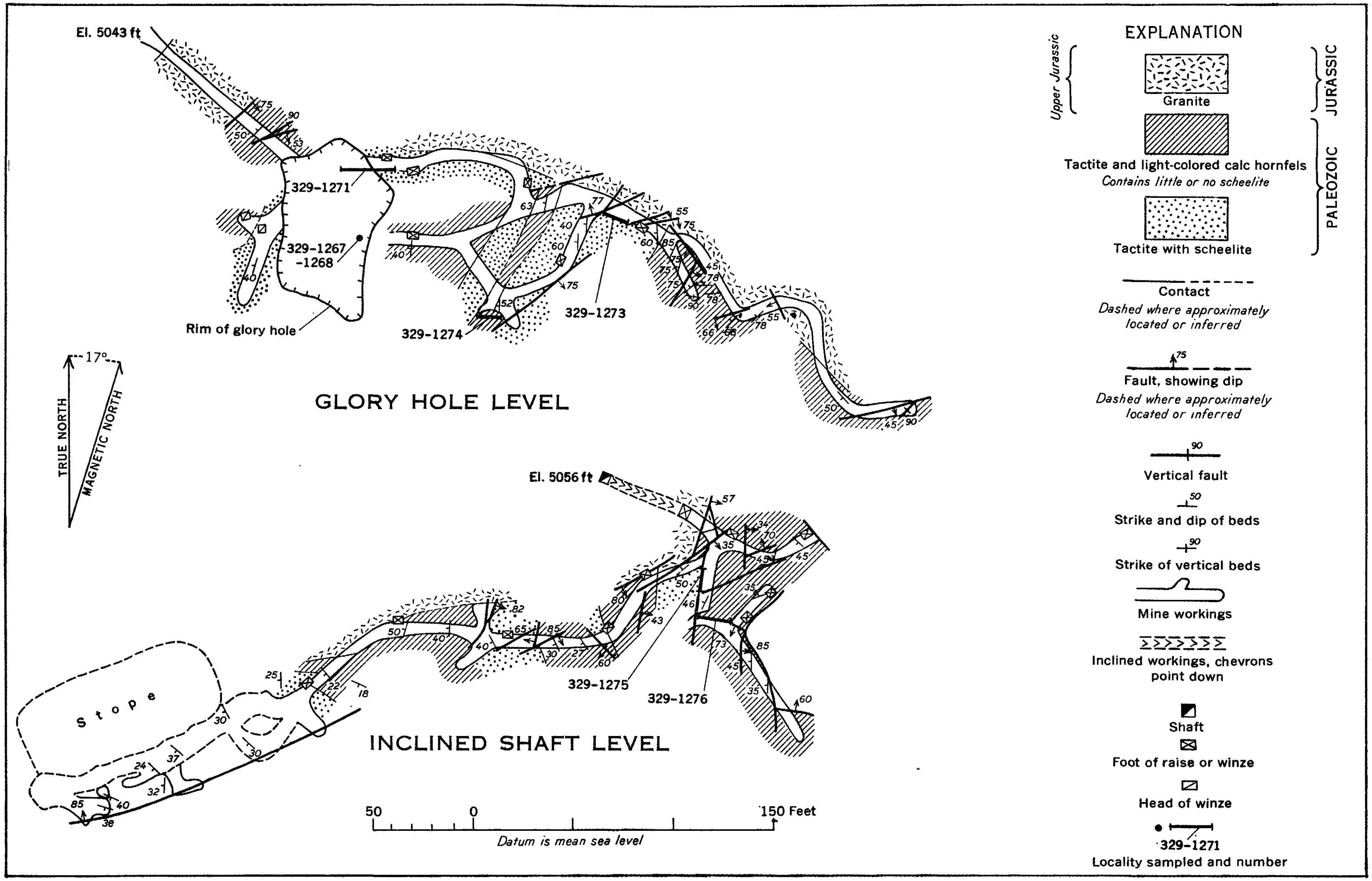
TABLE 40.—*Beryllia in samples from the Aeroplane mine*

Sample	Description	BeO (percent)
329-1292	Chip sample across full width of quartzite, lower adit. Coarser dioritic material not included in sample	0. 0001
1293	Chip sample of quartz diorite, lower adit. Chips taken at 2-ft intervals for 40 ft west of contact with quartzite	. 0001
1294	Chip sample across full width of calc-silicate rock, west margin of tactite body, lower adit	. 0001
1303	Chip sample of aplitic granite from summit of hill above Aeroplane mine	. 0001
1304	Chip sample of quartz diorite from outcrops about 100 yd southwest of glory hole	. 0001

ROUND VALLEY AREA

In the Round Valley area metasedimentary rocks form a pendant 600 to 1,000 feet wide and about 4,000 feet in exposed length. The pendant trends east-northeast and is surrounded by granite (Lemmon, 1941a, pl. 74). According to Lemmon, the pendant is composed mainly of mica schist but includes some tactite and limestone. There are two mines in the pendant: the Western Tungsten Co. mine in the western part, and the Round Valley mine in the eastern part. The Round Valley mine is the larger of the two mines and offers the better exposures. Sampling was, therefore, restricted to this mine and its immediate vicinity.

The workings at the Round Valley mine are in two groups. The western and more productive group consists of three adits, a glory hole, and an inclined shaft, with appended underground workings. These workings were driven for exploration and mining of two westward-dipping tactite beds. The workings are along the northern edge of the pendant of metasedimentary rocks and extend southward into the pendant. The upper adit, at altitude 5,093 feet, leads to underground workings in the upper part of the lower tactite bed and the enclosing rocks. The middle adit, at altitude 5,043 feet, intersects the bottom of the glory hole, which is in the upper tactite bed, and extends southeastward to the workings on this level in the lower tactite bed. A southeasterly extension of these workings follows the faulted contact of granite with the pendant. The inclined shaft leads to a level with drifts and inclined stopes on the upper tactite bed. The stopes extend both above and



After unpublished map by P. C. Bateman and M. P. Erickson

FIGURE 17.—Geologic map showing glory hole level and inclined shaft level of the Round Valley mine, Inyo County, Calif.

below the level, which is at altitude 4,997. The lower adit connects with these workings at a point southwest of the incline. The beds are much faulted and are difficult to trace in some parts of the mine. The middle adit level (glory hole level) and the level developed from the inclined shaft, which are the most important of the western workings, are shown on figure 17.

The eastern workings consist of three adits and appended underground workings that expose a third tactite bed. This bed dips westward and is stratigraphically below the tactite beds in the western workings. The two upper adits are short; the lower and main adit is about 175 feet long and leads to drifts, a winze, and several raises (see fig. 18).

The rocks explored by the workings are a varied assemblage of blue limestone, white to gray marble and silicated marble, calc-silicate rock, calc-hornfels, and tactite. The general geology of the mine area is shown in figure 19. The rocks are prevailingly thin-bedded and show marked changes in mineral composition across strike.

The beds overlying the upper tactite layer, in order of stratigraphic sequence from top to bottom, are ribbon tactite, consisting of alternating thin layers of garnet-rich and diopside-rich rock, gray to white marble veined by silicates, calc-silicate rock interlayered with tactite, and idocrase-bearing marble. The principal beds of the upper tactite layer are garnet-rich tactite and garnet-diopside ribbon tactite. A spotted tactite bed of undetermined mineral composition is present in the glory hole. The rock underlying the upper tactite layer and separating it from the lower tactite is thin-bedded calcareous shale, largely altered to calc-hornfels. The lower tactite layer is similar in composition to the upper tactite. These rocks constitute a more varied assemblage than those of most tactite

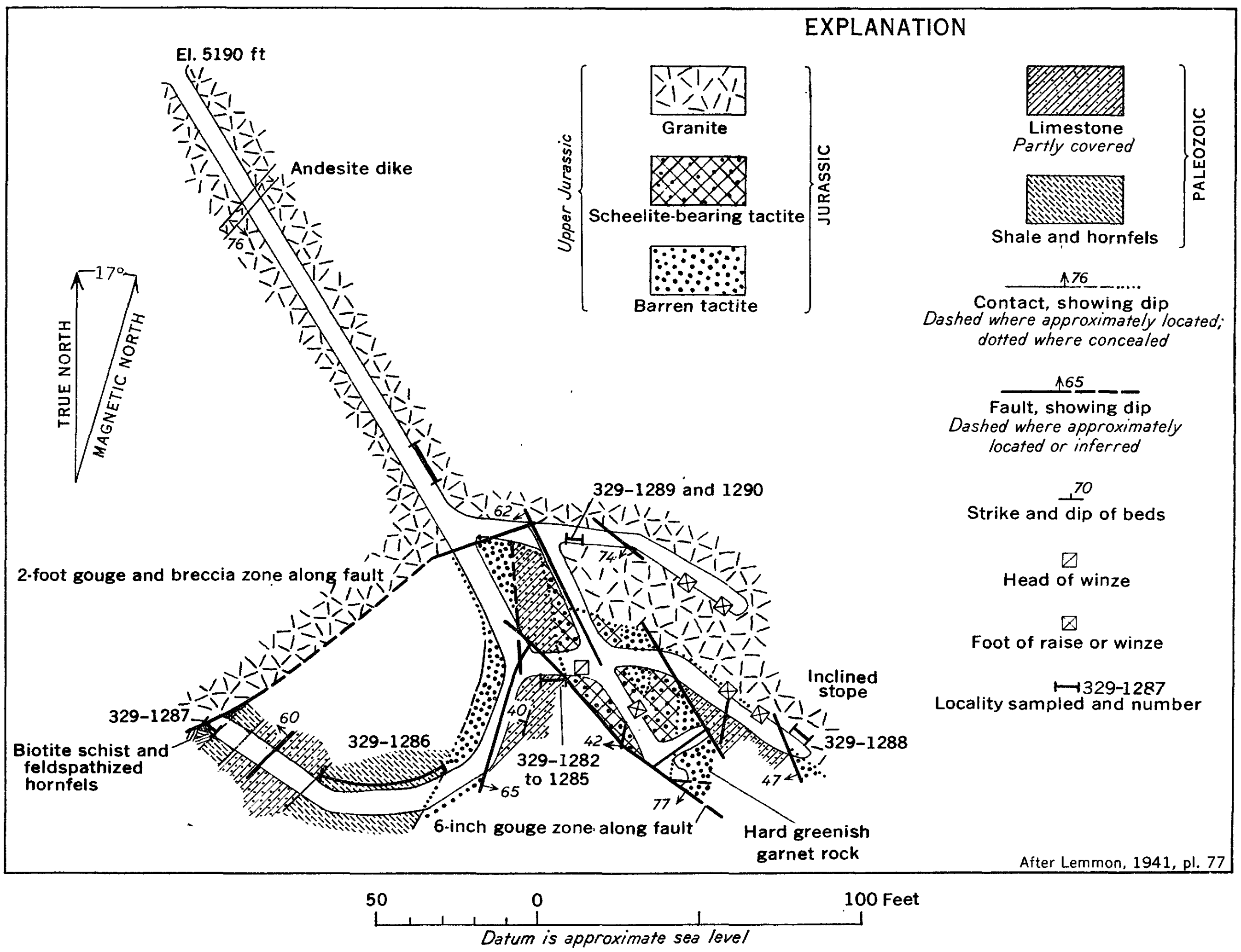


FIGURE 18.—Geologic map of the lower eastern adit, Round Valley mine, Tungsten Hills, Inyo County, Calif.

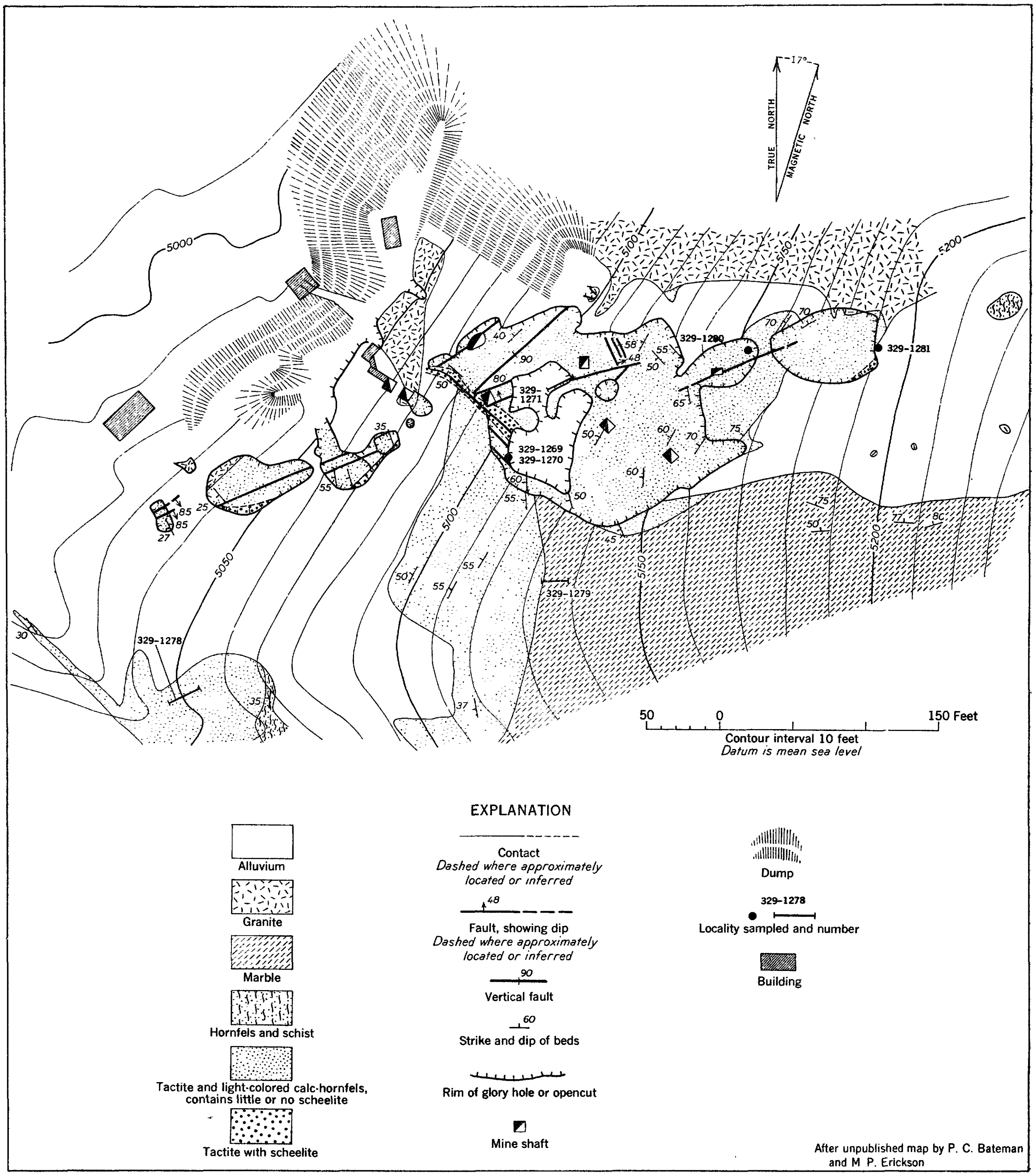


Figure 19.—Geologic map of the Round Valley mine, Inyo County, Calif.

deposits and were, therefore, sampled in detail. The samples are described in table 41.

TABLE 41.—*Beryllia in samples from the Round Valley mine*

Sample	*Description*	BeO (*percent*)
	WESTERN WORKINGS	
	Beds overlying main tactite:	
329–1271	Chip sample across lower 14 ft of interlayered calc-silicate rock and tactite, glory-hole level	<0.0001
1275	Chip sample along three lines at 5-ft intervals across idocrase-bearing marble immediately above tactite, inclined-shaft level	.0024
1278	Chip sample across outcrop of ribbon tactite, 300 ft southwest of glory hole	<.0001
1279	Chip sample across marble outcrop, 50 ft south of glory hole	<.0001
	Beds of main tactite zone:	
329–1269	Chip sample at intervals across spotted tactite layer, southwest wall of glory hole	.0045
1270	Chip sample across garnet-diopside tactite, southwest wall of glory hole	<.0001
1272	Chip sample across garnet diopside ribbon tactite, north side of glory hole	<.0001
1276	Chip sample across garnet tactite, inclined shaft level	.0019
	Beds underlying main tactite:	
329–1267	Chip sample of 7½ ft of calc-hornfels, east side of glory hole at adit level	.0006
1268	Chip sample of 7½ ft of calc-hornfels immediately below beds of sample 329–1267	.0003
1280	Chip sample of 10-ft thickness of calc-hornfels from shallow cut at northeast edge of glory hole	.0017
	Lower tactite zone:	
329–1273	Chip sample across 7-ft thickness of banded garnet-diopside tactite, glory-hole level	<.0001
1274	Chip sample of 15-ft thickness of calc-silicate rock containing coarse patches of light-pink garnet, glory-hole level	.0018
1281	Grab sample of garnet-tactite from dump of small glory hole east of main glory hole	.0017
	LOWER EASTERN ADIT	
329–1282	Chip sample across 55 in. of fine-grained garnet tactite containing a few thin layers of calc-silicate rock	<.0001
1283	Chip sample of thinly laminated light calc-silicate rock, 25 in. thick	<.0001
1284	Chip sample across 37 in. of thinly laminated limestone, poorly silicated	<.0001
1285	Chip sample across 41 in. of thin, alternating tactite and calc-silicate rock	<.0001
1286	Chip sample across entire thickness of shale and hornfels	<.0001
1287	Chip sample across 5-ft thickness of biotite schist (feldspathized hornfels)	<.0002
1288	Chip sample of granite, 1 to 5 ft from fault contact with limestone	.0001
1289	Chip sample of granite showing full textural range from aplite to fine-grained pegmatite	.0007
1290	Chip sample of vaguely defined dike of aplite, 2 ft wide	.0011

RESULTS OF SAMPLING

As in adjacent districts, the results of the sampling show that beryllium occurs somewhat more abundantly in tactite than in other rocks. In general however, the beryllium content of tactite deposits in the Tungsten Hills is low and compares to that of tactite deposits in the Mill City district, Nevada. The production of tungsten in both districts has been large and, inasmuch as tungsten and beryllium tend to be associated in tactite deposits, the scarcity of beryllium is puzzling. At the Round Valley mine the presence of idocrase and the occurrence of ribbon tactite that is structurally, though not mineralogically, similar to that at Iron Mountain, N. Mex., might be taken as indicators of helvite, but none was found. Only two samples from the Tungsten Hills—329–1255 from the Little Sister mine and 329–1269 from the Round Valley mine—contained more than 0.0025 percent BeO. These samples contained 0.0036 and 0.0045 percent BeO, respectively, and reserves of these grades probably are small. Because of the large number of samples taken at the two mines, there seems small hope that larger deposits of better grade would be revealed by further sampling. Though sampling at the Aeroplane mine was less extensive, the fact that beryllium was not detected in any of the samples collected is discouraging.

PINE CREEK DISTRICT

PINE CREEK TUNGSTEN MINE

The Pine Creek tungsten mine is in the northern part of the Mount Goddard quadrangle, 1 mile southeast of Mount Morgan, in the Sierra Nevada. The mine is reached from Bishop, Calif., by way of U. S. Highway 395 to Round Valley and thence by paved and gravel roads. The history of the mine and discussions of the tungsten-molybdenum-copper ore bodies have been given by Lemmon (1941b, p. 89–91) and by Bateman (1945). The deposits have been worked intermittently since 1916. Operations since 1938 have been conducted by U. S. Vanadium Corporation. A visit to the mine was made with Bateman on August 26, 1949.

The ore bodies are in a contact zone between marble and intrusive quartz diorite. The contact zone consists mainly of garnet-diopside tactite but includes quartz-epidote tactite, quartz, and quartz-feldspar rocks. Thicker parts of the contact zone constitute the ore bodies. The ore minerals are scheelite and molybdenite, with minor amounts of chalcopyrite and bornite. Gangue minerals are quartz, garnet, diopside, epidote, and feldspar. Five ore bodies crop out in the area of the Pine Creek mine. All contain tungsten in commercial amounts but only the North and South ore bodies contain molybdenum in important quantities. The geology in the vicinity of these two ore bodies is shown in figure 20.

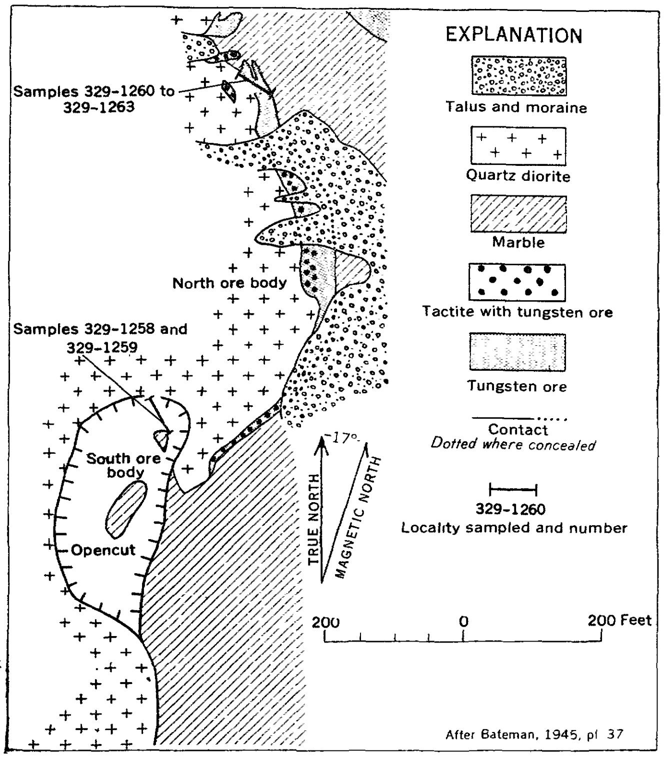


FIGURE 20.—Geologic map of part of Pine Creek mine area, Inyo County, Calif.

The South ore body is in a prong of altered marble that extends into the quartz diorite. In the opencut the ore body is 300 feet long and 150 feet wide; its width diminishes with depth. The ore dips steeply east and rakes 60° S. Near the center of the body are two horses of calc-silicate rock and silicated marble. The North ore body is largely covered.

Sampling data for the Pine Creek mine are given in table 42; locations of samples are shown on figure 20.

TABLE 42.—*Beryllia in samples from the Pine Creek mine*

Sample	*Description*	BeO (*percent*)
329–1258	Chip sample across silicated marble, 35 ft thick	0.0016
1259	Chip sample across tactite beds, 12 ft thick	.0018
1260	Chip sample across 10 ft of silicated marble adjoining the tactite	<.0001
1261	Chip sample across tactite layer	.0037
1262	Chip sample of quartz diorite next to tactite	.0044
1263	Chip sample across 15-ft thickness of marble forming east wall of ore body	.0014

TAILINGS FROM MILL OF TUNGSTAR MINE

The Tungstar mine is on the west shoulder of Mount Tom, at an altitude of 12,000 feet, in the northern part of the Mount Goddard quadrangle. The mine was worked for tungsten in the early 1940's, and the tactite ore was milled in Pine Creek Canyon below the mine. The mine is closed and the mill has been destroyed, but the tailing dumps remain. Two samples were taken. Sample 329–1265, consisting of handfulls of material taken at intervals along the edge of the main and older pile of tailings, contained 0.0058 percent BeO. A similar sample (329–1266) from the newer pile of tailings contained 0.0021 percent BeO.

YANEY TUNGSTEN PROSPECT, BISHOP DISTRICT

The Yaney prospect is at the base of the Sierra Nevada, about 5 miles southwest of Bishop, Calif. Workings consist of an opencut leading to irregular stopes in the upper part of the deposit, and an adit, at a level about 50 feet lower, leading to drifts. A brief inspection of the deposit was made with Paul C. Bateman, on August 29, 1949. Bateman furnished the information on which the following description is based.

The workings are in an altered tactite deposit along the contact of metasedimentary rocks and granite. Apparently the deposit originally was an assemblage of tactite and silicated limestone beds similar to those exposed in the deposits of the Tungsten Hills to the west. Subsequently, parts of the deposit were altered to a mixture of friable opaline silica, ocher, and jarosite, in various proportions. Alteration has been intense in places, and large masses of the alteration products are present. Some of the altered material contains crystals of ferberite 1/32 to 1/2 inch in diameter which are apparently pseudomorphs after scheelite. The average grade of the ore is about 1 percent WO_3. Unaltered tactite is exposed in the lower workings, but it is barren of scheelite. In places the tactite is altered to a clayey material. Samples taken at the prospect are described in table 43.

TABLE 43.—*Beryllia in samples from the Yaney prospect*

Sample	*Description*	BeO (*percent*)
329–1295	White opaline material, entrance cut, upper working	<0.0001
1296	Jarositic material with ferberite, entrance cut, upper working	<.0001
1297	Ocherous material, entrance cut, upper working	<.0001
1298	Ferberite-rich material, entrance cut, upper working	<.0001
1299	Clayey material, lower workings	<.0001
1300	White opaline material, ferberite free, lower level	<.0001
1301	Unaltered tactite, lower level	<.0001
1302	Nearly unaltered calc-silicate rock, lower level	<.0001

SAN BERNARDINO AND KERN COUNTIES

ATOLIA DISTRICT

The Atolia mining district in southeastern California straddles the boundary between San Bernardino and Kern Counties. Paved roads connect the district with Randsburg and Johannesburg, 4 miles to the north, and with Kramer, 23 miles to the south. Tungsten was discovered in the area in 1904, and placer and lode mining have been carried on intermittently. In late August 1949 a few of the mines were being operated on a small scale by men working under leasing arrangements with the Surcease Mining Co. The district has been described by Hulin (1925) and Lemmon and Dorr (1940).

Tungsten is found both in lode deposits and placer deposits. The lode deposits are veins that strike N. 75° E. to N. 75° W. and dip 45° N. to 85° S. Faulting during and after deposition of the minerals has complicated the structure of the deposits. The veins consist of scheelite in a gangue of quartz and carbonates, with pyrite, stibnite, and cinnabar. The scheelite ore bodies occur as steeply raking shoots as much as 1,260 feet in strike length and 1,080 feet in known pitch length. In places the ore is as much as 17 feet thick. The wallrock is quartz monzonite. The placer deposits are concentrations in Quaternary alluvium that blankets the area of the tungsten vein.

UNION MINE

The Union mine, largest producer of the district, has been worked to a depth of more than 1,000 feet. It consists of a series of inclined shafts leading to 14 levels; the main shaft was the only one open at the time of inspection. The workings are drifts, raises, winzes, and inclined stopes in two veins, the North vein and the South vein. The veins strike east-northeast and dip 40°–63° N. In the western part of the mine the veins are as much as 180 feet apart; eastward and downward the veins converge, intersecting at a low angle in the eastern part of the mine. Each vein contains one principal shoot. In the most productive parts of the veins, the strike lengths of the shoots range from 600 feet to about 1,000 feet. Samples taken at the mine are described in table 44.

TABLE 44.—*Beryllia in samples from the Union mine*

Sample	*Description*	BeO (*percent*)
329–1307	Chip sample across full width of north vein; 9th level, 200 ft west of main shaft, small stope upward from level	<0. 0001
1308	Chip sample across 18 in. of wallrock on either side of vein. Same locality as sample 1307	<. 0001
1309	Chip sample across full width of branch vein extending from south vein into hanging wall; 9th level, crosscut about 80 ft east of main shaft	<. 0001
1310	Chip sample across full width of south vein zone (8 ft wide) consisting of shattered quartz monzonite cemented by quartz, carbonates, and scheelite; sublevel between 9th and 10th levels, 200 ft east of shaft	<. 0001
1311	Chip sample across full width of mineralized zone, south vein; stope 100 ft east of main shaft, 40 ft below 9th level	<. 0001
1312	Chip sample across horse of quartz monzonite separating two parts of south vein. Same locality as sample 1311	<. 0001

FLATIRON-SPANISH VEIN SYSTEM

The Flatiron-Spanish vein system is an easterly-trending Y-shaped system of steep northeast-dipping linked veins. The stem of the Y is to the west. The Flatiron vein system forms the stem and south branch of the Y; the Spanish vein forms the north branch. The deposits are in general similar to those of the Union mine.

Two samples were taken in the vicinity of the intersection of the two vein systems. Sample 329–1314 is a grab sample of ore from a stringer two to four inches thick in a small stope. Sample 329–1315 is a grab sample of pieces of high-grade ore from the ore piles. The samples did not contain as much as 0.0001 percent BeO.

ARIZONA

By WILLIAM T. HOLSER

Field investigations for beryllium in nonpegmatite rocks in Arizona were undertaken in August 1949 by W. T. Holser, assisted by W. I. Finch. The districts from which samples were taken are shown on figure 21. Traces of beryllium had been found previously in samples from the pyrometasomatic deposits at the Christmas, Clifton-Morenci, and Old Hat districts; no additional work was done in these areas.

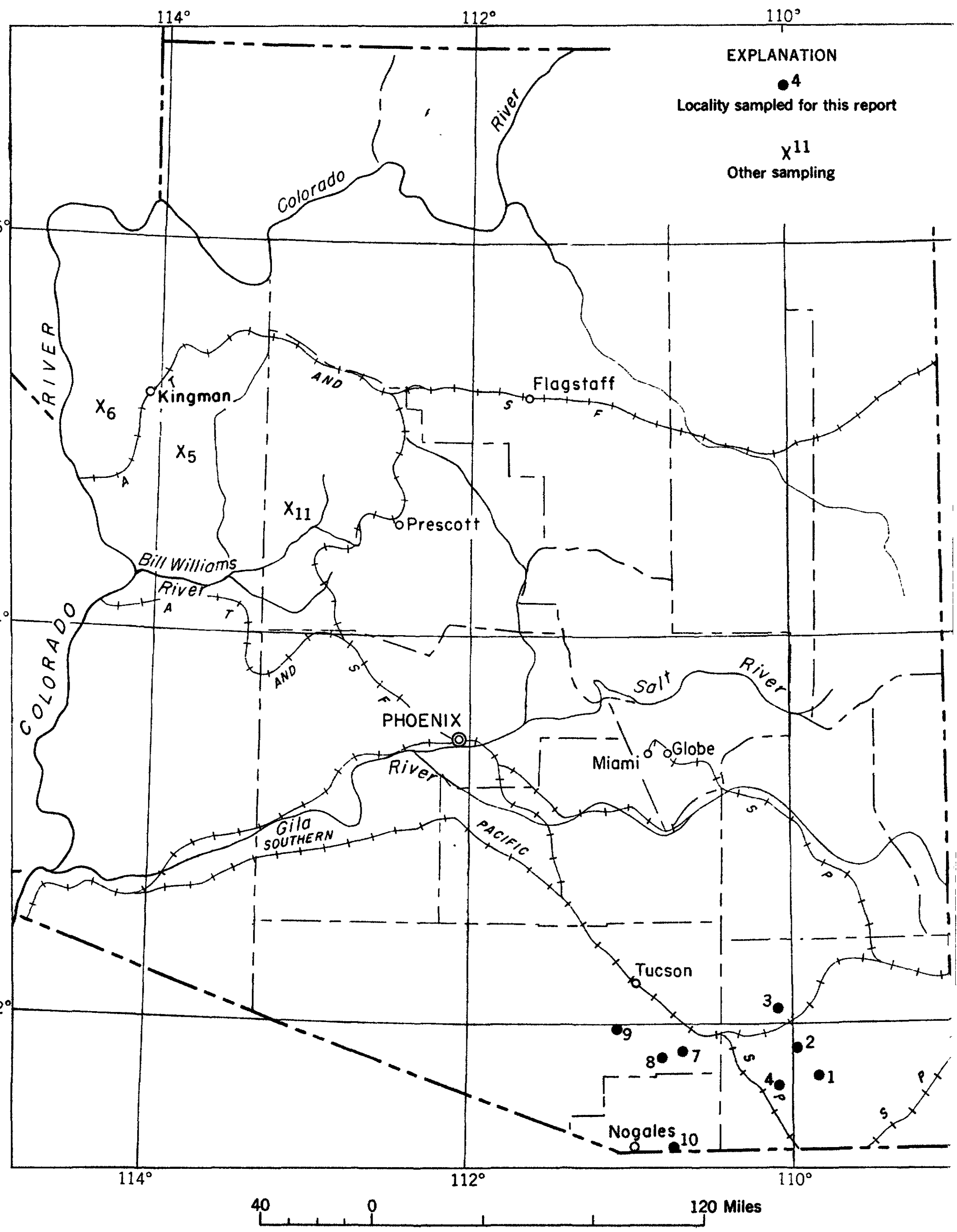
The most promising resources of nonpegmatite beryllium in Arizona are in beryl-bearing tungsten veins at Boulder Creek, Yavapai County; the Tungsten King mine, Little Dragoon Mountains, Cochise County; and the Boriana mine, Mohave County. Previous sampling in the San Francisco district, Mohave County, in connection with the Mine, Mill, and Smelter Survey, indicated the presence of beryllium in epithermal gold-silver veins. The only pyrometasomatic deposits in which beryllium was found are in the Dragoon Mountains, Cochise County.

COCHISE COUNTY

DRAGOON MOUNTAINS

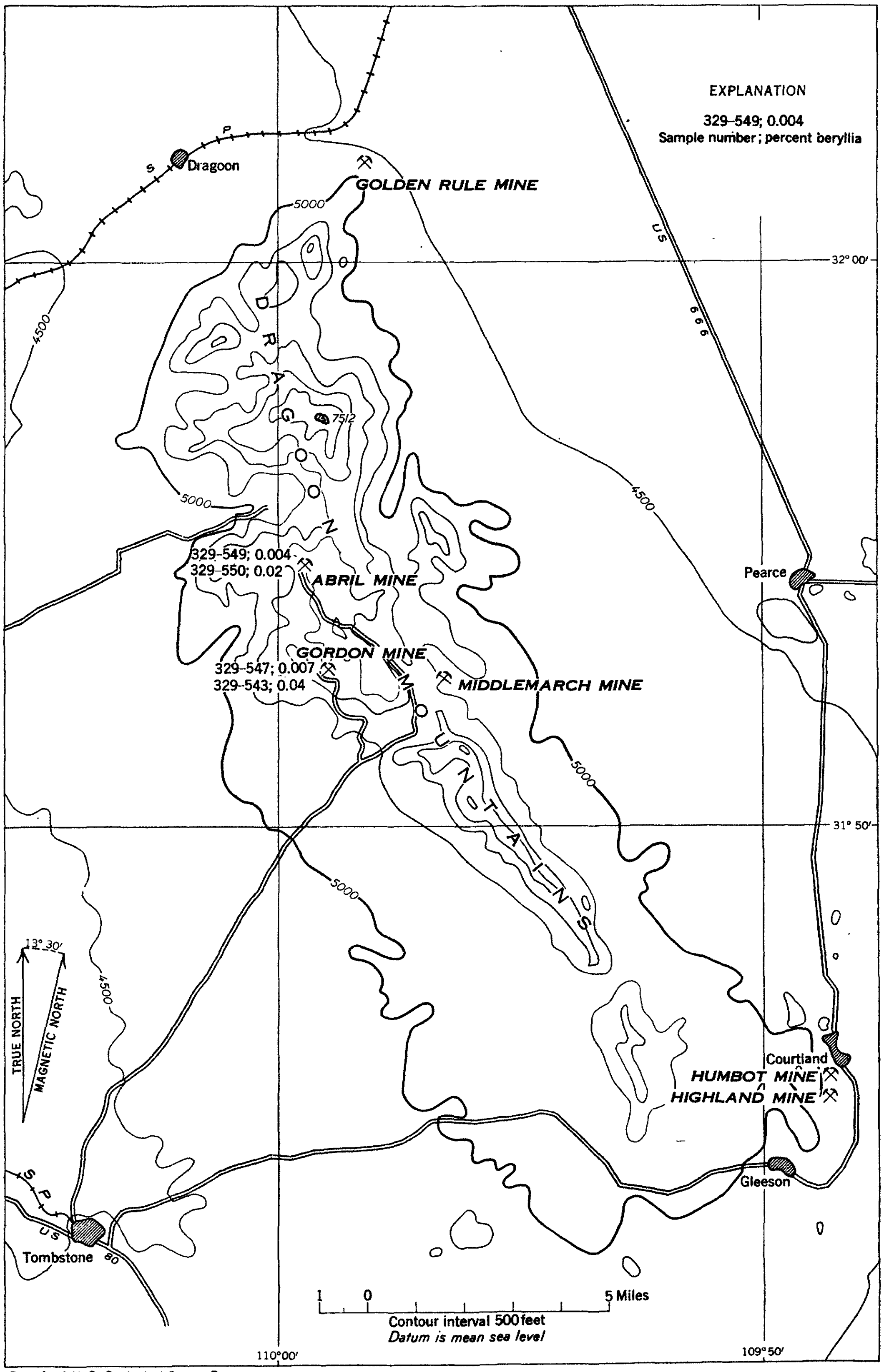
The Dragoon Mountains rise steeply from the desert 12 miles northeast of Tombstone, to an altitude of more than 7,500 feet (fig. 22). They have a northwesterly trend from the old mining camps of Courtland and Gleason for about 22 miles to Dragoon, a station on the Southern Pacific Railroad. A graded dirt road from Tombstone provides access to the southwestern side of the range, from where the mines are reached by steep mountain roads.

The geology of the Dragoon Mountains has been described by Darton (1925, p. 292–296) and by Gilluly (1941). Precambrian Pinal schist is overlain by Bolsa



Cochise County	Mohave County	Santa Cruz County
1. Courtland-Gleeson	5. Boriana	10. Patagonia
2. Gordon and Abril mines	6. San Francisco	
3. Little Dragoon Mountains	**Pima County**	**Yavapai County**
4. Tombstone	7. Empire	11. Boulder Creek
	8. Helvetia	
	9. Pima	

FIGURE 21.—Index map of localities sampled in Arizona.



Base from U. S. Geological Survey Dragoon, Cochise, Benson, and Pearce quadrangles

FIGURE 22.—Index map of beryllium occurrences in Dragoon Mountains, Cochise County, Ariz.

quartzite and Abrigo limestone of Cambrian age. Conformable on the Abrigo limestone are 350 feet of mixed shales and limestones of the Martin limestone of Devonian age which are succeeded by at least 700 feet of massive Escabrosa limestone of Mississippian age. A thick section of limestone of the Naco group of Pennsylvanian and Permian age overlies the Escabrosa limestone. The rocks of Paleozoic age have been deformed and invaded by intrusive rocks of Cenozoic age, chiefly the Stronghold granite. After erosion the region was covered by sandstones of the Upper Cretaceous and Tertiary volcanic rocks. The geology has been complicated further by thrust faulting.

Metamorphism of the sedimentary rocks of Paleozoic age has been particularly intense near their contact with the Stronghold granite. The Escabrosa limestone and part of the Naco group are changed to white marble with some tremolite. The more argillaceous parts of the Martin and Abrigo formations and the Naco group contain large quantities of andradite, hedenbergite, and epidote. Garnet also occurs in the sedimentary rocks along a fracture zone several thousand feet from the granite, and some metamorphism is found as much as 5 miles from the granite outcrop.

There has been little mining activity other than in the Courtland-Gleason district at the south end of the range. A small production has been credited to the Dragoon and Johnson (Cochise) districts. The Golden Rule mine, producing principally lead, at the north end of the range and the Middlemarch mine, producing principally copper, on the eastern side, were the only producers before World War II. The Gordon mine, on the southwest crest of the range, reportedly produced lead-zinc ore during World War II. The Abril mine, on the western slope, has been the source of considerable zinc since 1945. All of these mines are in sedimentary rocks close to the border of the Stronghold granite. The dominant ore minerals at the Golden Rule, Gordon, and Abril mines are chalcopyrite, galena, and sphalerite; the gangue minerals are garnet, epidote and specularite.

Samples from the Dragoon Mountains contain as much as 0.04 percent BeO (fig. 22). Although the beryllium-bearing mineral has not been identified, the analogy to other beryllium deposits suggests that helvite may be the source of the beryllium. The similarity between the ratios of beryllium and base metals in ore and gangue indicate that the beryllium is associated mainly with the ore. The amount of beryllium in the tactite at the Gordon and Abril mines is at least 10 times that found in 85 percent of the tactite deposits sampled in the Western United States.

COURTLAND-GLEESON DISTRICT

The Courtland-Gleeson district (Turquoise district) is in the southeastern part of the Dragoon Mountains, 15 miles east of Tombstone. The geology of the district was described by Ransome (1913) and by Wilson (1927). Limestones of Paleozoic age and shales and sandstones of Cretaceous age have been intruded by a variety of igneous rocks of which quartz monzonite porphyry is the most widespread. Contact metamorphism of the sedimentary rocks near the intrusive porphyry has been slight. Locally minor quantities of garnet, epidote, quartz, and pyrite have formed in the Abrigo limestone of Cambrian age. At least three periods of normal faulting and one of thrust faulting have been recognized.

Deposits containing disseminated chalcopyrite and minor quantities of galena occur in the metamorphosed Abrigo limestone. Oxidized copper minerals are common in the upper parts of the deposits. According to Ransome (1913, p. 533), the copper mineralization was simultaneous with the silication. The Humbot mine (Wilson, 1927, p. 55–56) is typical of these deposits. A 22-foot channel sample (329–551) was cut through garnet-epidote tactite from an outcrop 30 feet west of the Humbot shaft. A composite grab sample (329–552) of chalcopyrite-pyrite-specularite ore with garnet-epidote gangue was taken from the dumps of the Humbot and Highland mines. These samples did not contain as much as 0.0001 percent BeO.

GORDON MINE

The Gordon mine is near the southwestern crest of the range at an altitude of 7,000 feet, about 14 miles by graded dirt road from Tombstone. The mine workings include three adits.

The principal ore mineral is galena. It occurs along a west-trending fracture zone in the Abrigo limestone, a few hundred yards east of a mass of Stronghold granite. On the surface the fracture zone is 50 to 100 feet wide and can be traced for half a mile along the strike. In and adjoining the zone of fracturing are interlayered thin-bedded cherty limestones and epidote-garnet-specularite tactite. A 7-foot channel sample (329–547) taken across the tactite at the portal of the northern upper adit contained 0.007 percent BeO.

According to Mr. J. H. Macia, the mill at Tombstone was built during World War II to treat the ore from this mine. A grab sample (329–543) of ore from the receiving bin at this mill contained 0.04 percent BeO and 0.0X percent each of bismuth and cadmium.

ABRIL MINE

The Abril mine is at an altitude of 7,000 feet on the steep western slope of the Dragoon Mountains. The mine is accessible by a dirt road that leads from the southwestern side of the range. The mine was developed by Bargain Mines, Inc., in 1945. From 1945 to 1948 it was operated by the Shattuck-Denn Mining Corp., and about 20,000 tons of lead-zinc-copper ore was processed in their flotation mill at Bisbee, Ariz. The ore was carried on an inclined tramway to the bottom of Stronghold Canyon, whence it was trucked out.

The mine workings consist of several adits driven in a large block of Escabrosa(?) limestone, that is nearly surrounded by Stronghold granite. The limestone and interbedded shales have been metamorphosed to hornfels, marble, and tactite. Sphalerite and chalcopyrite fill small fractures and partly replace the epidote-specularite tactite. Some ore is found in garnet-epidote tactite. Samples of tactite (329–549) and of ore (329–550) from the dumps at the mine contained 0.004 and 0.02 percent BeO, respectively. Specimens of ore from this mine contained 0.0X percent tungsten.

LITTLE DRAGOON MOUNTAINS

The Little Dragoon Mountains are in northwestern Cochise County. The principal settlement is at the old mining camp of Johnson, on the eastern side of the mountains. Copper and zinc ore are produced from the Republic and other mines.

The Pinal schist of Precambrian age underlies much of the western part of the Little Dragoon Mountains. The schist is overlain by the Apache group of Precambrian age, which includes conglomerate, shale, and sandstone. Sedimentary rocks of Paleozoic age, predominantly limestone, are nearly conformable with the Apache group and are at least 2,500 feet thick. They constitute the Abrigo (Cambrian), Martin (Devonian), and Escabrosa (Mississippian) formations, and the Naco group (Pennsylvanian). Blocks of sandstones from the Bisbee group of Cretaceous age are faulted against the sedimentary rocks of Paleozoic age. Following regional folding and faulting a body of quartz monzonite was intruded, cutting rocks as young as the Bisbee group. Dikes of aplite and lamprophyre cut the quartz monzonite and the country rocks.

Sampling data for the little Dragoon Mountains are given in table 45 and the localities sampled are shown on figures 23 and 24. J. R. Cooper of the U. S. Geological Survey, who had previously sampled some of the localities, conducted the party over the area and assisted in the sampling. Mr. Oscar Jarrell of the Coronado Copper and Zinc Co., owner and operator of the Republic mine, generously furnished mill samples and analytical data. Mr. Edwin Over of Colorado Springs, Colo., supplied details concerning the occurrence of beryl at the Bluebird mine.

TABLE 45.—*Beryllia and tungsten in samples from the Little Dragoon Mountains*

Sample [1]	*Locality and description*	Percent BeO [2]	Percent W [3]
	TUNGSTEN KING MINE		
329–435	Channel sample across 2.5-ft quartz vein	0.0008	0.0860
436	do	.052	.1340
437	Channel sample across 3 ft of chlorite schist between quartz vein and quartz monzonite	.010	.0700
441	Channel sample across 2 ft of chlorite schist with some quartz	.016	.1340
442	Channel sample across 3 ft of altered quartz monzonite rock near sample 441	.0013	.0028
444	Chip sample of fresh quartz monzonite rock	.0014	.0016
	BLUEBIRD MINE		
329–446	Chip sample of 4-in. tungsten-bearing quartz-fluorite vein in quartz monzonite	.0005	.0014
447	Channel sample across 3.5 ft of quartz veins (1/3) and greisenized quartz monzonite (2/3)	.0019	.0034
JRC–1	Specimen of fresh quartz monzonite	.0016	(4)
2	Specimen of greisen next to quartz vein	.0028	(4)
3	Specimen of quartz monzonite with argillic alteration, 15 ft from vein at sample 2	<.001	(4)
4	Specimen of quartz vein containing huebnerite	<.001	(4)
	JOHNSON CAMP AREA		
329–449	Two-week composite of mill heads at Republic mine, June 1949. From 1200, 1500, and 1600 levels west. Garnet-diopside tactite, with some chalcopyrite and sphalerite	[5] .0007	[6] .0X
450	Same as sample 449, but taken in May 1948, from higher stopes	[5] .0007	[6] .0X
451	Same as sample 450, but tailings	[5] .0007	[6] .0X
453	Channel sample across 18-in vein of quartz, with fluorite and sulfides, cutting across Abrigo limestone, Mammoth mine	[5] .0007	[6] .0X
454A	Idocrase separated from marble of the Naco group, Black Prince mine	.005	(4)
455	Grab sample of idocrase-wollastonite tactite, with copper sulfides, from dump of Black Prince mine	.001	(4)
JRC–5	Specimen of garnet tactite, with chalcopyrite, sphalerite, and chlorite, from main ore zone in Mammoth mine	<.001	(4)
6	do	<.001	(4)
7	Specimen of epidote-tactite containing sulfide ore minerals, diopside, chlorite, garnet, and potash feldspar, from main ore zone, Republic mine	<.001	(4)

See footnotes at end of table.

TABLE 45.—*Beryllia and tungsten in samples from the Little Dragoon Mountains—Continued*

Sample[1]	*Locality and description*	Percent BeO[2]	Percent W[3]
	JOHNSON CAMP AREA—Continued		
8	Specimen of diopside-tremolite tactite, with quartz and calcite, from Abrigo limestone above ore zone, Mammoth mine	<0.001	(4)
9	Specimen of wollastonite-garnet-idocrase tactite from Abrigo limestone below main ore zone, Standard prospect	<.001	(4)
10	Specimen of idocrase-garnet-wollastonite tactite, with ore minerals in limestone of the Naco group, dump of Black Prince mine	.0023	(4)

[1] Samples bearing 329-numbers collected by W. T. Holser and W. I. Finch; those bearing JRC–numbers, collected by J. R. Cooper.
[2] Quantitative spectrographic determination by Saratoga Laboratories, unless otherwise noted.
[3] Determination by Frederick Ward, U. S. Geological Survey, unless otherwise noted.
[4] Not determined.
[5] Spectrographic analyses by J. D. Fletcher. BeO figures determined on plates exposed for general scanning but not for precise determination of BeO alone.
[6] Semiquantitative spectrographic analysis by J. D. Fletcher. These samples also contained 0.00X percent Mo, but no extraordinary amounts of 24 other elements (See table 15.)

TUNGSTEN KING MINE

The Tungsten King group of 12 unpatented claims is at an altitude of 5,200 feet near the head of Clark Canyon on the western slope of the Little Dragoon Mountains. The mouth of this canyon may be reached by about 16 miles of unimproved road leading up Tres Alamos Wash from Benson, Ariz. According to Wilson (1941, p. 43), scheelite was discovered here in 1916, and during World War I the mine was developed by open-cuts and short adits. Mining was renewed during World War II but the production was small.

The Tungsten King claims are along the northerly trending fault contact between quartz monzonite on the west and Pinal schist on the east (fig. 24). A quartz vein mined for scheelite follows the fault contact for most of its exposed length. The principal opening is a 275-foot adit which crosscuts the vein about 100 feet below the outcrop. The adit was partly flooded at the time of our visit, and we did not enter it. Drifts follow the vein for about 200 feet south and north of the adit. Many pits have been dug along the vein, particularly north of the adit. Near the adit, the vein is as much as 6 feet thick and dips about 60° E., but northward the dip becomes less.

The vein is composed mainly of fine- to coarse-grained quartz and contains also minor quantities of scheelite, beryl, feldspar (some altered to clay minerals), chlorite, and muscovite. The wallrocks at many places along the vein have been silicified. The structure of the vein is complex, particularly along the hanging-wall side, where the quartz occurs as a discontinuous lens and as irregular veins that cut the schist.

As shown in figure 24, the vein is offset in three places by steep cross faults. Near the top of the peaks east of the Tungsten King mine one of these faults cuts the small outlier of sedimentary rocks of Paleozoic age that overlie the schist. The displacements of the sedimentary rocks and of the vein indicate that the south side of the fault was moved downward about 2,000 feet.

Beryl occurs in the vein as prisms 2 or 3 centimeters long and 2 millimeters in diameter, terminated by the pinacoid. It is readily distinguished from the surrounding milky quartz by a characteristic pale-blue (5B7/4) color (Goddard and others, 1948). Most of it is reticulated through the quartz, in radiating or parallel groups. The beryl appears to be more common near the schist wall or near schist inclusions. Some was found in feldspar-rich selvage along the hanging-wall side of the vein. In the schist the beryl apparently is most abundant in small blebs and stringers of quartz or aplitic material that are common near the hanging wall. The beryl is very irregularly distributed and the quantity that may be readily seen is small.

Scheelite occurs in small shapeless patches, sparsely and irregularly distributed through the quartz and to an even lesser extent through the schist near the vein. It fluoresces white, indicating the presence of some molybdenum. In a pit north of the adit (near sample 329–341 in fig. 24) wulfenite was found on fracture surfaces and in small vugs. According to Wilson (1941, p. 43), chalcopyrite and galena are also found in the vein. We saw small cubes of limonite, pseudomorphous after pyrite, in the vein outcrop.

Along the footwall of the vein the quartz monzonite is intensely altered and silicified. It has a platy structure with some slicken-sides, as if it had been strongly sheared. The feldspar is altered to a clay mineral. Where the rock is apparently unaltered, as at the portal of the adit, it is similar to the quartz monzonite of Texas Canyon in the southeastern part of the mountains.

Channel samples were taken from several exposures of the vein (fig. 24). Results of spectrographic analyses (table 45) indicate that locally the vein contains more than 0.05 percent BeO. In general, however, the grade of beryl ore as determined by visual inspection in the vein is lower than indicated by analyses. Apparently, some beryl occurs in the chlorite schist adjacent to the vein. The continuity of the vein indicates a large reserve of low-grade material, but the small size of the beryl crystals prohibit recovery except by milling. The beryl might be a valuable byproduct of a scheelite milling operation.

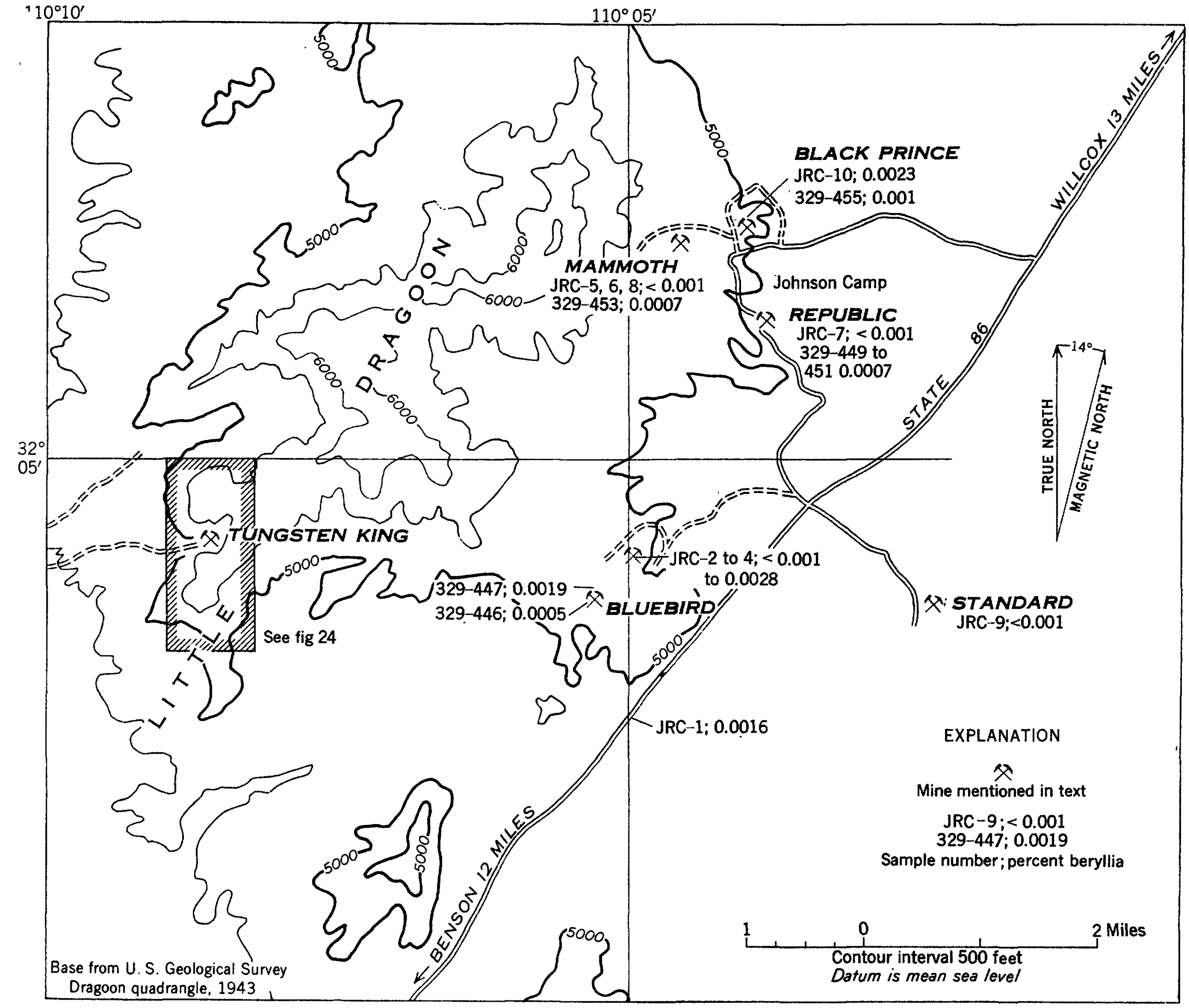


FIGURE 23.—Map showing localities sampled in the Little Dragoon Mountains, Cochise County, Ariz.

BLUEBIRD MINE

The principal workings at the Bluebird mine are in a group of 21 patented claims that are in the hills at the head of Texas Canyon. Several unimproved roads provide limited access to the area (fig. 23). Tungsten was mined in this area as early as 1899 (Richards, 1904), and Wilson (1941, p. 42) reports that about 2 tons of huebernite per day were produced in 1940.

The tungsten-bearing quartz veins of the Bluebird group are part of a vein system that trends northeastward from the head of Texas Canyon nearly to Johnson. The wall rock is quartz monzonite, which has been intruded by aplitic and lamprophyric dikes. The main group of veins is in a zone about 600 feet wide. Richards (1904, p. 264) describes the Bluebird vein as the best-defined one of this group. The space between walls is about 5 feet, but the ore is only 6 inches thick. Most veins in the area are only a few inches thick, and are bordered by a foot or more of greisen on either side.

A small quantity of beryl was collected from one of the narrow veins by Mr. Edwin Over of Colorado Springs, Colo. The colorless beryl crystals were found with quartz and fluorite in a small opening at the locality marked "Beryl" in figure 23 (Boericke property). We saw no beryl during our sampling of this property.

Analyses of samples from the Bluebird mine (see table 45 and fig. 23) indicate that the quartz veins are probably low in beryllium content. The greisen appears to have only slightly more beryllium than the quartz monozonite.

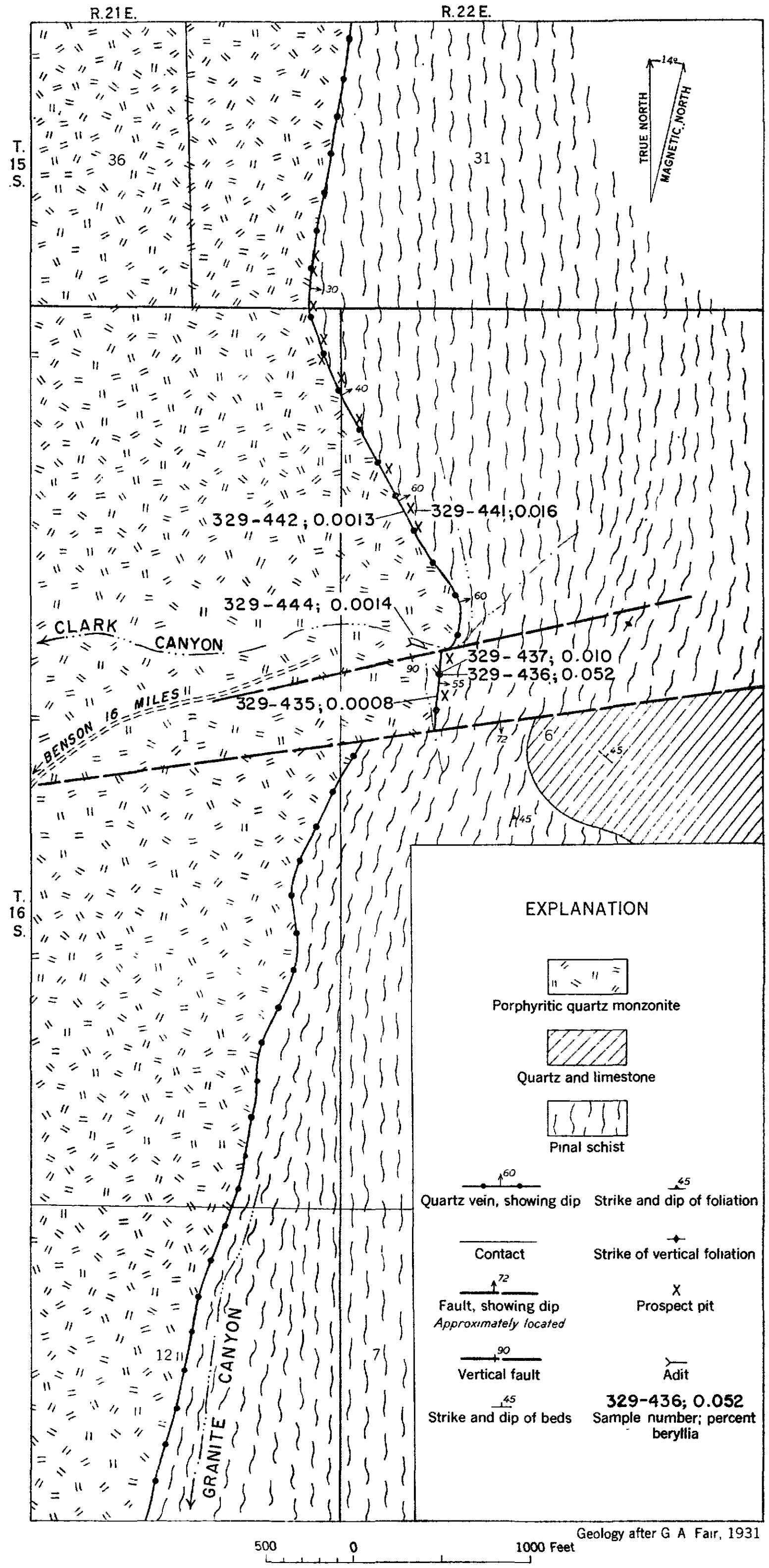


Figure 24.—Geology of the Tungsten King claims, Cochise County, Ariz.

JOHNSON CAMP AREA

The Johnson Camp area is on the east side of the Little Dragoon Mountains, about 2 miles northeast of the Bluebird mine (fig. 23). It is an old camp with extensive workings from which has come a large production of copper and zinc ore. The Republic mine was active in 1949. The geology of the area has been described by Cooper (1950).

The principal ore bodies in the Republic and Mammoth mines are associated with fractures in a bed of contact-metamorphosed Abrigo limestone. The ore consists of varying proportions of chalcopyrite, sphalerite, bornite, and pyrite, with a little molybdenite and scheelite, in a gangue of potash feldspar, garnet, epidote, diopside, quartz, and calcite. Analyses of specimens of typical ore and gangue that were collected by J. R. Cooper and of composite samples of mill heads and tails, that were furnished by the Coronado Copper and Zinc Co. indicate that beryllium is not abundant at these mines (table 45).

The Black Prince and Peabody mines were developed on an outlying hill in the northern part of the area. The ore is partly in thin shaly layers of the Naco group and partly in lamprophyre. In addition to the usual garnet and quartz gangue, the ore is found also in idocrase-wollastonite rock formed by metasomatism of limestone of the Naco group. Samples 329–455 and JCR–10 of the idocrase-wollastonite rock from the dump of the Black Prince adit contained 0.001 and 0.0023 percent BeO, respectively. Along the outcrop above the adit, green idocrase occurs in crystals as long as 3 centimeters in white, wollastonite-rich tactite. The idocrase crystals separated from this material contained 0.005 percent BeO. The small amount of beryllium in the metamorphosed limestones of this part of the district apparently is contained in idocrase.

Several quartz veins in the Johnson Camp area trend northwest. Sample 329–453 from a quartz vein in the Abrigo limestone above the Mammoth shaft contained 0.0007 percent BeO.

TOMBSTONE DISTRICT

The Tombstone district, in western Cochise County on U. S. Highway 80, was visited on August 1 and 2, 1949. Mr. J. H. Macia of Tombstone kindly served as a guide to the mines and provided much information on their operations.

The geology of the district was described by Butler, Wilson, and Rasor (1938). Sedimentary rocks of Paleozoic age nearly a mile in thickness, principally limestone of the Naco group of Pennsylvanian age, are overlain unconformably by more than 3,000 feet of sedimentary rocks of the Bisbee group of Cretaceous age. After extensive folding and faulting, these rocks were intruded in the western part of the district by the Uncle Sam porphyry (quartz latite) and in the southwest by the Schiefflin granodiorite. Deposits of silver, lead, gold, copper, and manganese are associated with northeast-trending fissures and related structures. The principal ore minerals are galena, gold, chalcopyrite, and argentiferous tetrahedrite, or their oxidation products. The wallrock at many of the mines is a sedimentary rock of the Bisbee group, but at some in the southern part of the district it is the more calcareous rocks of the Naco group. The limestone which is partially metamorphosed to garnet, epidote, and idocrase, crops out on Comstock Hill northwest of the town. Silicification of the limestone was irregular and apparently is related to dikes of the Schiefflin granodiorite.

Three samples were taken in the Tombstone district. Sample 329–539 was of manganese ore from the dump of the Oregon mine, 1.5 miles south-southwest of Tombstone. Sample 329–540 was chipped from a 60-foot-wide outcrop of garnet-calcite marble just west of the Luck Sure mine, 1.2 miles south-southwest of Tombstone. Beryllium could not be found in either sample. A chip sample (329–546) taken along a 50-foot line across an outcrop of garnet tactite and tremolite-calcite marble near the top of Comstock Hill contained 0.0007 percent BeO.

MOHAVE COUNTY

BORIANA DISTRICT

Beryl-bearing quartz-tungsten veins occur at the Boriana mine in the Hualpai Mountains about 18 miles east of Yucca, a town on the Atchison, Topeka and Santa Fe Railroad. The mine has been an important producer of tungsten ore. The veins were not sampled, but descriptions by Hobbs (1944, p. 247–258) and Kerr (1946a, p. 102–104) indicate that they may be potential sources of beryl.

According to Darton (1925, p. 180), the Hualpai Mountains "consist of Precambrian granite and gneiss cut by dikes of porphyry and other intrusive rocks." The country rock of the veins is a roof pendant of phyllite in a large mass of biotite granite. The phyllite crops out over a belt half a mile wide that trends northeasterly. Its foliation is roughly parallel to the vertical instrusive contact. The phyllite near the contact is recrystallized to a fine-grained schist composed of chlorite and muscovite.

The veins are parallel to the foliation of the schist, but are discontinuous, frayed, and have an echelon pattern. The principal gangue mineral is quartz which is accompanied by small quantities of fluorite, calcite, muscovite, and potash feldspar. Wolframite, scheelite, chalcopyrite, and minor amounts of pyrite, arsenopyrite, and molybdenite are the metallic minerals. According to Hobbs (1944, p. 254), "Some beryl was found in the veins on the 700-level and also in the veins which cut the granite at the surface." Veinlets of fluorite and muscovite cut the quartz in some places, and Kerr (1946a, p. 103) states that muscovite is most abundant near tungsten minerals. Scheelite replaces wolframite, and most of the sulfides were deposited with the scheelites. Some sulfides, with quartz and potash feldspar, are younger. Near the north end of the Boriana property, a sodic granite cuts across the phyllite. The veins decrease in width and increase in beryl content as they pass from the phyllite into the granite. The sodic granite is thought to be related to the source of the mineralizing solutions.

Reserves of tungsten ore were estimated at 2,400 measured tons, 9,900 indicated tons, and 44,000 inferred tons (Hobbs, 1944, p. 258). There were about 150,000 tons of unmined vein material between the underground workings and the surface. The beryllium content of this material is not known. The mine closed down in February 1943, and no additional production has been reported to date (1951).

SAN FRANCISCO DISTRICT

The San Francisco district is in the Black Mountains in southwestern Mohave County, near Oatman, a town on U. S. Highway 66. The southern part of the district is referred to as the Oatman district; the northern part as the Katherine or Union Pass district. Sampling by members of the Mine, Mill, and Smelter Survey during World War II indicated the presence of beryllium in the gold ores from this district. Although the district was not revisited during the present investigation, the results of the earlier sampling are of sufficient interest and importance to be included in this report.

The geology of the district has been described by Ransome (1923), Lausen (1931), and Wilson, Cunningham, and Butler (1934, p. 80–115). Precambrian rocks are extensive in the northern part of the district, where a coarse gneissic granite intrudes schists and gneisses. The granite forms the wall rock of the veins at the Katherine mine. The most abundant rocks of the Black Mountains are a thick series of Tertiary lava flows. They range in composition from rhyolite to olivine basalt; andesite and latite are the most important wall rocks of the veins near Oatman. Quartz monzonite and granite porphyries intrude the flows. The lavas dip gently eastward, presumably as a result of movement of several hundred feet along steep normal faults. The principal mineral deposits are fissure fillings in parts of the fault zones. Although the volcanic wallrocks are highly altered by both ascending and descending solutions, they have not in general been replaced by metals. Lausen (1931, p. 63–72), considers the veins to be epithermal and recognizes five stages in the deposition of the vein material. Most of the gold, with some silver in solid solution, was deposited with calcite, quartz, adularia, and fluorite during the fifth stage.

Routine sampling in connection with the Mine, Mill, and Smelter Survey in 1943 revealed significant quantities of beryllium in tailings of the Gold Road mill at Oatman and the Katherine mill at Katherine. Data for these and other samples taken from the district are listed in table 46. Locations of the mines listed in the table are shown in figure 25. The sample containing

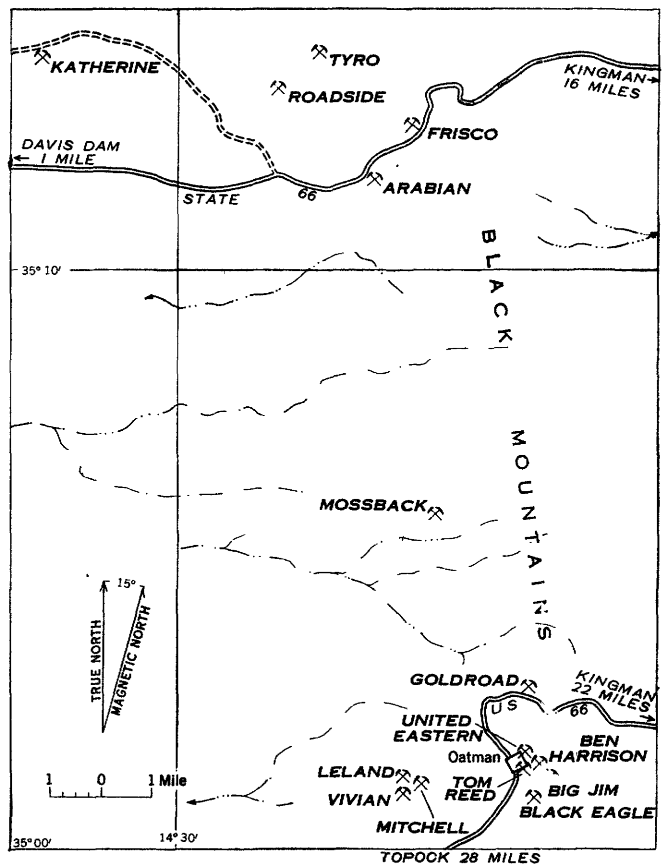


FIGURE 25.—Mines of the San Francisco district, Mohave County, Ariz.

0.03 percent BeO, taken at the Katherine mill, is from a large deposit of tailings (about 150,000 tons), and no samples of the various ores treated in the mill are available. The source of the beryllium in the sample was not determined.

Tailings samples from the Chloride and other districts in the Cerbat Range did not contain as much as 0.001 percent beryllium. The deposits in these districts are gold-silver veins of more complex mineralogy (Schrader, 1917, p. 199–206; Thomas, 1949).

TABLE 46.—*Beryllia in mill tailings from the San Francisco district*

[Analyst, John C. Rabbitt]

Sample	Mill and location	Contributing mines	BeO (percent)
85-MC-3	Katherine; Katherine.	Roadside, Arabian, Katherine, Frisco, Tyro.	0.03
9	Gold Road; Gold Road.	Gold Road	.006
5	Tom Reed; Oatman.	Tom Reed, Black Eagle, Ben Harrison.	.001
10	Louzon; Oatman	Mossback	<.001
7	United Eastern Mines Corp.; Oatman.	United Eastern, Big Jim.	<.001
6	Vivian Mining Co.; Oatman.	Leland, Vivian Mitchell.	<.001

PIMA COUNTY

EMPIRE DISTRICT

The Empire district is in the Empire Mountains in eastern Pima County, south of U. S. Highway 80 and east of State Highway 83. A pyrometasomatic tungsten deposit in the southern part of the district was sampled on July 31, 1949. The deposit is just east of the Hilton ranch house, on the road to State Highway 83.

The deposit was mapped and described by Marvin.[6] Southeasterly-dipping limestone of the Naco group (Pennsylvanian) is intruded by quartz monzonite. Within 50 feet of the contact, masses of the limestone have been changed to tactite that contain garnet, diopside, wollastonite, quartz, epidote, specularite, and some scheelite and copper minerals.

Four samples (329–524 to 329–527 inclusive) were chipped from tactite outcrops between the road and the next canyon, which is about 900 feet northeasterly along the contact. Beryllium could not be detected spectrographically in any of the samples.

HELVETIA DISTRICT

The Helvetia district is near the summit of the northern end of the Santa Rita Mountains about 30 miles southeast of Tucson. The western part of the district around the old camp of Helvetia is reached by 14 miles of graded road leading east from U. S. Highway 89 at Sahuarita. The eastern part of the district is accessible by several unimproved roads leading west from State Highway 83.

The geology of the district (fig. 26) was described by Schrader (1915, p. 91–140), Creasey and Quick (1943), and Johnson (1949). The principal sedimentary rocks are limestones of Carboniferous age and clastic rocks of Cretaceous age, both of which have been severely deformed and cut by thrust faults. The eastern part of the district is intruded by quartz monzonite of Late Cretaceous or post-Cretaceous age which has highly altered the country rock near its contact. The western part of the area is intruded by granite of probable Mesozoic age. The contact of the granite with overlying limestones in the western part of the area is along a thrust plane; the limestones contain bodies of tactite. The tactite, composed of garnet, quartz, diopside, actinolite, and wollastonite, forms the gangue for much of the ore. Creasey and Quick believe the metallic minerals, including pyrite, chalcopyrite, and minor amounts of scheelite, sphalerite, and molybdenite, to be later than the silicate minerals.

Channel samples were taken of tactite, mainly in or near areas containing copper or molybdenum minerals. The general locations of the samples with respect to the geology is indicated in figure 26; descriptions and analytical results are given in table 47.

TABLE 47.—*Beryllia in samples from the Helvetia district*

[Spectrographic analyses by J. D. Fletcher. BeO content determined on plates exposed for general scanning but not for precise determination of BeO alone]

Sample	Description	BeO (percent)
329–510	Grab sample of hornfels and tactite, with chalcopyrite, from glory holes of Mohawk mine in Helvetia Wash, half a mile east of Helvetia	<0.0004
512	Channel sample across 6 ft of garnet tactite, with pyrite, chalcopyrite, and molybdenite, from 40-ft sublevel of Leader mine	.0004
514	Channel sample across 6 ft of diopside-garnet tactite, with chalcopyrite (including 1 ft of fault gouge with secondary copper minerals) from main level of the Leader mine 420 ft from portal	.002
515	Channel sample across 20 ft of garnet tactite and marble overlying the granite, at portal of upper adit Heavyweight mine, 1 mile east of Helvetia	.0004
516	Chip sample from 25-ft outcrop of garnet tactite above King adit (Rosemont lease)	<.0004
517	Channel sample across 10 ft of garnet tactite, with quartz and copper carbonates, from portal of adit on Rosemont lease, 150 ft north of sample 516	<.0004
520	Grab sample of garnet-quartz-chalcopyrite-pyrite ore from bin at King adit	<.0004
521	Grab sample of garnet tactite from dump of Narragansett mine	<.0004
523	Grab sample of garnet tactite, with chalcopyrite and pyrite, from dump of Daylight adit	.0004

PIMA DISTRICT

The Pima district is on the eastern slope of the Sierritas, about 25 miles southwest of Tucson. The district was visited on July 28 and 29, 1949. Thanks are due to Mr. G. J. Duff, Arizona manager of the Eagle-Picher Mining and Smelting Co., for samples from the San Xavier mine.

The geology and ore deposits of the district were described by Ransome (1922, p. 407–428) and by Wilson (1950). Strata of Paleozoic age, mostly limestones,

[6] Marvin, T. C., 1942, Geology of the Hilton Ranch area: Arizona Univ. M. Sc. thesis.

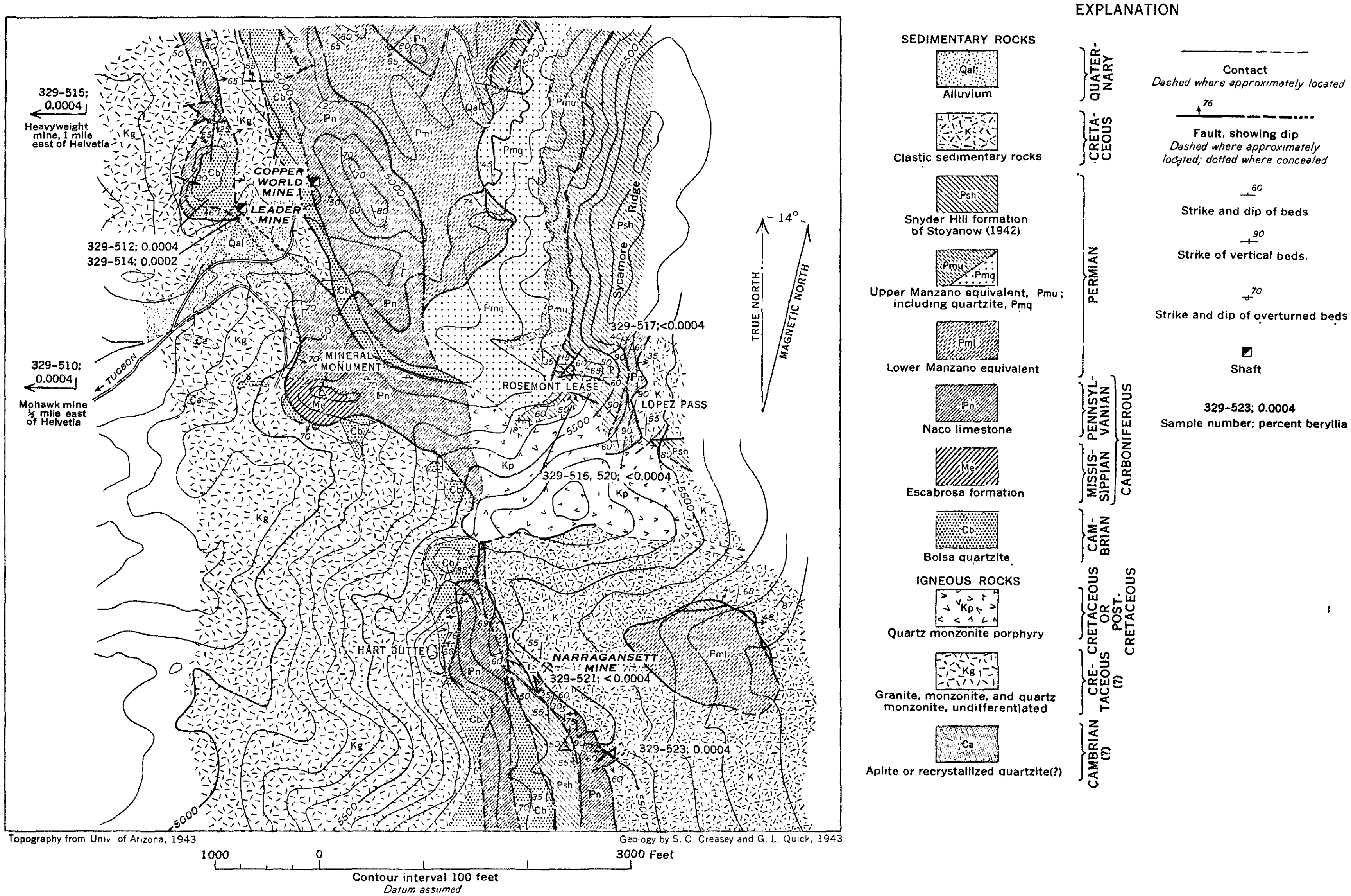


Figure 26.—Geologic map of part of the Helvetia district, Pima County, Ariz.

are intruded by coarse-grained rocks that range in composition from quartz monzonite to granodiorite. Their structure has been complicated by extensive folding, thrusting, and block faulting. The ore deposits are pyrometasomatic in origin. The ore nearest to the contact of the intrusive rocks is in tactite that is predominantly andradite, with some quartz, epiodote, wollastonite, and hedenbergite. The metallic minerals, including pyrite, chalcopyrite, magnetite, and rarely scheelite and molybdenite, are erratically distributed along fissures. The San Xavier mine is in ore farther from the intrusive rocks, and the gangue contains less garnet and more hedenbergite; calcite-sphalerite-galena-chalcopyrite ore replaces the gangue minerals along a fault zone.

The localities sampled for beryllium are shown on figure 27, and the sampling data are given in table 48.

TABLE 48.—*Beryllia in samples from the Pima district*

[Spectrographic analyses by J. D. Fletcher. BeO figures determined on plates exposed for general scanning but not for precise determination of BeO alone]

Sample	*Description*	BeO (*percent*)
329–490	Channel sample across 8 ft of yellow garnet tactite, with copper carbonates, at abandoned mine shaft	<0.0004
491	5.5-ft channel sample across quartz-limonite vein and garnet tactite, from prospect pit	<.0004
494	Channel sample across 15 ft of garnet tactite, with copper carbonates, from workings east of abandoned shaft	<.0004
496	Channel sample across 8 ft of garnet-hedenbergite tactite(?) from pit south of Minnie shaft	.001
497	Grab sample of garnet tactite and copper ore from Copper Queen dump	.001
498	Channel sample across 15 ft of garnet tactite, with quartz veins, from outcrop 70 ft south of Copper Queen shaft	<.0004
499	Chip sample across 150-ft outcrop of garnet tactite	<.0004
501	Channel sample across 2.5 ft of garnet tactite in pit 60 ft southwest of Morgan mine	<.0004
502	3-ft channel sample across quartz-scheelite vein, next to sample 501	<.0004
503	7-ft channel sample across quartz-scheelite vein in pit 250 ft southwest of Morgan mine	<.0004
506	Chip sample across 45-ft outcrop of garnet tactite at shaft 600 ft north of Morgan mine	.0004
507	Chip sample across 50-ft outcrop of garnet tactite 300 ft west of Morgan mine	<.0004
508	Tailings, from concentrator at Sahuarita, Ariz. (garnet-calcite-galena sphalerite ore from San Xavier mine), April-July 1949	<.0004
509	Heads from concentrator at Sahuarita, Ariz. average for July 1949 (ore from San Xavier mine)	<.0004

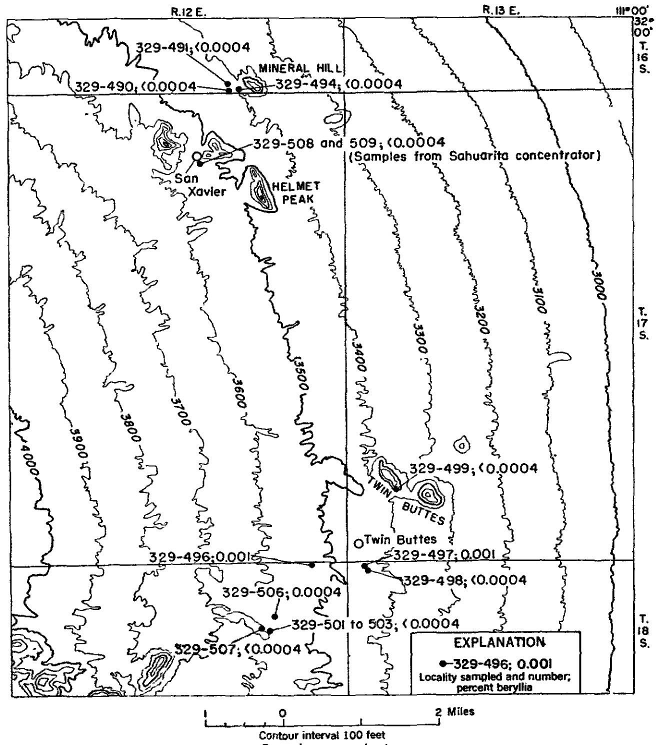


FIGURE 27.—Index map to locations of samples from the Pima district, Pima County, Ariz.

SANTA CRUZ COUNTY

PATAGONIA DISTRICT

The Patagonia district is in southeastern Santa Cruz County, just north of the Mexican border. It is about 25 miles by graded road south of the town of Patagonia, Ariz., which is on State Highway 86. The district was visited on July 31, 1949.

The geology of the district has been described by Schrader (1915, p. 292–348). The Washington-Duquesne area, in which all the pyrometasomatic deposits are found, was mapped by Arthur Richards and A. L. Brokaw of the Geological Survey during World War II, and their unpublished report was used as a guide in the sampling. In this area a block of limestone of Paleozoic age is surrounded by intrusive bodies of quartz monzonite and granite porphyry. Masses of the limestone have been metamorphosed to garnet-quartz tactite, with minor amounts of hornblende, diopside, and wollastonite near the southern end of the block. The principal ore bodies consist of pyrite, chalcopyrite, bornite, and sphalerite along fractures in the tactite.

The following samples were taken:

329–528 25-ft channel sample from outcrop of garnet tactite, with minor amounts of quartz, chalcopyrite, and calcite, at collar of new shaft on California claim.

529 Average sample of 20 tons of galena-chalcopyrite-sphalerite-pyrite shipping ore, from California claim.

531 4-ft core from the upper part of the tailings pond of the Duquesne mill.

532 Chip sample from 50-ft outcrop of garnet-quartz tactite at road cut on Big Crop claim.

533 Channel sample across 10 ft of hedenbergite-garnet-quartz tactite, with galena, sphalerite, chalcopyrite, and pyrite, from pillar of glory hole 300 ft S. 30° E. of Holland shaft.

535 6-ft channel sample from outcrop of garnet tactite, with limonite alteration, near Belmont shaft.

536 Chip sample of garnet tactite, with iron and manganese oxides, from 50 ft of north end of large open pit on the south end of the Belmont claim.

537 Channel sample across 25 ft of garnet-quartz tactite, with iron and manganese oxides, from prospect pit 200 ft east of sample 536.

538 6-ft channel sample of garnet tactite from adit on Empire claim.

Spectrographic analyses showed no samples more than 0.001 percent BeO. Sample 329–531 is a core of tailings and probably represents the average of a large amount of ore from the district. Samples of concentrates and tailings previously collected for the Mine, Mill, and Smelter Survey from the Nogales smelter, which was processing ores from the Patagonia district, also showed no more than 0.001 percent BeO.

YAVAPAI COUNTY

BOULDER CREEK AREA

The Boulder Creek (Bagdad) area is in western Yavapai County, 25 miles by road northwest of Hillside, a station on the Atchison, Topeka and Santa Fe Railroad. Two mines in the area have been active: the Bagdad mine at the town of Bagdad and the Hillside mine on Boulder Creek. Beryl occurs in quartz-tungsten veins at a prospect near the headwaters of Boulder Creek. Although time did not permit a visit to the prospect during the present investigation, information concerning it was furnished by C. A. Anderson of the U. S. Geological Survey.

The Bagdad region has been described by Anderson (1948, 1950a, 1950b), and the geology of the part drained by Boulder Creek is shown in figure 28. The

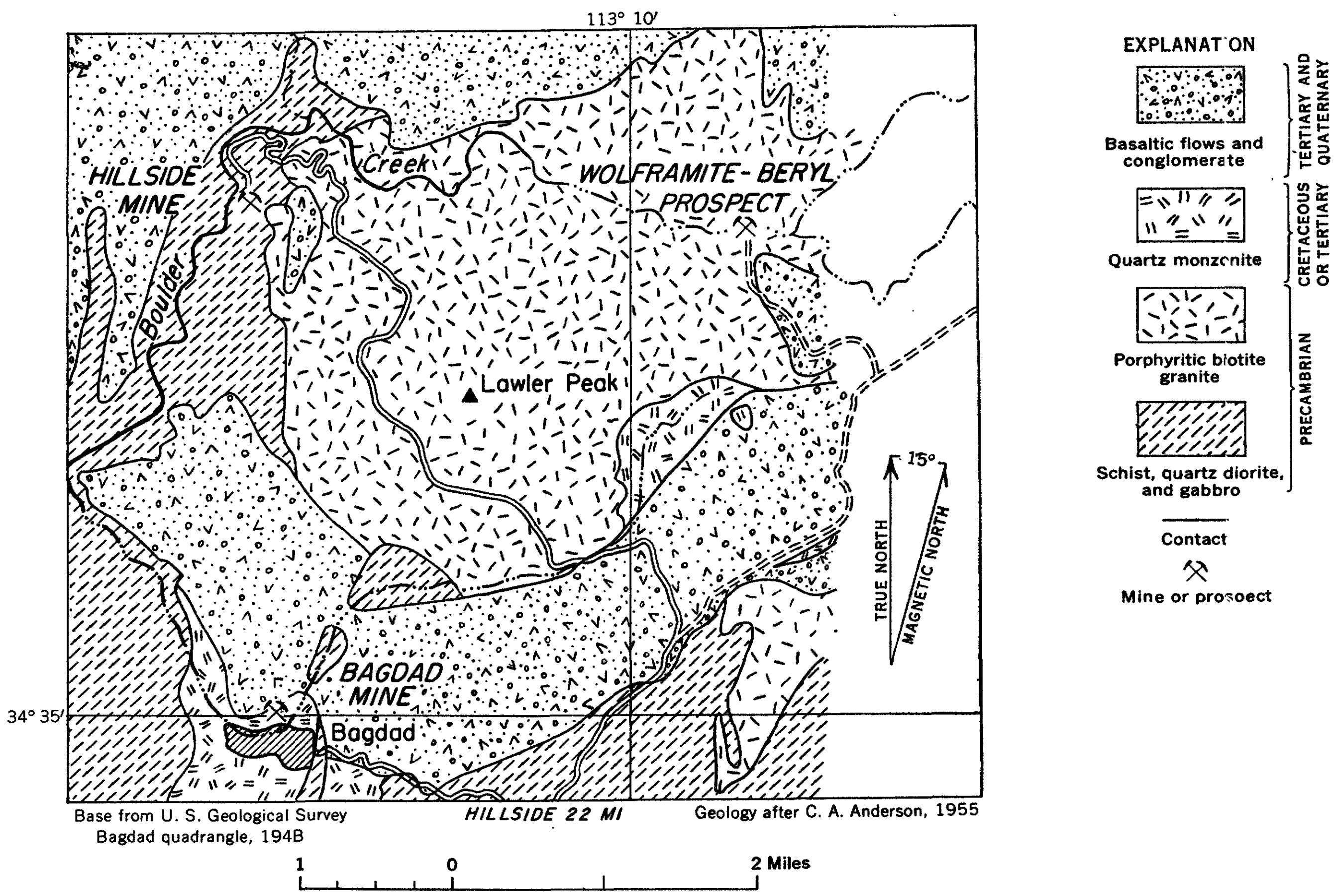


FIGURE 28.—Geologic map of Boulder Creek area, Yavapai County, Ariz.

Precambrian rocks are schists, quartzites, and amphibolites of the Yavapai schist that have been intruded by granite, gabbro, and a little quartz diorite. A stock (fig. 28) of Precambrian porphyritic biotite granite at Lawler Peak is about 3 miles in diameter. The rock is characterized by orthoclase phenocrysts as much as 2 inches in length. Small stocks of quartz monzonite intruded along a northeast-trending belt during Late Cretaceous or early Tertiary time. Pyrite, chalcopyrite, and molybdenite occur in the quartz monzonite as disseminations and small fracture fillings which constiture the ore of the Bagdad and other mines. Tertiary conglomerates and basalt flows cover the earlier rocks in parts of the area.

The tungsten-beryllium deposit is on the south side of Boulder Creek about 4 miles airline northeast of Bagdad (fig. 24), in sec. 24, T. 15 N., R. 9 W. In the vicinity of the prospect the porphyritic biotite granite is highly altered, with destruction of the biotite and formation of muscovite and minor amounts of garnet and fluorite. Some beryl occurs as poikilitic intergrowths with the other rock minerals and seems to be related to the alteration. The wolframite-bearing veins are also in muscovite-rich granite. The wolframite occurs in closely spaced nearly vertical parallel quartz veins as wide as 1 or 2 inches. South of Boulder Creek the veins form a northeast zone nearly 12 feet wide and 200 to 300 feet long. On the north side of the creek, an eastward-trending zone of veinlets 10 to 50 feet wide can be traced for more than 2,000 feet. Beryl is an important accessory in the veins and locally is abundant. Some scheelite occurs in thin films and crusts on the surface exposures. The veins are thought to be related genetically to the granite stock.

The vein zones were sampled by Anderson and his associates. A channel sample taken across the northern zone contained 0.16 percent WO_3 and 0.05 percent BeO, and a similar sample from the southern zone contained 0.13 percent WO_3 and 0.2 percent BeO.

Beryl is reported as a minor constituent of pegmatite dikes that are common in the porphyritic biotite granite. It also occurs in the granite about 2,000 feet southwest of the wolframite-beryl prospect. Specimens from this locality consist of a granular mass of quartz and cloudy feldspar that contains about 30 percent beryl. The beryl is in euhedral prisms about 3 millimeters in diameter and 2 centimeters long, reticulated in all directions through the mass of quartz and feldspar. The beryl-bearing rock occurs in at least two tabular bodies, or "veins," 6 to 10 inches wide and 30 feet long, and averages 4.5 percent BeO.

The minerals associated with intrusions of Tertiary age at the Bagdad mine seem to have no beryllium. According to Anderson (1950b, p. 618), the unaltered quartz monzonite contains less than 0.0004 percent BeO. A biotite-albite-quartz-orthoclase facies of altered quartz monzonite associated with the Bagdad ore deposits contains 0.0004 percent BeO. Beryllium was not detected in samples taken at the Bagdad mine and other mines in Yavapai County for the Mine, Mill, and Smelter Survey during World War II.

NEW MEXICO

By W. T. Holser

The localities at which pyrometasomatic deposits and alkalic igneous rocks were sampled in New Mexico are shown in figure 29. Tactite deposits are known in many of the mining districts of New Mexico (Lindgren, Graton, and Gordon, 1910, p. 51–53) and nearly all of these were sampled. Samples of tactite from the central New Mexico iron districts were obtained through the courtesy of V. C. Kelley of the University of New Mexico. The deposits in the Juarilla district, Otero County, had been sampled previously by the American Smelting and Refining Co. According to L. K. Wilson of Tucson, district geologist for the company, the samples contained little or no beryllium.

The largest known reserves of nonpegmatite beryllium in New Mexico are in the tactite deposits at Iron Mountain (Jahns, 1944a; 1944b). Vein and tactite deposits in the Victorio Mountains are also of potential importance. Small quantities of beryllium might be recovered from deposits in the Carpenter and Apache districts. Phonolitic lavas of large areal extent in the Raton volcanic region contain as much as 0.007 percent BeO, but the beryllium may not be recoverable.

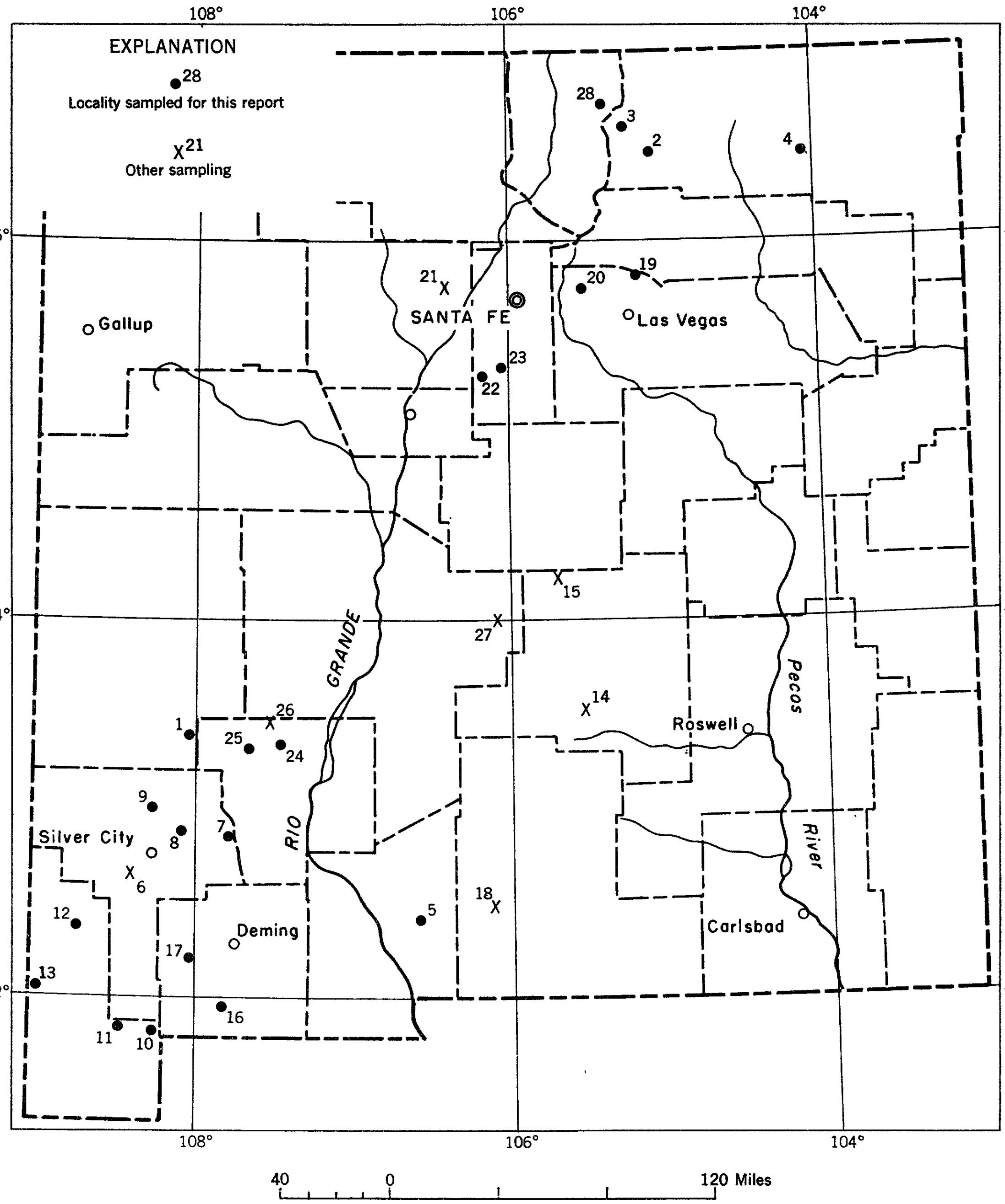
Alkalic igneous rocks were sampled in the Raton volcanic region, Colfax County, and in the Cornudas Mountains, Otero County. The rocks of the Cornudas Mountains are related to those of western Texas and are described in the section dealing with the Trans-Pecos Region.

CATRON COUNTY

BLACK RANGE DISTRICT

Tin deposits of the Black Range are in Catron and Sierra Counties, on the western slope of the range east of State Highway 61, about 50 miles north of Silver City, N. Mex. They were visited on August 22 and 23, 1949.

The tin deposits, which have been described by Fries (1940), and Fries and Butler (1943), occur in a rhyolitic volcanic series that contains some interlayered tuffs and breccias. Small veins that contain specularite and cassiterite and minor quantities of cristobalite, tridymite, fluorite, chalcedony, opal, and quartz occur in a



DISTRICTS

Catron County
1. Black Range

Colfax County
2. Cimarroncito
3. Elizabethtown
4. Raton volcanic region

Dona Ana County
5. Organ

Grant County
6. Burro Mountains
7. Carpenter
8. Central (includes Hanover, Fierro and Santa Rita districts)
9. Pinos Altos

Hidalgo County
10. Apache No. 2
11. Hachita
12. Lordsburg
13. San Simon

Lincoln County
14. Capitan
15. Gallinas

Luna County
16. Tres Hermanas
17. Victorio

Otero County
18. Juarilla

San Miguel County
19. Rociada
20. Willow Creek

Sandoval County
21. Cochiti

Santa Fe County
22. New Placers
23. Old Placers

Sierra County
24. Apache No. 1
25. Cuchillo Negro
26. Iron Mountain

Socorro County
27. Jones Camp

Taos County
28. Red River

FIGURE 29.—Index map showing localities sampled in New Mexico.

porphyritic rhyolite of the lower part of the series. Alluvial deposits near the veins are rich in placer cassiterite.

A grab sample (329–711) from a pit above the U. S. Bureau of Mines adit 1 N in the Taylor Creek area (Fries, 1940, pl. 55), contained 0.002 percent BeO. The beryllium-bearing mineral was not identified.

COLFAX COUNTY

CIMARRONCITO DISTRICT

The Cimarroncito district is in the Cimarron Range in western Colfax County on land of the Philmont Scout Ranch. Eight miles of private road lead from the ranch headquarters on State Highway 21 to Cimarroncito Camp (fig. 30). From there trails go up both the Middle and North Forks of Cimarroncito Creek to the mining area. The district was visited on July 19, 1949.

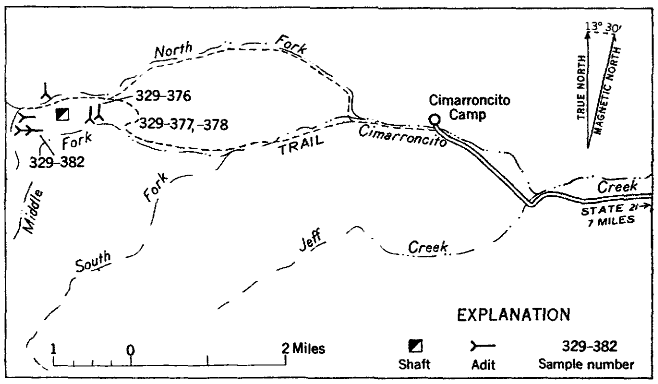


FIGURE 30.—Sketch map of localities sampled in the Cimarroncito district, Colfax County, N. Mex.

The mines of the district were described by Graton (Lindgren, Graton, and Gordon, 1910, p. 105–108). More recently the geology of the area was described by Smith and Ray (1943). Limestones of the Magdalena group of Pennsylvanian age are intruded by large sills and dikes of quartz-monzonite porphyry. North of the North Fork of Cimarroncito Creek, limestone of the Magdalena is overlain by Dakota sandstone and Pierre shale of Cretaceous age in the eastern limb of a large anticline. Near its contact with the porphyry, the limestone has been metamorphosed to tactite containing garnet, epidote, diopside, and coarse calcite. Pyrite, specularite, magnetite, and chalcopyrite occur with some of the tactite.

The approximate locations of the mines which were sampled are shown in figure 30. The mine on the North Fork of Cimarroncito Creek, from which sample 329–382 was taken, is known locally as the Cypher mine. It seems to best fit Gordon's description of the Thunder mine (Lindgren, Graton, and Gordon, 1910, p. 107–108). The mine area on the north slope of the Middle Fork, from which samples 329–376 to 378 were taken, is probably the one known locally as the Lambert mine, but does not correspond to any mine described by Gordon. As the mines were not accessible, samples were obtained from dumps and outcrops as follows:

329–376 Chip sample from 15 ft of outcrop of garnet tactite at portal of upper adit.
377 Grab sample of garnet-diopside tactite with pyrite, chalcopyrite, and specularite, from dump of lower adit.
378 Grab sample of specularite-hornblende tactite with pyrite, chalcopyrite, calcite, and epidote; same locality as sample 377.
382 Grab sample of garnet tactite from dump of upper adit. (No tactite in dump of lower adit.)

Spectrographic analyses of the samples showed no more than 0.0004 percent BeO.

ELIZABETHTOWN DISTRICT

The Elizabethtown district in western Colfax County is northeast of Eagle Nest, a small town on U. S. Highway 64. The geology of the district was described by Graton (Lindgren, Graton, and Gordon, 1910, p. 92–105), and that of the bordering Moreno Valley was described by Kelley (1949, p. 76–78). The principal sedimentary formation is the Pierre shale (Cretaceous), which is capped on some of the peaks by the Raton formation of Cretaceous and Paleocene age. The shales are intruded by large sills and in some places by irregular bodies of quartz monzonite porphyry. Near the contact the shales have been metamorphosed mainly to a fine-grained hornfels, but in the vicinity of Iron Mountain, in the southwestern part of the district, coarse-grained tactite bodies containing epidote, specularite, magnetite, diopside, hornblende, garnet, and scapolite have been formed. Gold, the major metal produced, has been mined principally from quartz-pyrite veins which are closely related to the intrusive porphyry. Copper-gold deposits in the tactite are of minor importance. The specularite-epidote tactite bodies on the western slope of Iron Mountain have been prospected but never mined.

The district was visited in June 1949. A description of the samples taken and the analytical results obtained are given in table 49. The iron-rich tactite on the west side of Iron Mountain and the copper-gold tactite deposits in Willow Creek on the east side of the mountain were sampled. Two samples were taken at the Baldy Deep tunnel, one of the larger mines in the northern part of the district.

TABLE 49.—*Beryllia in samples from the Elizabethtown district*

[Spectrographic analyses by J. D. Fletcher. BeO figures determined on plates exposed for general scanning but not for precise determination of BeO alone]

Sample	*Description*	BeO (*percent*)
329–262	Grab sample of quartz vein material with molybdenite in biotite granite, from dump of Baldy Deep tunnel	<0. 0004
263	Grab sample of epidote-garnet tactite, from same locality as sample 262	<. 0004
267	10-ft channel sample of epidote-specularite tactite from near portal of lower adit at Iron Mountain iron deposit	<. 0004
271	20-ft channel sample of epidote-specularite tactite from portal of upper adit, same deposit as sample 267	. 0004
272	Specimen of coarse specularite, from same locality as sample 271	<. 0004
273	Grab sample from 25 ft of outcrop of diopside hornfels in road cut on east side of Willow Creek above the Ajax mine	<. 0004
274	Specimen of hornblende-diopside tactite from outcrop at the Ajax mine	<. 0004
275	Specimen of scapolite(?)-diopside tactite, from same locality as sample 274	<. 0004

RATON VOLCANIC REGION

Volcanic cones and lava-capped mesas dominate the landscape throughout an area of about 1,500 square miles in Colfax and neighboring counties, adjacent to Raton (see fig. 31). Similarities of occurrence and composition indicate that these volcanic rocks are of common or related origin. Some of the rocks are analogous in their geological relations and composition to beryllium-bearing feldspathoidal rocks of the Trans-Pecos Region.

The Raton region was visited in June and July 1949, and samples were obtained at several localities. Although the beryllium found in the volcanic rocks probably is not recoverable, its distribution is of interest in connection with the thesis that beryllium tends to be concentrated in feldspathoidal members of a rock series.

GEOLOGY

The general geology of the Raton region was described by Lee (1922) and Griggs (1948); detailed discussions of the volcanic rock series are given by Collins (1949) and Stobbe (1949). The pre-Tertiary rocks are continental and marine strata of Mesozoic age, chiefly shale and sandstone but containing some limestone. Details of the stratigraphy are given in the publications cited. Earth movements in Tertiary time gave rise to the Raton basin and the Sierra Grande arch, which trends northeast across the center of the volcanic area. Planation of the deformed surface was followed by deposition of the Ogallala formation in Pliocene time. Later deformation, presumably related to the volcanic activity, in Quaternary time, gave the gravels a regional dip of about 50 feet per mile to the southeast.

The sequence of lavas in the Raton region was worked out by Mertie (Lee, 1922, p. 9) largely on the basis of physiographic evidence. Later workers have given conflicting interpretations, particularly for the rocks in southern Colfax County (Griggs, 1948, p. 37–40; Collins, 1949, p. 1032–1036; Stobbe, 1949, p. 1071–1077). The probable relation of the volcanic rocks in the Raton area to rocks in the Cimarron Range to the west (Smith and Ray, 1943) is given in table 50. In essence, the age correlations and structural interpretations of Collins (1949), and Stobbe (1949), and the geologic boundaries mapped by Griggs, Northrop, and Wood (Griggs, 1948, pl. 1) are adopted for this report. The names applied

TABLE 50.—*Correlation of volcanic rocks and related units in the Raton region*

[Equivalent or correlative rocks are connected by dashed lines]

	Smith and Ray, 1943 (Cimarron Range)		Mertie (in Lee, 1922, p. 1-12)(Raton-Brilliant-Koehler-quadrangles)		Griggs, Northrup, and Wood (in Griggs, 1948, pl. 1) (Colfax County)		Collins (1949) and Stobbe (1949) (Colfax and Union Counties) Quaternary rock names are those given by Collins (1949, p. 1022-1023)
		Quaternary	"Youngest lavas" (east of quadrangles)	Quaternary	Late basalt flows	Quaternary	Capulin basalts (flows).
			Basalt lava flows and stocks		Intermediate mafic flows (with mafic dikes, in part).		Clayton basalts (flows, minor dikes)
			Andesite flows and stocks		Intermediate felsic flows		Chico phonolites (flows, minor dikes, and sills).
							Slagle trachytes (sills, minor dikes).
Early Pleistocene	Basalt, rhyolite, and dacite (Urraca Mesa).		Basalt lava flows				Red Mountain dacites (flows, minor dikes).
Pliocene	Gravels (including Eagle Nest formation)		High-level gravels (in part)	Miocene(?) and Late Tertiary(?)	Early basalt flows (with mafic dikes, in part).		Raton basalts (flows, minor dikes)
	Basalt (in part - La Gruilla Mtn.)		Basalt lava flows		Ogallala formation	Pliocene	Ogallala formation
			High-level gravels (in part)				
Miocene	Quartz monzonite porphyry	Eocene	Quartz monzonite porphyry sills and dikes (southwest of quadrangles).	Early(?) Tertiary	Sills and dikes	Age unknown	Basic dikes

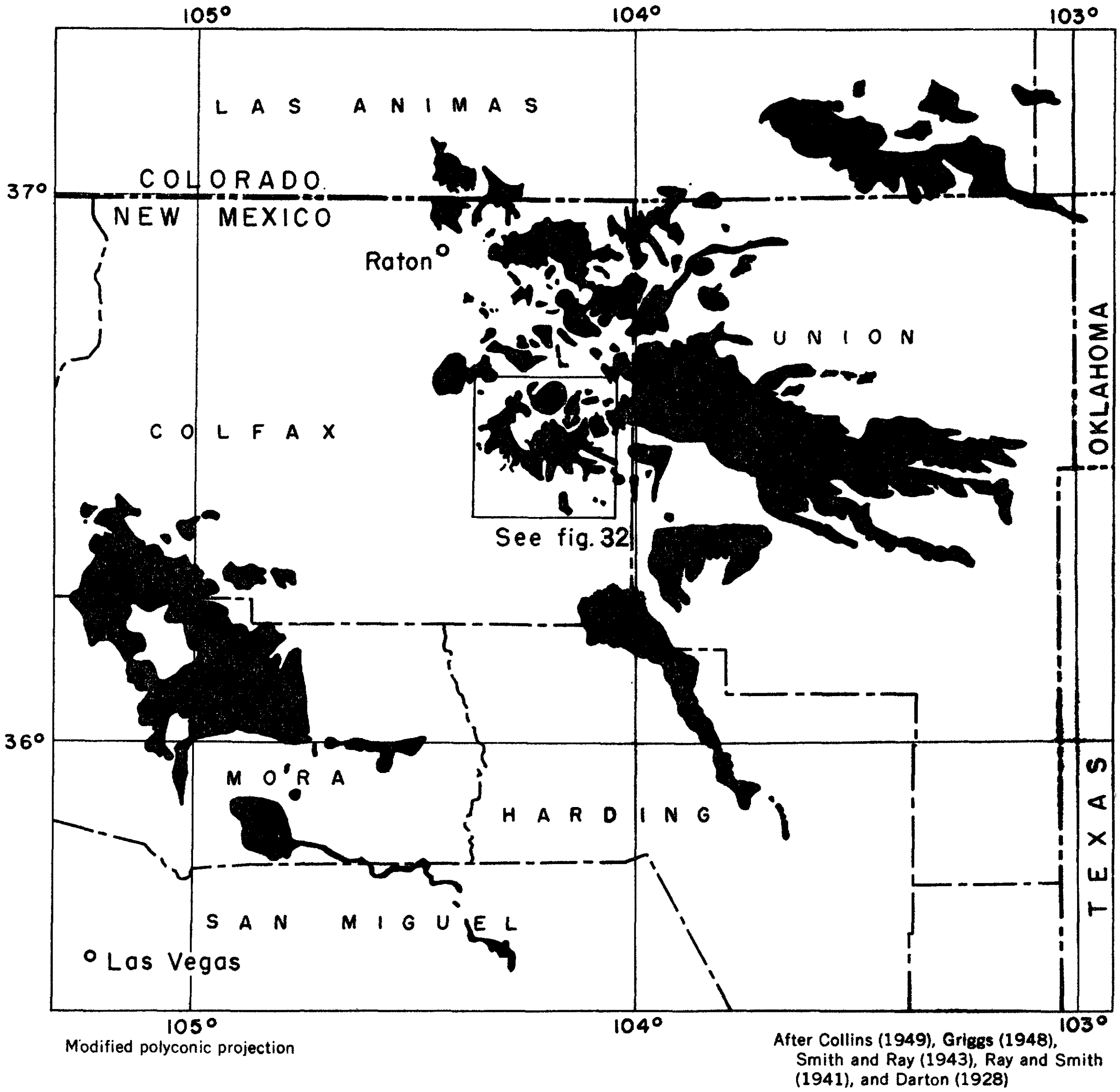


FIGURE 31.—Map of post-Cretaceous volcanic rocks of the Raton region, New Mexico.

to the rocks are those suggested by Collins (1949, p. 1022–1023).

Three ages of basalt flows have been recognized. The oldest flows, the Raton basalts of Collins (1949), cap the high mesas near Raton. They are gray, fine-grained, vesicular rocks with olivine phenocrysts. The basalts of intermediate age, the Clayton basalts of Collins (1949), occur at lower altitude. They contain olivine phenocrysts, and a few of the flows are feldspathoidal. The youngest basalts, the Capulin basalts of Collins (1949), generally are in the valleys. They are black, dense to vesicular rocks with large feldspar phenocrysts and some olivine.

The major differences of opinion concern the volcanic rocks other than basalt. These include the Red Mountain dacites, Chico phonolite, and Slagle trachytes, all of Collins (1949), which are mainly around volcanic centers in southeastern Colfax County. Collins' Red Mountain dacites are apparently equivalent to the "intermediate felsic flows" of Griggs, Northrop, and Wood, which they correlate with Collins' Clayton basalts. According to Collins (1949, p. 1032), the boundary relations between his Red Mountain dacites and his Clayton basalts indicate that the latter is younger. He assumes from physiographic and petrologic data that his Chico phonolites and his Slagle trachytes are closely related rocks that fall into the same age bracket (post-Raton and pre-Clayton) as the Red Mountain dacites. Apparently, the phonolite and trachyte correspond to rocks referred to by Griggs, Northrop, and Wood as "sills and dikes" of early (?) Tertiary age. Although there is general agreement that the trachytes are largely sills, Collins (1949, p. 1034) states that the phonolites are mainly flows, with few sills and dikes.

The phonolite is a green to gray, fine-grained rock containing phenocrysts of aegirite and feldspar. The groundmass is composed of nepheline, analcite, orthoclase, and aegirite, with accessory sodalite, magnetite, and sphene. The trachyte is light brown, fine grained, and contains sparse feldspar phenocrysts. The groundmass is mostly orthoclase, with some acmite-diopside and barkevikite.

OCCURRENCE OF BERYLLIUM

All of the major volcanic rock types were sampled, mainly in the vicinity of the volcanic centers in southeastern Colfax County. Most of the samples were chipped at intervals across fresh outcrops; in a few places carefully selected hand specimens were taken. The localities sampled are shown on figure 32, and analytical data are given in table 51.

The Chico phonolites of Collins (1943) and related dikes are the only rocks in which beryllium was found. These rocks are confined to an area of about 25 square miles in southeastern Colfax County (fig. 32). Most of the phonolite is associated with volcanic centers at Turkey Mountain and Temples Peak. Sills and dikes in the Slagle Canyon area, a few miles south of Turkey Mountain, are similar to the phonolite and probably related to it.

The distribution of BeO in the rocks appears to correlate roughly with the zirconium content, and an inverse relation to the chromium content is suggested. There is also an apparent correlation between BeO con-

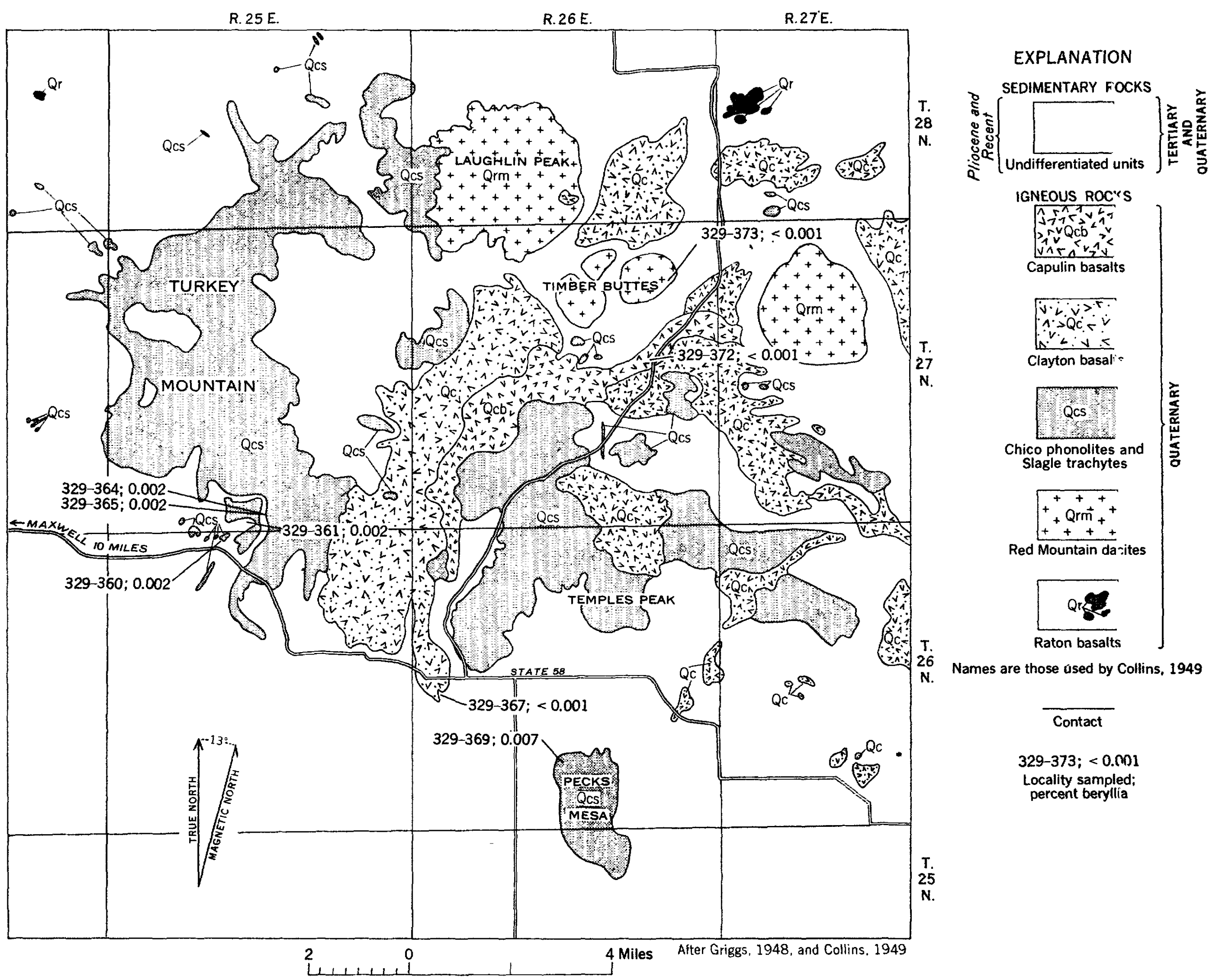


FIGURE 32.—Map of volcanic rocks of southeastern Colfax County, N. Mex.

TABLE 51.—*Beryllium and other elements in volcanic rocks of the Raton region*

Rock type [1]	Sample No.	Sample type	Description	Percent: BeO [2]	Cr [2]	Zr [2]	eU [3]	U [4]
Capulin basalts	329–372	Hand specimen from flow surface.	Highly vesicular black basalt.	<0. 001	0. 00X	0. 00X	<0. 001	-----
Clayton basalts	367	do	Gray fine-grained basalt.	<. 001	. 0X	. 00X	<. 001	-----
Chico phonolites	369	Chip sample across 150-ft section, northwest side Pecks Mesa.	Gray-green, fine-grained, porphyritic.	. 007	. 000X	. X	. 010	0. 004
	361	Chip sample across 125-ft section, east side Slagle Canyon.	Gray, slightly porphyritic.	. 002	. 000X	. 0X	. 007	. 003
Tinguaite dikes similar to Chico phonolites.	360	8-ft channel sample across vertical dike, east side Slagle Canyon.	Dark, green, porphyritic, vertical flow structure.	. 002	. 000X	. 0X	. 005	. 003
	364	Chip sample of 30-ft section of sill, east side Slagle Canyon.[5]	Green, porphyritic	. 002	. 00X	. 0X	. 007	. 002
Slagle trachytes (?) [6]	365	Chip sample of 15-ft section of flow, same locality as 364.	Gray, slightly porphyritic.	. 002	. 000X	. 0X	. 006	. 002
Red Mountain dacites (?).	373	Grab sample from east base of Timber Buttes.[7]	Gray to reddish brown	<. 001	. 000X	. 00X	<. 001	-----

[1] Rock names are those of Collins (1949, p. 1022–1023).
[2] Spectrographic analyses by J. D. Fletcher. BeO figures were obtained on plates exposed for general scanning, and not for precise determination of BeO alone.
[3] Radiometric analyses by J. N. Rosholt. Equivalent uranium is based on measurement of radioactivity wherein it is assumed that all of the radioactivity of a sample arises from uranium and its disintegration products, and that none of the radioactivity arises from the thorium series or from potassium; it is assumed, furthermore, that the uranium is in radioactive equilibrium with all of its disintegration products wherein each radioactive product in the series is disintegrating at exactly the same rate at which it is being formed.
[4] Analyses by L. F. Rader.
[5] Outcrop pictured by Collins, 1949, pl. 4, fig. 1. His thickness figures are apparently reversed.
[6] Designated trachyte by Collins (1949, pl. 4, p. 1034), although his map does not distinguish Slagle trachytes and Chico phonolites.
[7] Timber Buttes rock is said by Collins and Stobbe to be Chico phonolites. This sample, however, proved to be hornblende dacite.

tent and radioactivity in the samples, but the uranium content is fairly uniform. Most of the radioactivity probably is due to thorium. It is known that thorium may be hard to identify in zirconium minerals (Rankama and Sahama, 1950, p. 571).

The mineralogical compositions of the rocks are compared in table 52. The Chico phonolites of Collins (1949) are characterized by high nepheline content and its pyroxene is chiefly aegirite. As beryllium is relatively soluble in these minerals, they probably account for most of the BeO in the rock. It is doubtful that minerals containing beryllium as an essential constituent are present.

TABLE 52.—*Average mineralogical composition of volcanic rocks of the Raton region*

[Rock names are those of Collins (1949, p. 1022–1023)]

	1	2	3	4	5	6
Orthoclase	----	----	84	46	----	----
Plagioclase	46	28	3	----	54	44
Nepheline	----	----	----	39	----	----
Hornblende	----	11	2	----	----	----
Pyroxene	29	----	3	15	26	32
Olivine	17	----	----	----	6	5
Opaque minerals	8	4	8	----	14	19
Glass	----	57	----	----	----	----

1. Raton basalts. Average of nine modal analyses by Mertie (Lee, 1922, p. 9), "first period of eruption."
2. Red Mountain dacites. Average of four modal analyses by Stobbe (1949, p. 1068), including one from Red Mountain.
3. Slagle trachytes. Mode of specimen from Red Hill by Stobbe (1949, p. 1072).
4. Chico phonolites. Average of eight modal analyses by Stobbe (1949, p. 1074).
5. Clayton basalts. Average of six modal analyses by Stobbe (1949, p. 1052).
6. Capulin basalts. Average of four modal analyses by Stobbe (1949, p. 1052), including three from Mount Capulin.

DONA ANA COUNTY

ORGAN DISTRICT

The Organ district is in the Organ Mountains near U. S. Highway 70, about 15 miles east of Las Cruces. The district was visited on August 28, 1949.

The geology of the district has been described in detail by Dunham (1935, p. 194–242). A belt of limestone of Paleozoic age is upturned along the western slope of the range; a large body of Precambrian granite forms the core and the eastern slope of the range. Tertiary intrusive bodies of quartz monzonite and other rocks occur along the range; in the northern part of the district these are in contact with limestone. Near the contact, much of the limestone has been replaced by andradite, diopside, wollastonite, tremolite, epidote, specularite, phlogopite, and idocrase. Small areas of tactite are rich in magnetite. Quartz, sulfides, and tellurides were deposited in fractures in the tactite. Simple fissure veins in intrusive rocks and replacement veins in unmetamorphosed limestone were formed in other parts of the district at this same time.

Samples were taken of the tactite and related mineral deposits. Descriptions of samples and analytical data are given in table 53. None of the samples contained more than 0.0004 percent BeO.

TABLE 53. *Beryllia in samples from the Organ district*

[Spectrographic analyses by J. D. Fletcher. BeO figures determined on plates exposed for general scanning and not for precise determination of BeO alone]

Sample	*Description*	BeO (*percent*)
329-790	Chip sample across 90 ft of outcrop of garnet-wollastonite-diopside tactite, with later quartz veins, in Magdalena limestone next to quartz monzonite contact southeast of Roos shaft, Memphis mine	<0.0004
791	Channel sample across 1.5 ft of garnet tactite, with copper and iron stains, along footwall of fault next to Magdalena limestone at collar of shaft 400 ft southwest of Roos shaft	.0004
793	Chip sample across 25 ft of outcrop of garnet-quartz-specularite tactite in Lake Valley limestone next to quartz monzonite contact at Big Three mine	<.0004
794	Grab sample of garnet-quartz-specularite tactite from dump of Excelsior mine. Idocrase reported from this area (Dunham, 1935, p. 230)	<.0004
796	Channel sample across 18 ft of fine-grained garnet tactite from outcrop at portal of Merrimac mine	<.0004
797	Grab sample of garnet-sphalerite-specularite ore from bin of Merrimac mine	<.0004
797a	Channel sample across 7 ft of magnetite-chlorite-serpentine tactite in Fusselman or Montoya limestone at quartz monzonite contact, on Iron Mask claim (southeast of the Merrimac mine). (See Dunham, 1935, p. 234)	<.0004
799	Channel sample across 2 ft of garnet tactite from El Paso limestone at top of San Augustine ridge	<.0004
802	Specimens of galena-altaite ore from Hilltop mine	<.0004

GRANT COUNTY

BURRO MOUNTAINS DISTRICT

Although the Burro Mountains district was not visited during the present investigation, two samples were furnished by Elliot Gillerman, who has described mineral deposits of the district (Gillerman, 1952, p. 261–289).

Most of the Burro Mountains is composed of rocks of Precambrian age, which according to Paige (1916, p. 3)

> * * * comprise many granitoid varieties, some of which are gneissic, and minor ill-defined schistose and quartzitic masses, which are metamorphosed ancient sediments * * *. The granite of the Big Burro Mountains is a medium- to fine-grained gray biotite granite composed of dominant orthoclase with some albite, abundant quartz, and brown biotite, with accessory apatite, titanite, and iron oxide. Coarse-grained and porphyritic varieties are also found.

In the vicinity of Tyrone on the northeastern edge of the Burro Mountains, the Precambrian rocks are intruded by a stock of Cretaceous or Tertiary quartz monzonite porphyry. The principal ore deposits are disseminated copper in the quartz monzonite and gold-quartz fissure veins in the Precambrian granite.

A grab sample (329–318) of fluorite from the Long Lost Brother claim, on the western slope of the Burro Mountains (see Rothrock, Johnson, and Hahn, 1946, p. 73–74, and Gillerman, 1952, p. 278–279) contains 0.002 percent BeO. The other sample (329–319), from an unnamed prospect in T. 22 S., R. 15 W., on the southeastern slope of the Big Burro Mountains, consisted of scheelite-bearing tactite. It contained 0.001 percent BeO.

CARPENTER DISTRICT

The Carpenter district is high on the west slope of the Black Range in northeastern Grant County. The principal mines are reached by about 15 miles of rough graded road that leads northeastward from State Highway 61 just south of Sherman post office. The district was visited on July 27 and on August 23, 1949. Mr. H. A. Teel of San Lorenzo, N. Mex., owner of the Grandview mine, guided the writers over the area and supplied samples and information. Previous work for the U. S. Geological Survey has resulted in the discovery of helvite in the Grandview mine (Weissenborn, 1948), and therefore the sampling was concentrated in that area.

A short sketch of the geology of the district was given by Gordon (Lindgren, Graton, and Gordon, 1910, p. 272). During World War II the geology was studied in detail by R. L. Griggs, S. P. Ellison, D. M. Kinney, and A. E. Weissenborn of the U. S. Geological Survey, and exploratory work was carried on by the U. S. Bureau of Mines (Hill, 1946, p. 6–7). The geology of a part of the district is shown on figure 33.

Sedimentary rocks of Paleozoic age, mainly limestone, dip westward along the flank of the range. They include the El Paso (Ordovician), Montoya (Ordovician), Fusselman (Silurian), Percha (Devonian), Lake Valley (Mississippian), and Magdalena (Pennsylvanian) formations. Along the crest of the range, these rocks are covered by Tertiary volcanic breccias and flows. Normal faulting in places has brought the volcanic rocks into contact with rocks of early Paleozoic age. Small bodies of quartz monzonite, mainly in the forms of sills, intruded the volcanic rocks. Some of the limestone, particularly in the workings of the Grandview mine, has been altered to tactite composed of garnet, epidote, magnetite, and chlorite. The tactite is not found at igneous contacts, and its occurrence may be controlled by fractures. Replacement ore bodies of galena, sphalerite, and fluorite occur irregularly along fracture zones in the Montoya limestone.

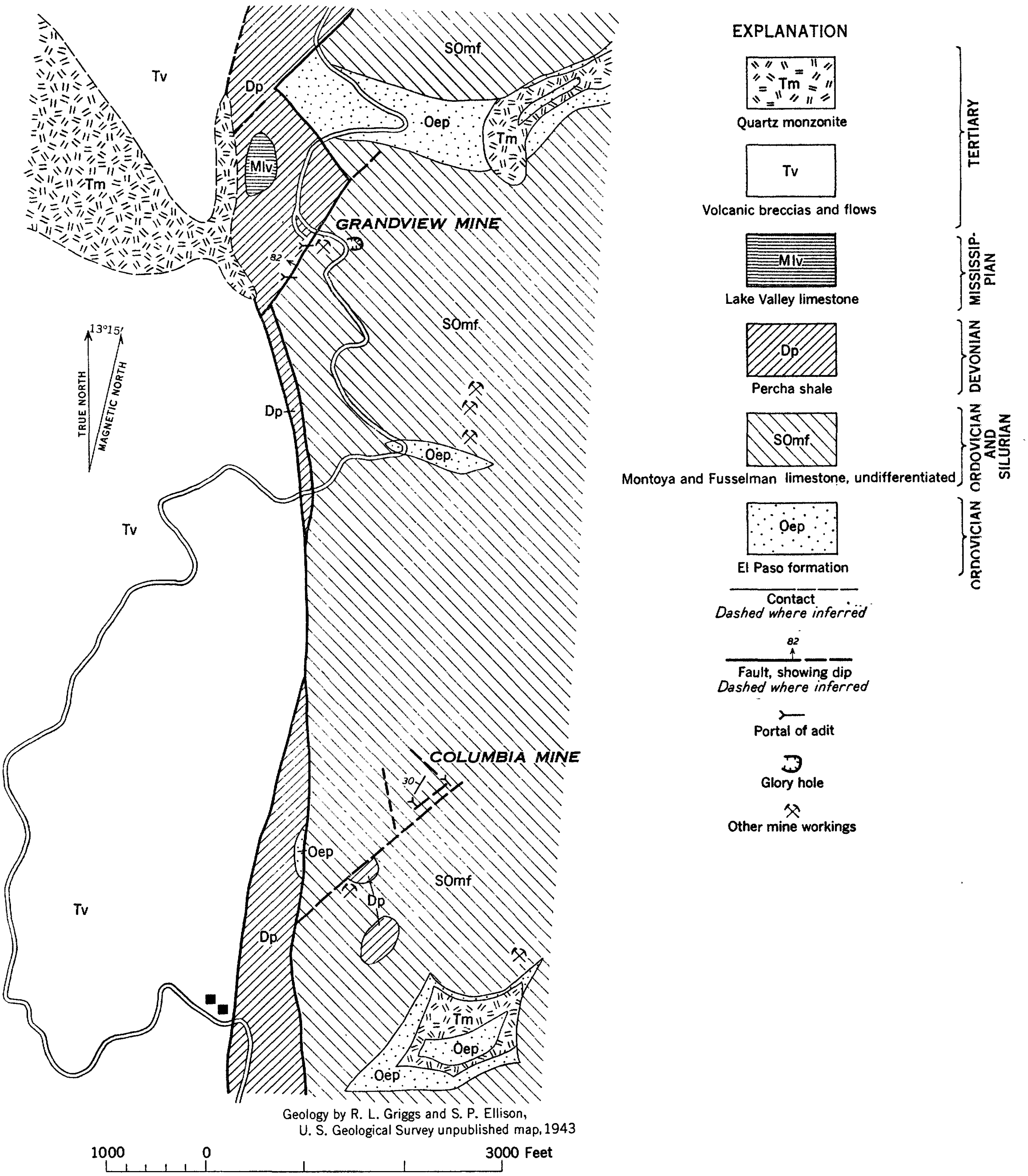


FIGURE 83.—Geologic map of part of the Carpenter district, Grant County, N. Mex.

GRANDVIEW MINE

The Grandview mine is in secs. 29 and 32, T. 16 S., R. 9 W., 15 miles by road northeast of State Highway 61. The claims had been prospected for about 50 years before the first shipment of lead-zinc ore was made in 1937. From 1938 to 1945 the mine was developed by the Black Range Development Co., and about 19,000 tons of ore, including 1,600 tons of zinc, 900 tons of lead, 46 tons of copper, and 14,000 ounces of silver were produced. The mine was idle from 1945 until 1948, when small shipments of ore were made to the Blackhawk custom mill at Hanover, N. Mex. In August 1949, the mine was not operating.

Development of the mine has been mainly through two adits at altitudes of 7,516 and 7,570 feet; several stopes connect with a glory hole at about 7,625 feet altitude. A winze goes a short distance below the 7,516-foot level. A short adit was driven about 250 feet south of the portal of the lower adit.

Helvite from the Grandview mine was first discovered by J. W. Adams on a specimen of fluorite collected by A. E. Weissenborn, both of the Geological Survey. During the present investigation several specimens of helvite were collected, both from the dumps and from small veins exposed in the glory hole. The refractive index of the helvite is variable but is near 1.730 (Weissenborn, 1948, p. 649); this indicates that it is essentially the manganian member of the series (Glass, Jahns, and Stevens, 1944, p. 183). The helvite occurs mainly in vugs lined with small prisms of quartz, mostly in cherty limestone. Many of the quartz crystals are coated with a thin layer of chalcedony. Crystals of fluorite and sphalerite are later than the quartz. Tetrahedra of helvite as much as 3 mm on an edge grow in or on the chalcedony but not on the quartz crystals. Some of the helvite is associated with fluorite, but a sample of the fluorite contained no beryllium.

Samples were taken from the dumps and underground workings at the Grandview mine, as described in table 54. No beryllium-bearing minerals other than helvite were found in the samples, and it is assumed that almost all of the beryllium is contained in helvite. The possibility of byproduct recovery of beryllium therefore appears to be good if the mine returns to operation as a lead-zinc producer.

Beryllium was not found in a garnet-rich sample (329–717) from the southern adit. This may indicate that the occurrence of beryllium at the Grandview mine is not related to pyrometasomatism. The association of helvite with chlorite and chalcedony in vugs suggests deposition at relatively low temperature.

TABLE 54.—*Beryllia in samples from the Carpenter district*

[Spectrographic analyses by J. D. Fletcher. BeO figures determined on plates exposed for general scanning but not for precise determination of BeO alone]

Sample	*Description*	BeO (*percent*)
329–315	Specimen of white fluorite from dump of lower adit, Grandview mine	0.001
712	Channel sample of rhodochrosite-galena vein, same adit	.001
717	Grab sample of garnet-galena ore from southern adit, Grandview mine	<.001
718	Grab sample of vuggy quartz vein material, with galena, sphalerite, and fluorite, from upper adit of Grandview mine. No helvite seen	.02
720	Channel sample of highly oxidized material, with chlorite, galena, and hematite, from short abandoned adit just north of main upper adit, Grandview mine	.02
721	Channel sample of limestone highly altered to chlorite, with iron and manganese oxides; same location as sample 720	<.001
722	Channel sample of cherty limestone with vugs containing quartz, galena, and helvite, along north-trending vein in glory hole of Grandview mine	.01
726	Grab sample of andradite-diopside banded tactite, with epidote, from dump of Columbia mine	.001
727	Specimen of sphalerite-galena-fluorite ore from dump of Columbia mine	<.001
735c	Composite sample of mill heads for 2 days in May and June 1949, from Grandview mine (Blackhawk mill, Hanover)	.01

OTHER MINES

The Columbia mine is about 4,000 feet south of the Grandview mine (fig. 33). About 600 feet of drifts explore small veins in the Montoya limestone. Samples of tactite and of sphalerite-galena-fluorite ore taken from the dumps contain less than 0.001 percent BeO (table 54).

CENTRAL DISTRICT (INCLUDING FIERRO, HANOVER, AND SANTA RITA DISTRICTS)

The Central mining district, about 15 miles east of Silver City, covers a large area between Bayard and Fierro, N. Mex. The principal mines are large producers of copper, zinc, lead, and iron. During the present investigation, the area was visited in July and August 1949. Several geologists with experience in the region furnished information and samples. Thanks are due especially to S. G. Lasky and R. M. Hernon of the U. S. Geological Survey, Harrison Schmitt, consulting geologist, of Silver City, and geologists and engineers of the American Smelting and Refining Co., Empire Zinc Co., Kennecott Copper Co., and Peru Mining Co.

The complex geology of the district has been the subject of much study; the numerous published reports include those by Lindgren, Graton, and Gordon (1910, p. 305–317), Paige (1916), Landon (1931), Schmitt (1935, 1939), Spencer and Paige (1935), Lasky (1936), Lasky and Hoagland (1948), Hernon (1949), Kelley (1949, p. 83–124), Graf and Kerr (1950), and Kerr, Kulp, Patterson, and Wright (1950). The district is on the Fort Bayard arch, which modifies the eastern limb of a broad syncline of sedimentary rocks of Paleozoic and Mesozoic ages. At various times the sediments were intruded by stocks, sills, and dikes of a variety of igneous rocks. Early quartz diorite sills are conspicuous; one known as the Marker sill is found in the Magdalena formation of Pennsylvanian age throughout most of the district. The principal intrusive body is the Hanover granodiorite stock, about 2½ miles long; the smaller intrusives at Santa Rita and Copper Flat are of similar age and composition. Related granodiorite dikes of at least two ages were intruded along steep northeast-trending faults.

Thermal metamorphism has been widespread and in most places was accompanied by large additions of material. Andradite, hedenbergite, magnetite, and ilvaite are the principal minerals in tactite bodies formed around the southern end of the Hanover stock and at Copper Flat, where they replace the Lake Valley (Mississippian), and the Magdalena (Pennsylvanian) limestones. The occurrence of tactite is controlled by dike-fault zones and favorable stratigraphic horizons, as well as by nearness to the intrusive body. Epidote is common in shaly members. The lower limestones of early Paleozoic age, particularly the El Paso (Ordovician) limestone at Fierro, are principally replaced by magnetite, serpentine, and wollastonite. Small amounts of magnetite and garnet occur along the northern border of the Santa Rita stock. Garnet and pyroxene are found in a few places along the dike complex that extends southwestward toward Vanadium.

Many of the ore deposits are associated with the tactite bodies. In the Hanover area large masses of sphalerite replace the tactite along its contact with the unsilicated marble, particularly in the upper member of the Lake Valley limestone. These deposits are represented by samples from the Empire Zinc Company quarries and from the Pewabic mine. At Copper Flat similar deposits occur within the tactite. Between the Hanover and Santa Rita stocks, sphalerite bodies lie along north-trending fissures. The gangue contains hedenbergite and a little garnet, ilvaite, rhodonite, and epidote, as well as calcite. Although the deposits are not close to intrusive rocks, they are probably similar in origin to those of the Pewabic and Empire zinc mines. This type of deposit is represented by samples from the Oswaldo mine.

In the southeastern part of the district, near Vanadium and Bayard, sphalerite-galena-chalcopyrite ore occurs along the contacts of the granodiorite dikes with Upper Cretaceous shale and limestone. Although both the dikes and the shale were extensively replaced by quartz, sericite, and pyrite, silicates such as pyroxene and garnet are much less common. This type of deposit is represented by the Ground Hog mine, where samples were taken mostly from the rare garnet-pyroxene zones. The large copper deposit at Sana Rita is a replacement of the granodiorite stock, and was not sampled.

The samples taken are described in table 55. Apparently the large tactite bodies at the southern end of the Hanover stock, both on the western side (Buckhorn Gulch and Hill 6650) and on the eastern side

TABLE 55.—*Beryllia in samples from the Central district*

[Spectrographic analyses by J. D. Fletcher. BeO figures determined or plates exposed for general scanning but not for precise determination of BeO alone]

Sample	*Description*	BeO (*percent*)
329–276	4-ft channel sample of hedenbergite-garnet-calcite marble from top of Lake Valley limestone in Uncle Sam quarry, Buckhorn Gulch, Hanover	<0.0004
277	8-ft channel sample of epidotized shale (so-called Parting shale of local usage) from base of Oswaldo formation, Magdalena group, from same locality as sample 276	.0008
280	Chip sample from 50-ft exposure of garnet tactite, lower part of Oswaldo formation at south end of "150 quarry," Buckhorn Gulch	<.0004
281	8-ft channel sample of magnetite-garnet tactite from Oswaldo formation in iron mine at top of Hill 6650, ¼ mile west of Hanover	<.0004
282	Chip sample from exposure of garnet-hedenbergite tactite in Oswaldo formation above white marble and below epidotized shale, "350 quarry," Buckhorn Gulch	<.0004
284	Chip sample from 125-ft exposure of garnet tactite in Oswaldo formation between Hanover stock and Hanover sill, in road cut 800 ft south of Hanover	.0004
286	Chip sample from 20-ft exposure of magnetite-garnet tactite in upper part of Lake Valley formation, open pit of Snowflake iron mine	<.0004
287	Chip sample from 6-ft exposure of magnetite-serpentine in so-called parting shale of local usage of Oswaldo formation, from same locality as sample 329–286	<.0004
288	Chip sample from 2-ft bed of garnet-pyroxene hornfels in upper part of Abo sandstone, near Mountain Home mine on Humboldt Mountain. Idocrase reported from this locality (Schmitt, 1939, p. 812) but none was noted in the sampling	<.0004
289	Specimen of rhodonite- and hedenbergite-bearing limestone from 445N stope of Oswaldo mine	.000X
291	Core split of garnet-diopside tactite, with pyrite, magnetite, chalcopyrite, and sphalerite, in Oswaldo formation, from 41 to 302 ft in diamond-drill hole 1101, Santa Rita area	<.0004
292	Core split of garnet-pyroxene-epidote tactite and some hornfels, with pyrite, magnetite, and chalcopyrite, in upper part of Lake Valley limestone, from 320 to 590 ft in diamond-drill hole 1101, Santa Rita area	<.0004

TABLE 55.—*Beryllia in samples from the Central district*—Con.

Sample	Description	BeO (percent)
293	Core split of epidote-chlorite-pyrite-serpentine rock, with some massive biotite hornfels, in lower part of Lake Valley limestone, from 590 to 685 ft in diamond-drill hole 1101, Santa Rita area	<0.0004
294	Core split of 6 in. out of 15.5 ft of highly altered granodiorite dike in Lake Valley limestone, from horizontal drill hole east of 436 drift in Oswaldo mine	.0004
295	Core split of 7 in. out of 12.5 ft of epidote-garnet-pyrite tactite from same formation and drill hole as sample 294	<.0004
296	Core split of 5 in. out of 1.5 ft of sphalerite and tactite from same formation and drill hole as sample 294	.001
297	Core split of 5 in. out of 10 ft of unmetamorphosed limestone, same formation and drill hole as sample 294	<.0004
301	Chip sample from 50-ft exposure of garnet and sphalerite in lower part of Lake Valley limestone on 160 level Pewabic mine	<.0004
302	6-ft channel sample of garnet-diopside tactite in upper part of Lake Valley limestone on 160 level of Pewabic mine	<.0004
303	6-ft channel sample of garnet tactite in upper part of Oswaldo formation, on 160 level of Pewabic mine	<.0004
305	Grab sample from 500-sq-ft exposure of granodiorite of Hanover stock, 1,000 ft east of Hanover. Aplite dikes excluded from sample	<.0004
306	30-ft channel sample of magnetite-serpentine tactite highly altered to clay, from upper part of El Paso limestone at northwest end of open pit at Jim Fair mine, Fierro	<.0004
308	Grab sample from 2,000-sq-ft exposure of garnet tactite in Oswaldo formation, west side Yellowdog Gulch, near west edge of Copper Flat stock. Idocrase reported from this locality (personal communication from R. M. Hernon) but none was found during sampling	<.0004
730	4.5-ft channel sample of hedenbergite tactite altered to chlorite, with sphalerite, in upper part of Lake Valley limestone near quartz granodiorite porphyry dike on 1,800 level of Groundhog mine	.001
732	Specimen of hedenbergite and sphalerite-pyrite ore, in upper part of Lake Valley limestone near hornblende granodiorite porphyry dike 25 ft above 1,800 level of Groundhog mine	.0008
733	4-ft channel sample of hematite-pyrite-sphalerite-hedenbergite tactite at contact of quartz granodiorite porphyry dike and limestone, 1,800 level of Groundhog mine	.0008
734	Grab sample from 4-in. vein of rhodonite-sphalerite-hedenbergite in limestone near quartz granodiorite porphyry dike on 1,800 level of Groundhog mine	<.0004
807	Grab sample[1] of garnet ($Gr_{08}An_{88}Al_{04}$)-hedenbergite tactite with sphalerite, at dike contact on 1,800 level of Groundhog mine	.002

[1] Sample collected by Mr. B. C. Hardie of American Smelting & Refining Co.

(Pewabic mine), contain little or no beryllium. The same is true of the magnetite deposits farther north (Snowflake and Jim Fair mines). Small amounts of beryllium were detected in the limestone replacement ores of the Ground Hog and Oswaldo mines. The highest value—0.002 percent BeO—was found in garnet tactite from the Ground Hog mine, but such material is quite rare in this part of the district.

PINOS ALTOS DISTRICT

The Pinos Altos district is in the Pinos Altos Mountains about 8 miles north of Silver City. The district was visited on August 24, 1949. James Neumann, chief geologist for the United States Smelting and Refining Co. at Vanadium, N. Mex., supplied specimens of the ores and information concerning the mining operations.

The geology of the Pinos Altos district was described by Graton (Lindgren, Graton, and Gordon, 1910, p. 297–301) and by Paige (1910; 1916, p. 14). On the west side of the Pinos Altos Mountains is a north-trending mass of limestones of Paleozoic age about 1½ miles long and less than a mile wide. Early mafic intrusive rocks, principally diorite porphyry, are cut by a mass of granodiorite about 2 miles in diameter. Both the main intrusive and diorite porphyry dikes cut the limestones and are accompanied by some pyrometasomatic alteration. Tactites composed of garnet, pyroxene, and epidote are of limited and irregular extent. The ore is composed of sphalerite, pyrite, chalcopyrite, bismuthinite, and quartz; at places it occurs in the tactite. Both thrust and normal faults are common and some faults are mineralized.

The largest mine in the western part of the district is the Cleveland tunnel, described in detail by Paige (1910, p. 122–125). A grab sample (329–738) of sphalerite-pyrite ore collected from the dump contained less than 0.0004 percent BeO. Although Graton (Lindgren, Graton, and Gordon, 1910, p. 300) describes much garnet and specularite from this tunnel, none was observed on the dump. At the Houston-Thomas mine, which adjoins the Cleveland tunnel on the northwest, some garnet-pyroxene-epidote tactite was found. A grab sample (329–740) of sphalerite-pyrite-chalcopyrite ore from the dump of the new shaft of this mine contained less than 0.0004 percent BeO. The geology of the mine is described in a report by Soule (1948). The gold-quartz fissure veins in the granodiorite of the eastern part of the district were not sampled.

HIDALGO COUNTY

APACHE NO. 2 DISTRICT

The Apache No. 2 district is in the Apache Hills, 6 miles southeast of Hachita, N. Mex., which is on the Southern Pacific Railroad and State Highways 9 and 81. The district is reached by an unimproved road from Hachita. It was visited on August 26 and 27, 1949. Albert Fitch of Hachita, owner of the Apache mine, furnished much information on the deposits of this and neighboring districts. Little work seems to have been done in the district since 1938 when the United States Smelting and Refining Co. ceased operations at their new shaft on the Apache claim.

The geology of the district was described briefly by Lindgren (Lindgren, Graton, and Gordon, 1910, p. 343–344). Gently-dipping Cretaceous and possibly Pennsylvanian limestones are exposed in the northern part of the Apache Hills (Darton, 1928, p. 348). A sill-like intrusive body of granodiorite porphyry crops out along the southern slope of the hills. Ore deposits are found only at the southern contact of this body with limestone and consist of large masses of marble and tactite that are partly replaced by iron, copper, bismuth, and silver minerals. The ore minerals have been oxidized to a depth of at least 500 feet. Scheelite and wolframite are reported to occur in large quantities in part of the Apache mine.

Four samples were taken at localities shown in figure 34 and are described below:

Sample	*Description*
329–752	Chip sample from 15 ft of exposure of garnetized marble, with copper and iron stains, in face of glory hole 125 ft N. 20° W. of Apache shaft. Scheelite reported at this locality.
755	Grab sample of garnet-epidote-calcite-pyrite marble from dump of new Apache shaft.
781	Grab sample of garnet tactite from two lenses exposed in limestone and conglomerate.
783	6-ft channel sample of garnet tactite, with copper and iron stains, in limestone (sample 781 from same layer).

Spectrographic analysis by Janet D. Fletcher did not detect beryllium in these samples, the limit of detection being about 0.0004 percent BeO.

HACHITA DISTRICT (INCLUDING EUREKA AND SYLVANITE DISTRICTS)

The Hachita district is in the Little Hatchet Mountains about 12 miles southwest of Hachita. The mines in the northeastern part of the range, near Old Hachita, commonly known as the Eureka district, are reached by a graded road from Hachita. This part of the district is in Grant County. The mines in the southern part of the range, including the old camp of Sylvanite, are best reached over a road leading southwestward from Hachita across a pass in the Little Hatchet Mountains. The road along the southwestern part of the range south of Sylvanite was barely passable when the district was visited on August 25 and 26, 1949.

An account of the geology of the Little Hatchet Mountains by Lasky (1947) contains excellent descrip-

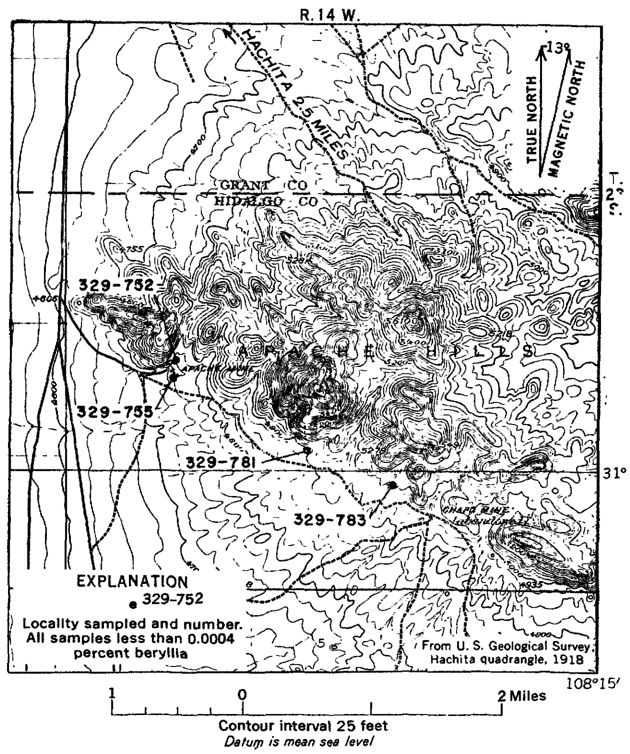


FIGURE 34.—Index map showing localities sampled in the Apache No. 2 district, Hidalgo County, N. Mex.

tions of the metamorphism and mineral deposits in the area. The sedimentary rocks of the Little Hatchet Mountains are of Early Cretaceous age (Bisbee group), and include possibly 5,000 feet of the Broken Jug limestone overlain by about 15,000 feet of clastic sediments and volcanic rocks. The several intrusive bodies are mostly of Late Cretaceous or early Tertiary age. Outcrops of monzonite and quartz monzonite near Eureka and Sylvanite are interpreted as being segments of a large continuous sill-like body in the sedimentary rocks. The rocks are displaced by the Copper Dick fault which down drops the northern half of the range by 3 miles. A stock of granitic rocks forms the southern tip of the range where dikes are common.

Near their contact with the stock, the sedimentary rocks are metamorphosed to tactite and hornfels containing garnet, pyroxene, scapolite, and feldspar. A zone of actinolite marble occurs at greater but variable distances from the contact.

The few short veins are mostly within or near the monzonite at Eureka and Sylvanite. At Sylvanite native gold occurs with chalcopyrite, hessite, tetradymite, arsenopyrite, and pyrite in a gangue of tourmaline, actinolite, quartz, and calcite. At Eureka galena and sphalerite are in a gangue composed chiefly of manganosiderite. Scheelite and molybdenite are uncommon.

The following samples from the Hachita district were analyzed for beryllium:

Sample	*Description*
329–740a	Sample from several 8-in. channels across vein of scheelite-hematite-tetradymite ore at contact of monzonite and marble, from 25-ft shaft 200 ft south of the southeast corner of the Virginia claim (Lasky, 1947, p. 67).
741	4-ft core of mill tailings at American mill.
742	Grab sample of arsenopyrite-pyrite-sphalerite-manganosiderite-calcite ore, from dump of American mine.
743	Grab sample of manganese carbonate and oxides from dump of American mine.
744	Chip sample from 100 sq ft of garnet-pyroxene tactite exposed northeast of Fitzgerald shaft, American mine.
745	Chip sample across 30 ft of garnet-quartz tactite exposed north of Fitzgerald shaft, American mine.
746	Grab sample of chalcopyrite-garnet ore from dump of Copper Dick mine.
747	20-ft channel sample of garnet tactite, with copper carbonates, from northeast face of opencuts at Copper Dick mine.
749	Sample of oxidized ore from Santa Maria tunnel, originally consisting chiefly of quartz, calcite, barite, chalcopyrite, pyrite, molybdenite, and epidote.
750	Grab sample of garnet-chalcopyrite-molybdenite ore from metamorphosed Broken Jug limestone at contact of monzonite stock, on Wyoming claim northwest of Hachita Peak.
751	Chip sample from outcrop of coarse amphibole tactite, from Howells Ridge formation near monzonite contact, south side of Sylvanite Gulch.

Spectrographic analyses by J. D. Fletcher did not detect beryllium in any of these samples, the limit of detection being about 0.0004 percent BeO. The gold-quartz veins of the Sylvanite area were not sampled.

LORDSBURG DISTRICT

The Lordsburg mining district, also known as the Virginia district, is in the northern Pyramid Mountains, a few miles southwest of Lordsburg, which is on the Southern Pacific Railroad and U. S. Highway 80. The district was visited on July 25, 1949.

The geology of the district was described in detail by Lasky (1938) and that of the fluorspar mines by Rothrock, Johnson, and Hahn (1946, p. 104–108). The oldest rocks are basalts of Early Cretaceous age, intruded by plugs of basalt and rhyolite. An irregular stock of granodiorite forms the northeastern part of the mountains. Faults in the granodiorite which trend from east to northeast are the loci of the ore deposits. The most important veins contain chalcopyrite, galena, pyrite, and specularite in a gangue of quartz, calcite, and tourmaline. The earliest stage of vein formation included intensive replacement of the granodiorite wall rock by sericite, chlorite, calcite, tourmaline, and specularite. Fluorspar was deposited with calcite and quartz in open fissures during a late stage of mineralization.

Samples were taken in the Lordsburg district as described below:

Sample	*Description*
329–421	3-ft channel sample across quartz-gossan at outcrop of "85" vein.
422	Grab sample of quartz-sericite-tourmaline vein material with minor chalcopyrite, in granodiorite, from dump of "85" mine.
423	Grab sample of quartz-specularite-chalcopyrite ore in basalt, from dump of "85" mine.
424	Channel sample across 2.5-ft vein of fluorite, 30 ft northeast of Fluorite (Kneyer) No. 1 shaft. (See Rothrock, Johnson, and Hahn, 1946, p. 105–106.)
425	Grab sample fluorite-calcite ore from outcrops and dumps of Fluorite No. 8 claim.
426	Same, from Fluorite No. 9 claim.

Spectrographic analyses by J. D. Fletcher showed no beryllium in any of the samples. The samples from the "85" mine were analyzed qualitatively with a limit of detection of about 0.0004 percent BeO, and the samples from the Fluorite claims were analyzed quantitatively with a limit of detection of about 0.0001 percent BeO. Samples collected in 1943 from the Bonner mill in Lordsburg, which was treating ores from the Bonney and Anita No. 1 mines, for the Mine, Mill, and Smelter Survey of the U. S. Geological Survey also showed no beryllium, the limit of detection being 0.001 percent BeO. Analysis of samples collected in 1943 showed 0.003 percent BeO in the fluorite of the Kneyer No. 1 mine, but the analysis obtained for sample 329–424 is probably more reliable.

SAN SIMON DISTRICT

The San Simon district is in western Hidalgo County, next to the Arizona boundary. It is in the southern part of the Peloncillo Mountains between Steins Pass on the north and Antelope Pass on the south. U. S. Highway 80 crosses Granite Gap about 2 miles north of Antelope Pass. An unimproved road leading south from the highway at the west end of Steins Pass provides limited access to the district. Part of the district was visited on July 25, 1949.

The geology of the district was described briefly by Lindgren and Graton (Lindgren, Graton, and Gordor, 1910, p. 329–332). The principal operation in 1949 was the Silver Hill mine. It is at the head of a canyon on the western slope of the mountains, 4 miles directly east of New Mexico-Arizona boundary monument No. 334 and 5 miles south of Steins Pass. This part of the mountains is composed of a thick section of gray thick-bedded limestone that dips 25° to the north; according to Graton (Lindgren, Graton, and Gordon, 1910, p. 331) it is probably Carboniferous in age. A monzonite porphyry dike 150-feet thick trends southwest for several miles. Garnet, galena, and sphalerite replace limestone in the contact zone near the dike. About 500 feet north of the Silver Hill shaft, an aplitic branch of the dike strikes S. 50° W. Several hundred feet from the main dike the contact zone along the aplite branch has been explored by a 30-foot adit on the S and W claim. The ore here is similar to that at the Silver Hill mine. Two unidentified silicates, one of which resembles wollastonite, form part of the gangue at this locality. About half a mile south of the Silver Hill mine the workings of the Johnny Bull mine explore a similar dike contact zone. Garnet, quartz, and possible wollastonite and pyroxene are accompanied by pyrite, chalcopyrite, bornite, and oxidized copper and iron minerals.

A 4-foot channel sample (329–427) was taken across the ore near the collar of the Silver Hill shaft and a 5-foot channel sample (329–429) was cut across the ore at the portal of the adit on the S and W claim. A sample of tactite (329–433) was chipped from a 10-foot exposure in an open pit below the north shaft of the Johnny Bull mine. Spectrographic analyses by J. D. Fletcher showed no beryllium in any of the samples, the limit of detection being 0.0004 percent BeO.

LINCOLN COUNTY

CAPITAN DISTRICT

The Capitan iron-mining district is at the western end of the Capitan Mountains, just east of State Highway 48, 6 miles north of Capitan. Although time did not permit a visit to the district, a sample of contact metamorphic rock was furnished by V. C. Kelley, who had been studying the iron deposits for the U. S. Geological Survey and the New Mexico Bureau of Mines and Resources. According to his report (Kelley, 1949, p. 144–153), a large stock of granite aplite intrudes the San Andres formation of Permian age. The main iron deposit is a ring-shaped body in the limestone member of the San Andres formation about 2,000 feet west of the contact with the granite. Structural relations suggest that the ore was localized in a pre-intrusion sink hole or collapse structure. An inner zone of epidote, phlogopite, and tremolite is surrounded by a phlogopite-tremolite zone, with magnetite concentrated toward the outside.

The sample (329–810) collected by Kelley was from the outer part of the phlogopite-tremolite zone, between magnetite ore and limestone. The locality is shown in the lower center of his figure 25 (Kelley, 1949) as the northernmost of a pair of trenches just west of the Capitan road. Spectrographic analysis by J. D. Fletcher indicated 0.005 percent BeO. Further sampling for beryllium in this area seems warranted.

GALLINAS DISTRICT

The Gallinas district occupies about 10 square miles at the eastern end of the Gallinas Mountains in northern Lincoln County. The area is served by U. S. Highway 54 and by the Southern Pacific Railroad at Gallinas siding, 8 miles east of the district. Although time did not permit a visit to the district, samples were furnished by V. C. Kelley of the University of New Mexico, and R. G. Knickerbocker of the U. S. Bureau of Mines.

The geology of the district is described by Kelley, Rothrock, and Smalley (1947). Precambrian granite and gneiss are overlain by sandstone and siltstone of Permian age. In early Tertiary time these rocks were intruded by laccoliths and sills of syenite porphyry, with some monzonite and monzonite breccia. The rocks were cut by faults and breccia zones. Ore deposits of magnetite and of fluorite-barite-calcite-bastnaesite with minor amounts of sulfides, occur in the fractures and breccia zones. Locally, as at the American iron mine, epidote and tremolite are associated with the ore.

Sample 329–808 is a specimen of magnetite-actinolite rock from the southeastern edge of the main bench of the American mine (Kelley, 1949, fig. 34). Quantitative spectrographic analysis of this sample by Janet D. Fletcher showed 0.008 percent BeO. Sample 329–866c is a composite of fluorite ore (bastnaesite-bearing) from the Red Cloud mine. Quantitative spectrographic analysis by J. K. Murata showed 0.0002 percent BeO. During a previous mineralogical study of the bastnaesite (Glass and Smalley, 1945), spectrographic analysis had not detected any beryllium in this mineral (J. J. Glass, oral communication). The relatively high beryllium content of the sample from the American mine indicates that further sampling for beryllium in the district is warranted.

LUNA COUNTY

TRES HERMANAS DISTRICT

The Tres Hermanas district is in the Tres Hermanas Mountains, just north of Columbus, in southern Luna County. Two localities in this district were visited on August 26, 1949.

The geology of the Tres Hermanas Mountains was described briefly by Darton (1916, p. 79–82) and the mines by Lindgren, Graton, and Gordon (1910, p. 292–295). The central mass of the mountains is composed of granite porphyry, flanked in part by andesite, rhyolite, and agglomerate, all of Tertiary age. In the northern part of the mountains some of the porphyry has intruded Gym limestone (Permian), which is upturned and metamorphosed to garnet-wollastonite tactite. Spurrite has also been identified in the tactite (Lasky and Wooton, 1933, p. 83).

The principal mineral deposits are those at the northwestern tip of the range which were mined for zinc. Limestone beds 1,000 to 2,000 feet north of the porphyry and limestone contact have been replaced by zinc and lead minerals. Most of the zinc is oxidized, principally to willemite; smithsonite, hydrozincite, and calamine are also present. A chip sample (329–756) of garnet-amphibole-calcite tactite from near the contact contains less than 0.0004 percent BeO.

The Tres Hermanas mine is at the contact of the porphyry and the limestone on the east slope of South Peak. In this area the sediments have been metamorphosed to interbedded garnet-tactite and calcite-marble for a distance of 150 feet from the contact. According to Darton (1916, p. 82), idocrase occurs at this locality. In a channel sample (329–760) taken of a 1-foot bed of the tactite, the BeO content is less than 0.0004 percent.

VICTORIO DISTRICT

The Victorio district comprises a group of mines and prospects at the southeast end of the Victorio Mountains 3 miles south of Gage, a station on the Southern Pacific Railroad. The Victorio Mountains are a range of hills that rise about 800 feet above the neighboring bolson. The area was visited in September 1949 in the company of Mr. D. S. Tedford of Columbus, N. Mex., who generously supplied maps and information. Two days were spent in sampling and mapping an area containing beryllium-bearing veins and tactite deposits.

Most of the production has been from the eastern part of the district, where mines in the vicinity of Mine Hill have produced more than a million dollars in gold, silver, copper, lead, and zinc since 1880. In 1949, mining operations had ceased except for development work. The area containing tungsten and beryllium deposits is about a mile northwest of Mine Hill in secs. 29 and 30, T. 24 S., R. 12 W., New Mexico principal meridian. The deposits are mainly on claims of the Bogle group, including the Eloi, Morlock, Ogre, Bogle, and Yahoo claims, owned by D. S. Tedford, and the Tungsten Hill group, owned by H. R. Eaton of Silver City, N. Mex. Prospecting has been in progress for many years, and a little tungsten ore was produced in 1943.

GEOLOGY

Brief descriptions of the geology of the region are in reports by Lindgren, Graton, and Gordon (1910, p. 290–292), and Darton (1916, p. 83–85). The rocks of Paleozoic age are mainly limestone and include the Montoya (Ordovician), Fusselman (Silurian), and Gym (Permian) formations. These are overlain by Tertiary rocks consisting mainly of shales and sandstones, with some coarse conglomerate beds. Thin flows of andesite and rhyolite of Tertiary age form the top of the section. Most of the beds in the southern part of the range dip southward, but in the northern part they are flat or dip northward. Two or more thrust faults may be present in the region.

In the area containing the tungsten and beryllium deposits, the Fusselman limestone does not crop out and may be absent as a result of faulting or of unconformable overlap. The Montoya and Gym limestones are cut by small masses of light-colored granitic rock. The mineral deposits occur mainly in veins and tactites in Montoya limestone.

TUNGSTEN AND BERYLLIUM DEPOSITS

Tungsten was first reported in 1908 from a vein on what are now the Eloi and Morlock claims (Hess, 1908, p. 726); the vein was described briefly by Lindgren (Lindgren, Graton, and Gordon, 1910, p. 292). Beryl was discovered in this vein in 1948 by W. P. Johnston of the New Jersey Zinc Exploration Co., Hanover, N. Mex. Helvite was found in the scheelite-bearing tactite deposits east of the vein by W. I. Finch during the present investigation. The tungsten deposits are explored by several shafts and many prospect pits. The occurrence of beryllium in the deposits has been discussed by Holser (1953).

Samples obtain from the deposits are described in table 56 and the localities sampled are shown on figure

TABLE 56.—*Beryllia and tungsten in samples from the Victorio district*

[Spectrographic analyses by Janet D. Fletcher. BeO and W figures determined on plates exposed for general scanning but not for precise determination of BeO and W alone]

Sample	*Description*	BeO (*percent*)	W (*percent*)
329–390	6-ft channel sample of altered limestone from south end of pit on Bogle claim. Another sample reportedly from same locality contained 1.06 percent BeO	0.02	0.02
392	4-ft channel sample of altered limestone from pit on Bogle claim	.003	<.01
393	2-ft channel sample of altered limestone from pit on Bogle claim	.004	<.01
394	Grab sample of serpentinized limestone with clay, from bottom of Bogle shaft	.005	<.01
397	Grab sample of garnet marble from dump of Morlock shaft	<.001	.06
399	5-ft channel sample of silicated limestone from collar of Yahoo shaft	.1	.0X
399a	Grossularite separated from sample 399	.007	--------
400	2-ft channel sample from limestone on hanging wall of quartz vein near its north end, in prospect pit on Eloi claim	.02	<.01
401	2-ft channel sample across quartz-muscovite-beryl-wolframite vein, same locality as sample 400	.2	.08

TABLE 56.—*Beryllia and tungsten in samples from the Victorio district*—Continued

Sample	*Description*	BeO (*percent*)	W (*percent*)
402	2-ft channel sample of limestone from footwall of quartz vein, same locality as sample 400	0.005	<0.01
403	Chip sample from outcrop of 3-ft rhyolite dike, on Morlock claim	.003	<.01
404	Two 1-ft channel samples from quartz vein near its south end on Morlock claim	.02	.08
405	1-ft channel sample from quartz vein at bottom of inclined shaft on Morlock claim	.01	.1
408	6-ft channel sample of tactite from pit on Tungsten Hill No. 3 claim	.03	.0X
410a	Idocrase separate from idocrase-fluorite-tremolite-grossularite banded tactite, from pit on the Tungsten Hill No. 2 claim	.02	--------
411	Grab sample of garnet marble and tactite, average of dump at shaft 2 on Tungsten Hill No. 3 claim	.006	.04
414	4-ft channel sample of quartz vein from north end of 35-ft level, Eloi claim	.01	.1
415	4-ft channel sample of garnet tactite from western edge Eloi claim	.06	.06
416	Chip sample of 3-in. quartz-calcite-wolframite vein from shaft near middle of Eloi claim	.02	.X
417	Chip sample of fluorite-quartz vein, a few feet east of sample 416	.005	.2
418	Chip sample of green clay-size material in altered limestone, from pit on Tungsten Hill No. 2 claim	.008	<.01
420	Grab sample of garnet tactite from dump of shaft on Tungsten Hill No. 2 claim	.002	<.01

35. Samples of the vein material contain as much as 0.2 percent BeO and average about 0.04 percent; the maximum BeO content of the tactite and marble samples is 0.1 percent, with the average about 0.02 percent. These amounts are higher than those obtained in any other district sampled during the present investigation. Recovery of beryllium in connection with tungsten mining appears feasible, although the tonnage of tungsten ore probably is not large. Much of the beryllium in the tactite may not be recoverable and their tungsten content is low; the quartz veins are more promising.

Quartz veins

The main quartz vein strikes north for a distance of about 600 feet on the Eloi and Morlock claims, and dips 60° E. It is a uniform fissure filling from 1 to 2 feet thick, making sharp contact with the limestone. A shaft on the Morlock claim follows the vein down 35 feet to short drifts, above which small stopes extend upward. Several other shafts and pits have been dug along the vein outcrop.

Prismatic beryl crystals oriented perpendicular to the vein wall occur mostly as part of a selvage on the hanging-wall side. The beryl crystals, as much as 5 centimeters long and 1 centimeter in diameter, are bounded by simple prisms and pinacoid. The beryl is very pale green (5G 9/2) to colorless (Goddard and others, 1948). The refractive index (N_o) is 1.574± 0.001 corresponding to a composition of about 13.5 percent BeO. Milky quartz and some fine-grained muscovite make up most of the vein. The tungsten mineral is a member of the wolframite series. Accessory minerals are fluorite, galena, pyrite, wulfenite, lead carbonates, and scheelite. The beryl-bearing selvage is most evident in the pits near the northern end of the vein. Beryl could not be seen in samples taken from the southern end of the vein and from the underground workings, but the analyses suggest that it is present.

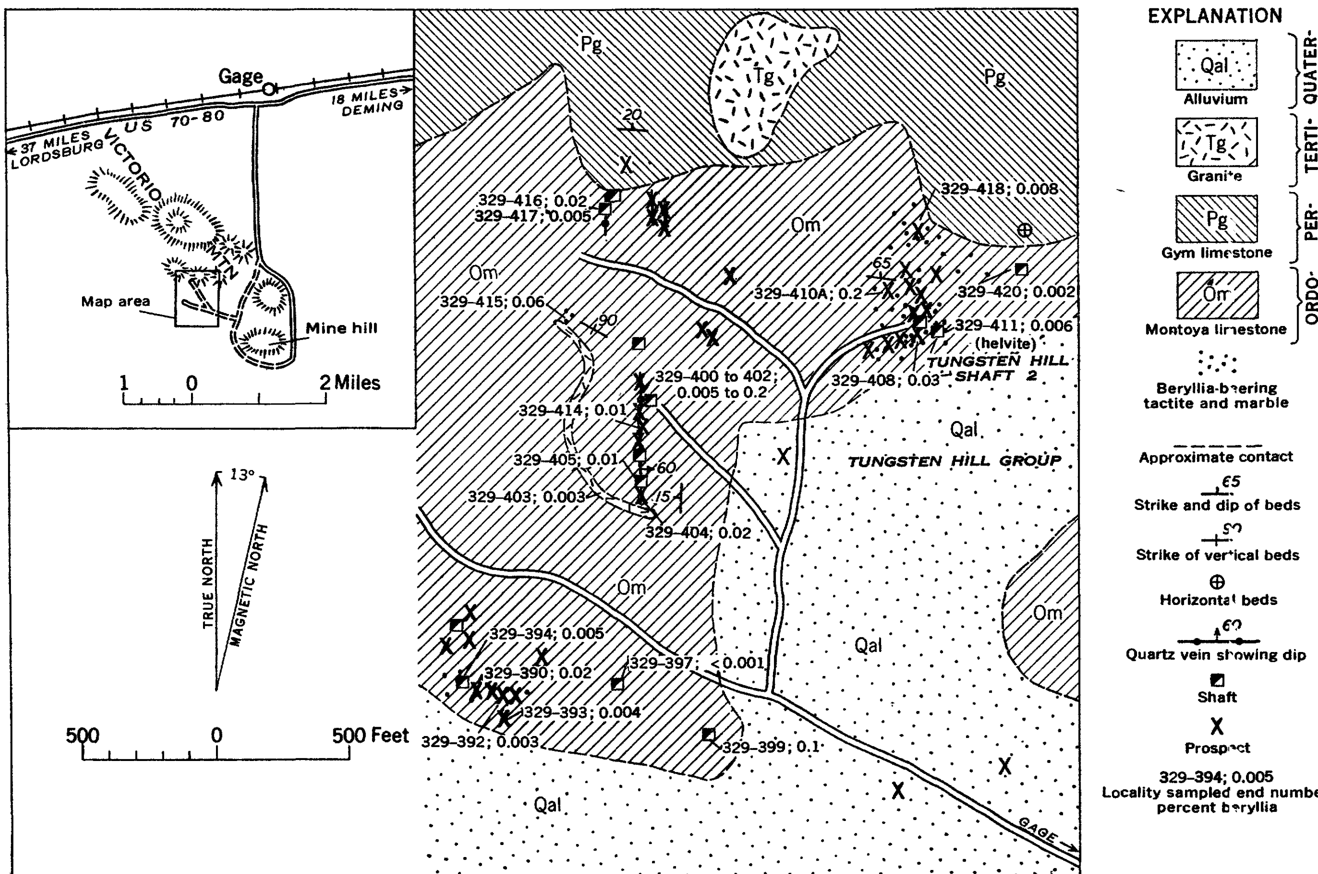
On the hill near the middle of the Eloi claim just below a conglomerate bed that presumably marks the base of the Gym limestone, several small veins have been prospected by shafts or pits (fig. 35). In the westernmost shaft, a 3-inch quartz vein contains calcite and wolframite, and a similar vein that crops out a few feet east is rich in fluorite. Samples 329–416 and 329–417 of these veins contained 0.02 percent and 0.005 percent BeO, respectively.

The walls of the main quartz vein are not greatly altered, the limestone retaining its gray color and fine grain; locally it contains small crystals of grossularite. Near the northern end of the vein, a sample (329–401) across the total width of the vein contained 0.2 percent BeO. A sample (329–400) across 2 feet of the hanging wall contained 0.02 percent BeO and a similar sample (329–402) of the footwall contained 0.005 percent BeO. The small veins on the Eloi claim are bordered partly by tactite.

Pyrometasomatic deposits

Marble and tactite are most common on the Tungsten Hill No. 3 claim (fig. 35) where they occur as irregular lenses and bands several feet in length surrounded by unaltered Montoya limestone. The marble and tactite are not near an exposed intrusive body, although a small mass of granitic rock crops out on the hill to the north. Most of the altered limestone dip steeply.

The most common type of tactite is a coarse aggregate of grossularite and calcite, although in some places the grossularite has entirely replaced the calcite. A pyroxene with optical properties near augite is a common associate of the garnet. These minerals are replaced by fine-grained tremolite and talc. A mineral resembling psilomelane coats some of the garnet. Scheelite is rare. Specimens of grossularite marble



Base from claim map by D S. Tedford

Geology by W. T. Holser and W. I. Finch, September 1949

FIGURE 35.—Tungsten and beryllium deposits in the Victorio district, Luna County, N. Mex.

from the dump of the main shaft on the Tungsten Hill No. 3 claim, contained about 10 percent helvite. The helvite is medium yellow (5Y 7/6) (Goddard and others, 1948) very similar in color to several other minerals in this district, such as grossularite, vanadinite-mimetite, and serpentine. However, the helvite is easily recognized, for it occurs in distinctive sharp tetrahedra scattered through the calcite. The crystals are about 5 millimeters across. Some are twinned on (111). The helvite has a refractive index of 1.735±0.005, and a specific gravity of 3.25, corresponding to a composition of about 85 percent helvite, 15 percent danalite (Glass, Jahns, and Stevens, 1944, p. 183). In thin section the helvite is pale yellow, isotropic, and shows some dark peripheral zones of very fine inclusions, similar to the helvite from Casa La Plata, Cordova Province, Argentina, and Schwartzenberg, Germany (Fischer, 1925, p. 146). Crystals of grossularite are euhedral to subhedral against the helvite.

A green tactite from the Tungsten Hill No. 2 claim is composed of bands of idocrase and fluorite alternating with bands of tremolite, largely altered to talc, and garnet. The idocrase occurs as radiating clusters about 3 millimeters in diameter. It is anomalously biaxial negative, with a very small optic angle, and very low birefringence. The index of refraction (N_x or N_y) is 1.701±0.002. Spectrographic analysis of hand-picked grains (329–410A) showed 0.2 percent BeO.

In the southern part of the area, on the Ogre, Bogle, Morlock, and Yahoo claims, exposures are poor. Pits expose several feet of loose bouldery material partly cemented by caliche. The lower part of the loose material is nearly in place, apparently a product of weathering from the underlying pediment. The rock is highly oxidized and appears to have been originally marble containing garnet and pyroxene. Specimens from shafts on the Ogre and Bogle claims were particularly rich in serpentine. A sample taken from one of these prospects by the U. S. Bureau of Mines was reported to contain 1.06 percent BeO (J. H. Soulé, 1949, personal communication). The highest value obtained in samples of altered limestone and marble taken during the present examination was 0.1 percent BeO (see table 56, samples 329–390 to 329–399).

Helvite was seen only in the specimens from the shaft on the Tungsten No. 3 claim. To trace the occurrence of beryllium in the other tactite, several samples whose analyses showed beryllium were separated in heavy liquid. The heavy separate (mostly grossularite) was tested for helvite by staining (Gruner, 1944), and the light separate (mostly carbonates) was examined optically for beryl. In several thousand grains examined, no grain of either mineral was found. Idocrase was found in only one sample (329–410). Grossularite was separated from a sample containing 0.1 percent BeO (329–399), but was found to contain only 0.007 percent BeO. The mode of occurrence of beryllium in the tactite may be similar to that in the tactite at Iron Mountain, N. Mex., where beryllium occurs in several silicates and an unidentified alteration product (Jahns, 1944b, p. 58).

OTERO COUNTY

The occurrence of beryllium in the feldspathoidal igneous rocks of the Cornudas Mountains, southern Otero County, is discussed in the section on the Trans-Pecos Region, Texas and New Mexico.

The mines of the Juarilla district, northwest of Orogrande, expose extensive tactite zones (Lindgren, Graton, and Gordon, 1910, p. 184–187). Earlier sampling of some of this tactite by the American Smelting and Refining Co. did not detect any beryllium. The district was not visited during the present investigation.

SAN MIGUEL COUNTY

ROCIADA DISTRICT

The Rociada district is in the eastern foothills of the Sangre de Cristo Range. It is reached by improved roads leading westward from State Highway 3. The district was visited on July 20, 1949.

The geology of the district was described briefly by Harley (1940, p. 52–56). The mineral deposits are in Precambrian gneisses and mica schists that have been intruded by sills of diabase and masses of granite. Quartz veins in the metamorphic rocks contain pyrite, chalcopyrite, bornite, chalcocite, sphalerite, and galena, with minor amounts of gold and molybdenite.

At the Azure-Rising Sun mine, 4 miles southwest of Rociada, tactite minerals are associated with the veins in quartz-biotite schist. Epidote, garnet, amphibole, specularite, and tourmaline occur in the ore and in adjacent wall rock. A grab sample (329–384) from the dumps containing both ore and wall rock contains less than 0.0004 percent BeO.

WILLOW CREEK DISTRICT

The Willow Creek district is on State Highway 83, about 14 miles north of Pecos. The Pecos mine, which has been one of New Mexico's principal metal producers, was visited on July 21, 1949.

The geology of the mine is discussed in many papers, which are summarized and supplemented by Harley (1940, p. 69–89). The mineral deposits are in Precambrian schist and diabase intruded by Precambrian granite. These rocks are exposed in a window in limestone of the Magdalena group (Pennsylvanian and Permian). The ore deposits occur along a shear zone that trends northeasterly through the schist and diabase. The ore contains pyrite, sphalerite, chalcopyrite, galena, pyrrhotite, bornite, and gold. Chlorite, actinolite, sericite, quartz, tourmaline, and roscoelite have formed in the wallrock.

A grab sample (329–386) of ore and wall rock from the main dumps at the Pecos mine contains less than 0.0004 percent BeO.

SANDOVAL COUNTY

COCHITI DISTRICT

The Cochiti, or Bland, district is in the Valles Mountains about 30 miles west of Santa Fe. The geology of the district was described in detail by Graton (Lindgren, Graton, and Gordon, 1910, p. 150–162). Intrusive monzonitic rocks that are exposed in the lower parts of the canyons are covered by extensive flows of rhyolite. Quartz, sphalerite, pyrite, and chalcopyrite with minor amounts of argentite and gold, were deposited along fracture and breccia zones in the monzonitic rocks.

According to Mr. C. W. Arnold of Pena Blanca, N. Mex. (personal communication), a vein at the Big Sambo mine, near Bland, was reported to contain as much as 1.0 percent BeO. The mine workings consist of a short adit in monzonite and a crosscut that intersects a fracture zone containing quartz and calcite. The monzonite is highly altered. Two samples were taken at the mine by J. W. Adams of the U. S. Geological Survey. A 6-foot channel sample (JA–49–4) across the fracture zone contained 0.0005 percent BeO, and a grab sample (JA–49–5) of the altered monzonite contained 0.0007 percent BeO.

SANTA FE COUNTY

NEW PLACERS DISTRICT

The New Placers, or San Pedro, district is in southwestern Santa Fe County, just east of the village of Golden on State Highway 10. It was visited on July 12 and 13, 1949, when, except for the New Placers mine on the northern slope of the mountains, the district was inactive.

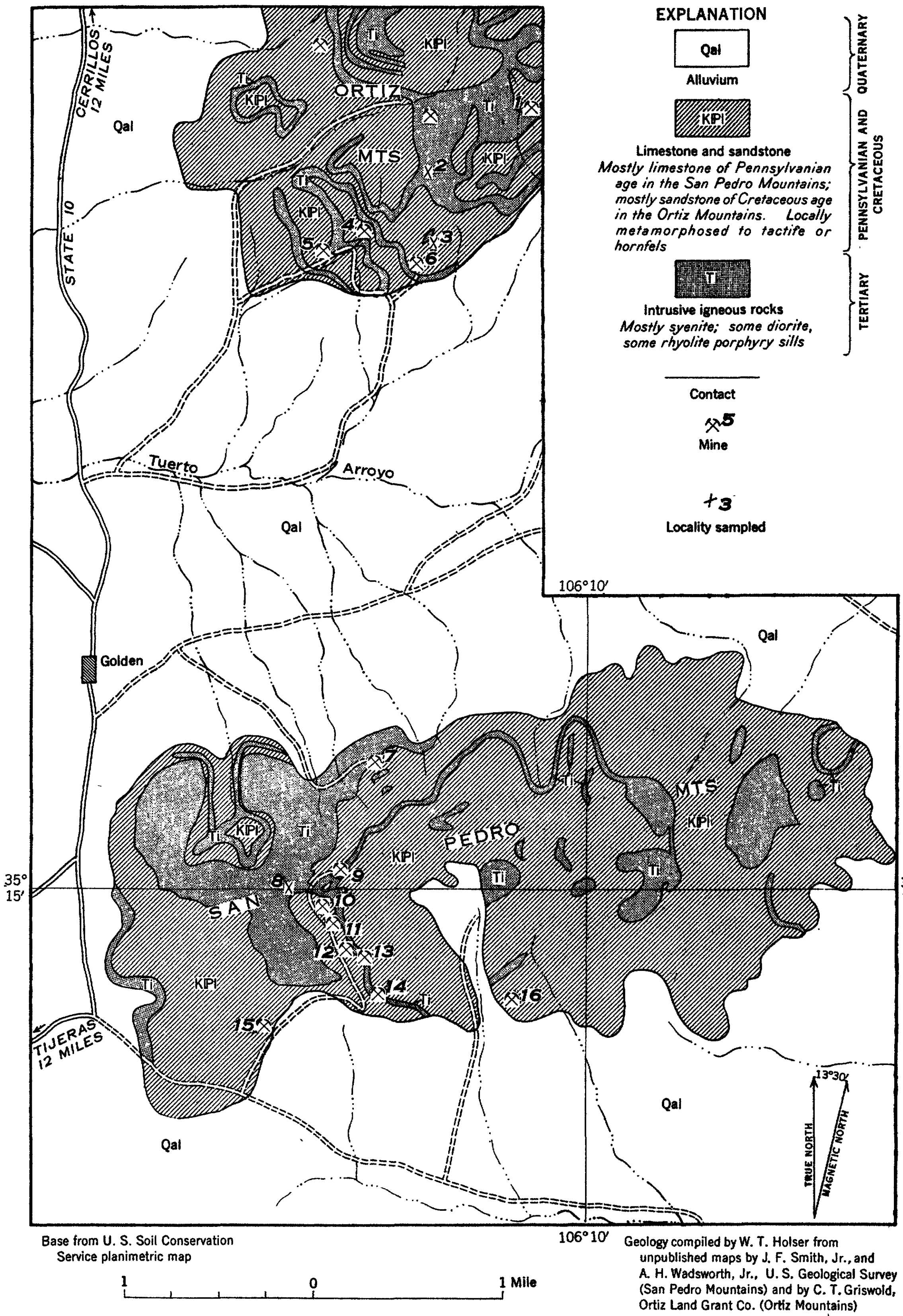


FIGURE 36.—Geologic map of the New Placers and part of the Old Placers districts, Santa Fe County, N. Mex.

The geology of the district was described by Yung and McCaffery (1903) and by Lindgren (Lindgren, Graton, and Gordon, 1910, p. 170–174). The major geologic features are shown in figure 36. The sedimentary rocks in the San Pedro Mountains consist of about 1,500 feet of flat-lying limestones, shales, and sandstones of the Madera formation (Pennsylvanian) In the western part of the mountains is a laccolithic mass of porphyritic rock that appears to be mainly syenite and monzonite. Two 60-foot sills that are stratigraphically above and below the laccolith are of younger rhyolite porphyry. The small intrusive bodies in the eastern part of the mountains are diorite.

Near the laccolith and beneath the upper rhyolite sill, shale is altered to hornfels and limestone to tactite. Garnet is the most common mineral in the tactite, but diopside, feldspar, quartz, specularite, epidote, idocrase, and wollastonite are also present. Some of the limestone has been changed to coarse white marble.

The ore deposits are in the metamorphosed rocks between the laccolith and the upper rhyolite sill. The chief ore mineral is chalcopyrite. It is disseminated, along with some scheelite and molybdenite, in the tactite and marble.

Samples were taken at most of the mines in the district, as shown in figure 36. The samples are described in table 57.

Table 57.—*Beryllia in samples from the New Placers district*

[Spectrographic analyses by Janet D. Fletcher. BeO figures determined on plates exposed for general scanning but not for precise determination of BeO alone]

Sample	*Description*	BeO (*percent*)
329–323	6-ft channel sample of very coarse marble from "lower 50 bed" in Home tunnel	<0. 0004
324	6-ft channel sample of garnet tactite, with chalcopyrite, from Swan tunnel at west side Richman shaft	<. 0004
325	6-ft channel sample in garnet-calcite tactite, with chalcopyrite, from Swan tunnel workings	<. 0004
326	6-ft channel sample of garnet tactite from Swan tunnel workings	<. 0004
328	5-ft channel sample of garnet-calcite from Swan tunnel workings	<. 0004
333	4-ft channel sample of garnet tactite replaced by copper, iron, and manganese minerals, in "24 beds" (?), upper part of Spanish opencut	<. 0004
334	Chip sample of 1.5 ft of garnet tactite replaced by copper, iron, and manganese minerals, lower part of Spanish opencut	<. 0004

Table 57.—*Beryllia in samples from the New Placers district*—Continued

Sample	*Description*	BeO (*percent*)
336	Grab sample of garnet-epidote tactite at face of New Placers adit	<0 0004
340	Grab sample of 1-ft quartz vein and associated quartz-garnet tactite of the "50 beds"(?), near Montezuma shaft	<. 0004
341	15-ft channel sample of garnet tactite with copper stains, from the "50 beds" at Virginia adit	<. 0004
342	6-ft channel sample of garnet tactite with chalcopyrite, from "24 beds" at Virginia adit	<. 0004
345	Chip sample from outcrop of syenite near its upper contact with Madera formation, west of the Montezuma shaft	. 0004

OLD PLACERS DISTRICT

The Old Placers district, also known as the Dolores or Ortiz district, is in the Ortiz Mountains just north of the New Placers district. It is east of State Highway 10 and is accessible by several unimproved roads (fig. 36). The district was visited on July 13, 1949.

The geology of the region has been briefly described by Yung and McCaffery (1903) and by Lindgren (Lindgren, Graton, and Gordon, 1910, p. 167–170). Mr. C. T. Griswold of Albuquerque, N. Mex., who has worked in the district for several years, furnished further information on the geology of the Ortiz Mountains.

Sedimentary rocks, mainly the Mancos shale of Cretaceous age, are invaded by intrusive igneous bodies which, according to Griswold, are thick sills. Most of the igneous rocks are granular and composed of hornblende and andesine, but the composition varies considerably; some are porphyritic. These rocks were called syenite porphyry by Yung and McCaffery (1903, p. 351), essexite, diorite, dacite, and andesite by Ogilvie (1908, p. 230), and quartz monzonite, monzonite, and diorite by Lindgren, Graton, and Gordon (1910, p. 40).

Near the Black Prince (Old Reliable) and Pat Collins claims (fig. 36) along Alpine Gulch, most of the Mancos shale has been metamorphosed to hornfels, and locally it is completely altered to a coarse garnet tactite containing chalcopyrite, pyrite, and gold. Tactite occurs also in the next canyon north and on the Buckeye claim to the northeast. No tactite is present at the Candelaria mine, the largest in the area.

Figure 36—Continued

MINES AND LOCALITIES SAMPLED

1. Buckeye
2. 329–350
3. 329–349
4. Black Prince (Old Reliable) 329–353
5. Pat Collins
6. Candelaria
7. New Placers adit 329–336
8. 329–345
9. Virginia adit 329–341 and –342
10. Montezuma shaft 329–340
11. Spanish opencut 329–333 and –334
12. Home tunnel 329–323
13. Richman shaft
14. Swan tunnel 329–324 to –326, –328
15. Carnahan
16. Lazarus

Samples of the igneous rocks and tactite that were analyzed are described below; localities sampled are shown on figure 36.

Sample	*Description*
329–349	Specimen of leucocratic pyroxene syenite(?) from locality 3.
350	Specimen of syenite(?) from main intrusive body at locality 2.
353	6-ft channel sample of garnet tactite from opencuts on Black Prince claim.
359	Specimen of porphyritic intrusive rock from road cut where State Highway 10 turns northeast across Ortiz Mountains (not shown on fig. 36).

These samples do not contain as much as 0.0004 percent BeO.

SIERRA COUNTY

APACHE NO. 1 DISTRICT

The Apache No. 1 (Chloride) district is on the east slope of the Black Range, a few miles southwest of the old mining camp of Chloride (fig. 37). Production amounting to less than a million dollars has been mainly in gold, silver, and copper. The district was visited on August 21 and 22, 1949, and there was little mining activity at that time.

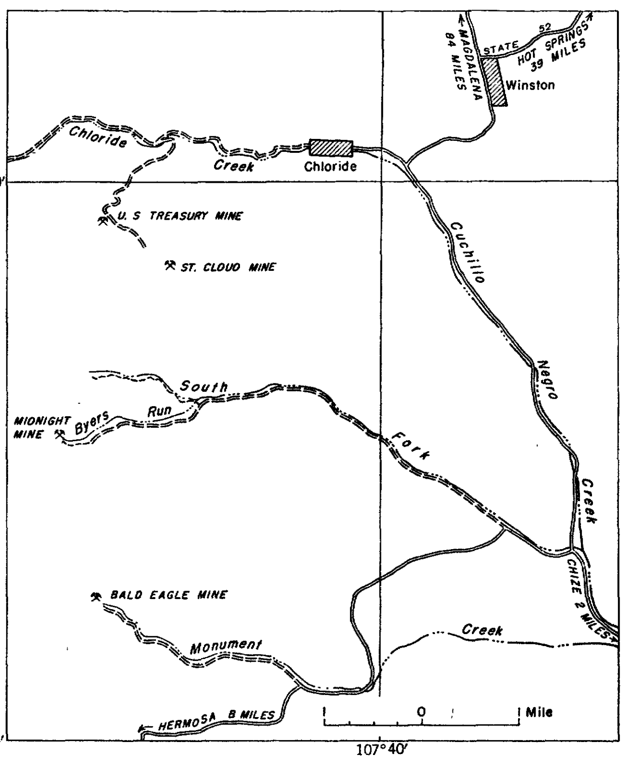


FIGURE 37.—Index map of the Apache mining district, Sierra County, N. Mex.

The geology and mineral deposits of the area have been described by Harley (1934, p. 73–77) and by Gordon (Lindgren, Graton, and Gordon, 1910, p. 260–266). The sedimentary rocks are limestone of the Magdalena group (Pennsylvanian) and Abo sandstone (Permian), which dip eastward on the lower slopes of the range. They are overlain on the upper slopes by Tertiary volcanic rocks, including andesite, rhyolite tuff, and breccia. No intrusive rocks are exposed in the district, the nearest being a large monzonite sill in the Cuchillo Negro Range several miles east of Winston. North-trending normal faults slice the eastern part of the range into long narrow blocks that are downthrown on the east; cross faulting is common.

Most of the veins are fissure fillings in andesite, but some are traceable into underlying limestone. The principal metallic minerals are pyrite and chalcopyrite, with associated gold and silver. The gangue minerals are quartz and calcite, with some barite. The veins show delicate banding and crustification. Harley (1934, p. 76) classified the deposits as epithermal.

Samples were taken only at the Midnight mine, where small amounts of garnet and epidote had been reported (Harley, 1934, p. 85). The vein is principally quartz with some calcite and fine-grained epidote. Limestone on the footwall is marmorized and silicified; greenish sandstone forms the hanging wall. Ore on the dump contains bornite and copper carbonates. A sample (329–705) cut across the vein at the collar of the south shaft contains less than 0.0004 percent BeO, but a grab sample (329–706) of copper-rich ore from the dump contained 0.01 percent BeO. Further sampling is needed to determine the nature and extent of the beryllium-bearing material.

CUCHILLO NEGRO DISTRICT

The Cuchillo Negro district, which is south of State Highway 52 in the Cuchillo Negro Mountains, was visited on August 21, 1949. The geology, as described by Harley (1934, p. 113–125), is similar to that in the Apache district a short distance west in that an eastwardly dipping section of about 1,500 feet of limestone of the Magdalena group (Pennsylvanian) is overlain by Tertiary volcanic rocks. A thick sill of monzonite porphyry about 8 miles long intrudes the limestone, which has been replaced along fractures by garnet, epidote, and quartz, accompanied by galena, sphalerite, chalcopyrite, and oxidation products.

Samples were taken in the vicinity of the Sentinel (Dictator) mine, which is reached by a road turning south from State Highway 52, about 2 miles west of the HOK ranch. The mine is described in detail by Harley (1934, p. 120–123). A grab sample (329–700) of galena-sphalerite-calcite ore from the dump of the Sentinel adit contained 0.001 percent BeO. Sample

329–701 from the same dump was composed of garnet, epidote, quartz, and calcite, and contained 0.0007 percent BeO.

A sample (329–702) of highly altered rock from the monzonite next to its contact with the marble at the Sentinel shaft contained 0.0005 percent BeO. The area to the north and west of the Sentinel mine, including the Silver Bell mine, was also inspected, but no other tactite bodies of any consequence were found.

Although the geology of this district is somewhat similar to that at Iron Mountain immediately to the north, the ore bodies are small and the beryllium content of the tactite is apparently low.

IRON MOUNTAIN DISTRICT

Pyrometasomatic deposits containing beryllium and tungsten occur in an area of about 15 square miles, largely in northern Sierra County but extending into southern Socorro County. The deposits were studied and sampled in detail by the U. S. Geological Survey and the U. S. Bureau of Mines during 1942–43 (Jahns, 1944a, 1944b; Glass, Jahns, and Stevens, 1944; Storms, 1947). The district was visited briefly on August 22, 1949, in connection with the present investigation. Little development work had been done since 1943, and further sampling was regarded as unnecessary.

Iron Mountain is a narrow north-trending fault block composed mainly of eastward-dipping rocks of late Paleozoic age of the Magdalena group and Abo sandstone. To the east, these rocks are overlain by Cretaceous sedimentary rocks which are in turn overlain by several thousand feet of Tertiary volcanic rocks. Sills, dikes, and pluglike bodies of monzonite, rhyolite, granite, and aplite cut the sedimentary rocks and part of the volcanic series. The sedimentary rocks in the Iron Mountain block were contact-metamorphosed next to the intrusive bodies, and some of the more calcareous rocks were altered to tactite, particularly at the northern end of the block.

Two main types of tactite are recognized: a massive, garnet-rich tactite and a banded tactite, or "ribbon rock." The massive tactite is locally rich in magnetite or fluorite, and parts of it contain sufficient scheelite and powellite to be valuable as tungsten ore. The "ribbon rock" consists mainly of magnetite, hematite, and fluorite, with some garnet, diopside, idocrase, and other silicates. It contains virtually all of the beryllium, mainly in helvite but some in grossularite, idocrase, chlorite, and other minerals.

Beryllium reserves of the district amount to 3,500 tons of indicated ore and 1,000 tons of inferred ore, both containing an average of 0.7 percent BeO, and 84,000 tons of indicated ore and 100,000 tons of inferred ore thought to average about 0.2 percent BeO (Jahns, 1944a, p. 76). Recovery of the beryllium involves rather complex mining and metallurgical problems, and there has been no production. Results of flotation experiments conducted by the U. S. Bureau of Mines on similar ores (Kennedy and O'Meara, 1948) suggest that ultimately the problems may be surmounted.

SOCORRO COUNTY

JONES CAMP DISTRICT

Jones Camp is on Chupadera Mesa in eastern Socorro County, north of U. S. Highway 380. The area was not visited, but a specimen of tactite from one of the deposits was obtained from V. C. Kelley.

The geology of the district has been described in detail by Kelley (1949, p. 213–222). Chupadera Mesa is capped by sandstone, limestone, and gypsum beds of the San Andres and Yeso formations of Permian age. An anticline in these rocks is intruded by a dike that trends northwest along the fold axis for about 10 miles. The dike is complex, consisting mainly of monzonite and syenite, with some later but closely associated diabase. A narrow and irregular metamorphic zone composed of actinolite, tremolite, and magnetite occurs in the sedimentary rock along the dike. The magnetite ore bodies replace actinolite rock, diabase, and limestone.

A specimen (sample 329–809) of actinolite tactite from the contact of the diabase dike in trench 9 (Kelley, 1949, fig. 44) contains less than 0.0004 percent BeO.

TAOS COUNTY

RED RIVER DISTRICT

The Red River district is on the western slope of the Sangre de Cristo Mountains and is crossed by State Highway 38. The district was visited on August 30–September 1, 1948. E. C. Anderson and P. F. McKinlay of the New Mexico Bureau of Mines, who accompanied the party, suggested areas for sampling.

The geology of the district was described briefly by Graton (Lindgren, Graton, and Gordon, 1910, p. 84–88) and the Questa mine was described by Larsen and Ross (1920) and by Vanderwilt (1938). More recent work by the New Mexico Bureau of Mines and the U. S. Geological Survey (Park and McKinlay, 1948a, 1948b) deals only with the part of the district southeast of the area sampled.

The Precambrian rocks of the district include hornblende gneiss, schists, and quartzite that are intruded and locally replaced by granite. Conglomerates, shales, limestone, and sandstones belong at least in part to the Magdalena group of Pennsylvanian and Permian age. These rocks are intruded by stocks and sills that range in composition from granodiorite and monzonite to granite. Later intrusions and flows of andesite and rhyolite cover much of the area. The structure is complex.

In general, hydrothermal alteration has been intense in the district, particularly in the granodiorite west of Red River. At this locality quartz-gold veins occur both in the granodiorite and in overlying volcanic rocks. In places along the granodiorite contact, as at the Hornet mine on Cabresto Creek, some galena and sphalerite occur with garnet and other tactite minerals.

The Questa mine is near the edge of a small granite stock and explores quartz veins containing molybdenite, fluorite, pyrite, and rhodochrosite. The granite and sedimentary rocks nearby are almost entirely altered to chlorite and clay in the vicinity of the mine.

Most of the sampling was confined to the molybdenum-rich area between Red River and Questa; the samples are described in table 58. The analytical results indicate that the molybdenum-bearing veins and altered granitic rocks contain small quantities of beryllium, though probably not enough to be recoverable by present methods.

TABLE 58.—*Beryllia in samples from the Red River district*

[Quantitative spectrographic analyses by A. A. Chodos]

Sample	*Description*	BeO (*percent*)
329–214	Grab sample along 6 ft of outcrop of 6-in. fluorite vein in rhyolite, Chokecherry Canyon, 3 miles east of Questa	0.0007
221	Grab sample of highly altered monzonite on the north side of Red River Canyon, 3 miles west of Red River	<.0003
222	Grab sample of yellow clay from same alteration zone as sample 221	<.0003
223	Sample of heads from molybdenum ore run August 31, 1948, Questa mill	.002
226	Specimen of rich molybdenum ore from Questa mine	.001
227	4-ft core of tailings pile at Questa mill	.004
233	Specimen of alaskite, with molybdenite veinlets, from dump of Questa mine	.001
234	Specimen of coarse granitic rock, with molybdenite veinlets, from dump of Questa mine	.0005
236	4-ft channel sample of molybdenite vein, 200 ft inside north tunnel of BJB mine, 3½ miles east of Questa	.0005
237	Grab sample of garnet-rich galena-sphalerite ore from dump of Hornet mine, north side of Cabresto Creek 7 miles east of Questa	.0008
238	Channel sample across 10-ft vein of quartz, calcite, pyrite, and galena, between granodiorite and quartzite, at upper tunnel of Hornet mine	.0003

TRANS-PECOS REGION, TEXAS AND NEW MEXICO

By W. T. HOLSER

INTRODUCTION

The study of beryllium-bearing rocks in the Trans-Pecos Region was restricted to the relatively flat and barren Diablo Plateau in Hudspeth, Culberson, and El Paso Counties, Tex., and Otero County, N. Mex. This plateau is at an altitude of 3,500 to 5,000 feet and is bounded on the west and south by Rio Grande valley, on the east by Salt Basin, and on the north by the Sacramento Mountains. The edges of the plateau are characterized by a rough scarp topography resulting from headward erosion of tributary streams into flat-lying sedimentary rocks. Laccoliths, plugs, dikes, and sills of more resistant igneous rock form erosion remnants that are prominent features of the landscape.

Early reconnaissance surveys by Baker (1927), Beede (1918), and Richardson (1904, 1909, 1914), and recent work by King and others (King, 1948, 1949); King, Branson and others (1949); King, King, and Knight (1945); King and Knight (1944); Adams and others (1949); and Smith and Albritton (1949) emphasized the sedimentary rocks and their structure. Huffington (1943) described in detail the igneous rocks of the Quitman Mountains and Clabaugh [7], Timm [8], and Zapp [9] made detailed studies of the igneous rocks of the Cornudas Mountains.

Most of the Diablo Plateau is underlain by flat-lying limestone of Permian age that unconformably overlies older Paleozoic and Precambrian rocks. These rocks are exposed only along the eastern margin of the plateau where they have been upthrown by faulting and folding. Cretaceous and Jurassic sedimentary rocks crop out in the southwestern part of the plateau and are complexly folded and faulted. The sedimentary rocks were intruded by laccoliths, plugs, sills, and dikes of alkalic igneous rocks, probably of early Tertiary age. In most places, contact metamorphism and metasomatism have been slight, although rather extensive zones of marble, hornfels, or tactite were formed around a few of the intrusive bodies.

Samples of igneous and contact-metamorphosed rocks collected during an earlier trace elements investigation by the U. S. Geological Survey from Cave Peak, Culberson County, Tex., and Wind Mountain, Otero County, N. Mex., were reported to contain as much as 0.3 percent BeO. The igneous rocks of the Trans-Pecos Region were known to include feldspathoidal types that, on theoretical grounds, are likely to contain beryllium-bearing minerals. The region was, therefore, marked for special study during the present investigation.

During August 1948, the Cave Peak and Wind Mountain areas were studied and resampled by Holser and Wilmarth. Detailed geologic maps were made of the beryllium-bearing localities in these areas by Holser and

[7] Clabaugh, S. E., 1941, Geology of the northwestern Cornudas Mountains, N. Mex.: Univ. Texas M. Sc. thesis.

[8] Timm, B. C., 1941, Geology of the southern Cornudas Mountains, Texas and New Mexico: Univ. Texas M. Sc. thesis.

[9] Zapp, A. D., 1941, Geology of the northeastern Cornudas Mountains, N. Mex.: Univ. Texas M. Sc. thesis.

W. I. Finch in July 1949. A general reconnaissance was made of the other intrusive igneous rocks in the region. P. B. King, Earl Ingerson, Charles Milton, and J. F. Smith of the U. S. Geological Survey supplied the field party with information about several of the areas visited.

INTRUSIVE IGNEOUS BODIES AND CONTACT ZONES

Most of the intrusive igneous bodies of the Diablo Plateau are small, ranging from laccolithic masses as much as 3 miles in diameter, and sills as much as 1,500 feet thick, to dikes less than a foot thick. The majority of the rocks are alkalic; most are silica-rich, but many are feldspathoidal. With few exceptions they are sufficiently similar in composition to suggest that they represent a petrographic province. The highly deformed Quitman Mountains are included in the Trans-Pecos Region for convenience although their structural setting and granitic rocks are more nearly comparable with the mountains of the Arizona and New Mexico region. They contain some syenitic rocks which are common in the Trans-Pecos but unknown in the Arizona and New Mexico region.

The areal extent of the intrusive igneous rocks in the Trans-Pecos Region is shown in plate 1. The general distribution is peripheral to the Diablo Plateau. Most of the intrusive bodies were examined, and many samples of the igneous and associated metamorphic rocks were taken. Brief descriptions of the bodies, the contact zones, and the samples collected are given, together with analytical data, in table 59. Little beryllium is indicated in these rocks, except at Wind Mountain and Cave Peak.

SYENITIC ROCKS

Syenites are common in the region, particularly in the northern part (table 62). The most characteristic rock is a fine-grained, dark gray-green syenite containing small phenocrysts of feldspar. Its principal minerals are sodic plagioclase and sodic pyroxene; the pyroxene ranges in composition from aegirite to augite. Potassic feldspar, sodic amphibole, and biotite are less abundant. Many of the syenites contain small subhedral crystals of analcite or nepheline in the groundmass. Several of these intrusive rocks, such as those at Alamo Mountain, Sierra Tinaja Pinta, and Sierra Prieta, have a finer grained, dark schistose border phase just above the basal contact. The structure parallels the contact in most places and is the result of orientation of the dark minerals by flow.

A less common coarse-grained and porphyritic syenite forms the main intrusive masses of the Wind Mountain, Little Wind Mountain, and Black Mountains. Phenocrysts of perthitic feldspar, as much as 1 inch long, constitute most of the rock. Smaller crystals of perthitic feldspar, nepheline, analcite, aegirite, and minor amounts of biotite form the groundmass. Both the large and small perthitic feldspar crystals show a pronounced orientation caused by flow. The border phase of this rock is darker, finer grained, and nonporphyritic. Similar porphyritic syenites form the intrusive bodies at Cornuda Mountain, Granite Mountain, and Hueco Tanks. The norm of these rocks contains no nepheline, and none was seen in thin section.

The coarse-grained syenite of Marble Canyon in the Sierra Diablo, according to Charles Milton (1941, written communication), contains more than 50 percent sodic plagioclase that is intergrown perthitically with some potassium feldspar. Highly altered hornblende and biotite are the only mafic minerals. About 6 percent quartz is graphically intergrown with the feldspar. The boarder phase of this syenite is a finer grained mela-syenite.

Subsidiary intrusive bodies are remarkably lacking around and in most of the large syenite masses. Most of the intrusive bodies are single masses of rock that have sharp boundaries with the surrounding sediments. The intrusive mass at Marble Canyon, however, has a number of associated aplite dikes and one nepheline syenite dike. The main intrusive mass at Wind Mountain is surrounded by numerous small dikes and sills, most of which are medium-grained, dark aegirite-nepheline rocks (malignite); some are feldspar-rich and are coarse grained or pegmatitic in texture. The only other dike rocks seen along the many miles of igneous contact examined were a few thin phonolite dikes at the southern contact of the intrusive body at Sierra Prieta. It may be significant that the dike rocks apparently are associated only with the coarse-grained porphyritic syenite intrusive rocks.

GRANITIC ROCKS

Granitic rocks are found in the intrusive masses in the Quitman Mountains, Wylie Mountains, Sierra Blanca, Cave Peak, and Sierra Diablo. Most of the Quitman Mountains mass is a medium-grained quartz monzonite that contains orthoclase, oligoclase, biotite, and small grains of quartz. Granite occurs in the southwestern part of the intrusive mass (Huffington, 1943, p. 1035) and locally rocks are syenitic. Small diorite xenoliths are present in the quartz monzonite. In the Wylie Mountains and at Sierra Diablo the granitic rocks occur next to intrusive syenitic rocks. The central part of the intrusive mass at Cave Peak is composed of granite, associated with rhyolite porphyries and breccias.

TABLE 59.—*Beryllia in intrusive rocks and contact zones of part of the Trans-Pecos Region*

Locality No. on plate 1	Area	Igneous rock	Intruded rock [1]	Metamorphism	Samples: No.	Samples: Description	Samples: BeO (percent)
	HEUCO MOUNTAINS						
1	Peak 5106	Plug(?) of syenite porphyry.	None exposed		None		
2	Hueco Tanks	Plug of biotite syenite porphyry.	do		329–601	Specimen of biotite syenite porphyry from northeast side of the tanks.	0.001
3	Cerro Alto	do	Hueco limestone	None	603	Specimen of biotite syenite porphyry from southeast side.	.004
	CORNUDAS MOUNTAINS						
4	Alamo Mountain	800-ft sill of nepheline-biotite phonolite, some porphyritic.	Sandstone and limestone of Washita group.	Minor silication	None		
5	Flattop Mountain	50-to-75 ft sill of nepheline phonolite porphyry; augite syenite dike at northeast side.	Bone Spring limestone	None observed	None		
6	Little Wind Mountain (Deer Mountain).	Laccolith(?) of granular analcite-nepheline syenite.	None exposed		329–653	Specimen of granular analcite nepheline syenite from southeast side.	.002
7	Wind Mountain	Laccolith, with southwest feeder, of porphyritic nepheline syenite; border and dike phases variable.	Hueco limestone with included shale.	Pyroxene hornfels; minor marble and tactite.		See table 61.	
8	Cornudas Mountain	Laccolith(?) of porphyritic syenite.	Hueco limestone	None	329–610	Specimen of porphyritic syenite of main mass.	.0008
					609	5-ft channel sample of altered porphyritic syenite from southwestern contact.	.002
9	Black Mountain	200-ft sill of porphyritic nepheline syenite.	Sandstone of Washita group.	None observed	650	Specimen of porphyritic nepheline syenite from western side.	.0066
10	San Antonio Mountain.	Laccolith of analcite syenite porphyry.	Washita group, not exposed.		None		
11	Washburn Mountain	400-ft sill of analcite syenite porphyry.	Sandstone of Washita group.	None observed	None		
12	Chattfield Mountain	Flat laccolith of nepheline phonolite porphyry.	Washita group, not exposed.		None		
13	Dog Mountains	Sills of syenite porphyry, up to 500 ft thick.	Sandstone of Washita group(?), Bone Spring limestone.	Minor marble and silification.	329–095	8-ft channel sample of highly altered syenite porphyry from western side.	<.004
					090	3-ft channel sample of iron- and manganese-stained limestone at contact of small sill.	<.004
	SIERRA TINAJA PINTA						
14	Miller Mountain	600-ft sill of coarse syenite porphyry, fine-grained border.	Sandstone of Washita group(?), Hueco limestone at northern end.	Sandstone to quartzite; narrow zone of marble.	519	Specimen of pyroxene hornfels and marble from northwestern contact.	<.004
15	Peak 5650	500-ft sill of syenite porphyry, coarser above dike at north end.	Hueco limestone in north, Bone Spring limestone in south.	None	None		

16	Cerro Diablo	Laccolith of analcite syenite porphyry.	Sandstone in Washita group(?) to south Hueco limestone in north.	Sandstone to dark quartzite; minor marble.	329–094a	Specimen of dike in syenite porphyry on south side.	<.001
17	Cornudas Station	6-ft sill of phonolite	Bone Spring limestone	None at contact, small marble zone 50 ft south.	None		
18	Antelope Hill	100-ft sill porphyritic syenite.	Fredericksburg group sandstone.	Quartzite	None		
19	Sierra Prieta	1,500-ft "trapdoor sill" of fine-grained nepheline syenite porphyry.	Hueco limestone to sandstone of Fredericksburg group.	3–20 ft bleached and recrystallized limestone, minor silication.	329–114	4-ft channel sample in marble near southwest contact.	<.004
					119	2-ft channel sample in altered shale at contact small sill.	<.004
	SIERRA DIABLO						
20	Marble Canyon	Plug of coarse porphyritic syenite with syenogabbro border. Dikes of aplite.	Hueco and Bone Spring limestones.	400 ft of marble and hornfels of sanidinite facies.	028	7 channel samples of hornfels and marble at varying distances from southwest contact. (Each analyzed separately.)	<.004
21	Cave Peak	Ring dikes of rhyolite and rhyolite breccias, around small plug of granite; rhyolite dikes.	Hueco limestone	0 to 400 ft marble and hornfels of sanidinite facies.	--------	See table 63.	
22	Mine Canyon	1 to 50-ft sills of rhyolite	Hueco limestone	Minor marmorization	None		
23	Granite Mountain	300-ft sill(?) of hornblende syenite.	Sandstone of Fredericksburg group.	None observed	None		
	FINLAY MOUNTAINS						
24	Finlay Mountains	10 to 100-ft dikes of hornblende porphyry.	Limestone, shale, and conglomerate of Leonard series; limestone and conglomerate of Trinity group.	do	None		
25	Peak 5558	Sills of hornblende porphyry.	Sandstone of Fredericksburg group.	None observed	None		
	SIERRA BLANCA						
26	Round Top	Laccolith of augite granite(?).	Limestone of Washita group.	do	None		
27	Little Blanca Mountain.	do	do	do	None		
28	Triple Hill	do	Limestone of Trinity group.	do	None		
29	Sierra Blanca	do	Limestone of Washita group.	do	None		
30	Flat Mesa	Dikes and sills of rhyolite porphyry.	Sandstone of Fredericksburg group.	do	None		

1 For stratigraphic details, see Adams and others, (1949); King, Branson, and others (1949); Smith and Albritton (1949).

TABLE 59.—*Beryllia in intrusive rocks and contact zones of part of the Trans-Pecos Region*—Continued

Locality No. on plate 1	Area	Igneous rock	Intruded rock[1]	Metamorphism	Samples: No.	Samples: Description	Samples: BeO (percent)
	QUITMAN MOUNTAIN						
31	Pinnacle Peak	Stock of quartz monzonite	Limestones, conglomerates, and sandstones of Trinity and Washita groups.	0 to 500 ft grossularite tactite with quartz, epidote, and hematite. (Some sphalerite, galena, magnetite, scheelite, and wulfenite.)	329–171	4-ft channel sample across clay-siderite altered hornfels near southeast contact of stock.	<0.004
					175	10-ft channel sample across brecciated and altered garnet tactite near 174.	<.004
32	Red Chief Peak	Ring dike of quartz monzonite.			179	6-ft channel sample across lens of thinly banded magnetite-serpentine rock, in limestone top Zimpleman Pass.	<.004
					180	6-ft channel sample across clay-pyrite-malachite near 179.	<.004
					193	5-ft channel sample across serpentine-clay-hematite alteration zone in limestone on west side Zimpleman Pass.	<.004
					184 to 186	3 channel samples (separately analyzed) of garnet-epidote-scheelite tactite at Moore tungsten mine at west contact of stock.	
					187	5.5-ft channel sample across pyrite-chalcopyrite-pyrrhotite zone in garnet tactite south of Moore tungsten mine.	<.004
	WYLIE MOUNTAINS						
33	Wylie Mountain	Granite and syenite complex stock.	Hueco limestone(?)	Minor marble	687	Specimen of quartz syenite with mafic inclusions from north-central part.	.0002
					688	Specimen of syenite with pegmatite inclusions or segregations, northwest ridge.	.002

[1] For stratigraphic details, see Adams and others, (1949); King, Branson, and others (1949); Smith and Albritton (1949).

METAMORPHIC ROCKS

The limestone and other sedimentary rocks show little contact metamorphism near most of the syenitic bodies. At most places the limestone has been bleached and recrystallized, forming a zone of marble as much as 25 feet wide. Some of the marble is cut by small veinlets of dark, partly serpentinized silicates.

The syenite intrusive mass at Marble Canyon, however, is surrounded by a zone about 200 feet wide of white, brucite-calcite marble and akermanite-merwinite hornfels. An inner zone of quartz-diopside and plagioclase-diopside hornfelses is found at some places. A narrower, more irregular zone borders part of the intrusive body at Cave Peak. It consists of hornfels, with spurrite, merwinite, radiophyllite (?) and periclase, and locally contains grossularite and idocrase. At Wind Mountain and Sierra Prieta narrow zones of marble and hornfels border the intrusive bodies at a few places. At the Miller Mountain and Cerro Diablo intrusive masses much of the loosely cemented sandstone wallrock is silicified.

The granite of the Quitman Mountains is surrounded by a zone of coarse garnet tactite, with or without diopside, olivine, quartz, calcite, hematite, or magnetite (Huffington, 1943, p. 1043–1044). The tactite masses are distributed irregularly; the largest masses are along the west-central and south sides of the Pinnacle Peak stock, in Zimpleman Pass. Here the stock is bordered by a zone 50 feet wide of coarse quartz-specularite tactite, surrounded by a zone, as much as 500 feet wide, that contains abundant coarse green grossularite.

WIND MOUNTAIN AREA

Wind Mountain, in Otero County, N. Mex., is one of the largest intrusive masses of the group that form the Cornudas Mountains of Texas and New Mexico (pl. 1). The area is most easily accessible by a graded road that turns north from U. S. Highway 62–180 at the Hueco Inn, 50 miles east of El Paso, Tex. Wind Mountain is reached by a graded road that leads south from Cornudas Ranch to Wind Tank.

The geology of the area was studied by Zapp [10], who discovered eudialite-bearing syenite dikes on the western side of Wind Mountain; the eudialite was later described by Clabaugh (1950). In 1944 members of the U. S. Geological Survey sampled some of the eudialite-bearing dikes and associated rocks for trace elements. One of the samples was reported to contain 0.2 percent BeO (Fleischer and Cameron, 1946). The area was examined briefly in August 1948 and was studied more thoroughly in July 1949. The earlier geologic map [11] was revised (fig. 38) and areas on the west, south, and east sides of the mountain were mapped and sampled in detail (pls. 2–4).

[10] See footnote 9, page 130.
[11] See footnote 8, page 130.

GEOLOGY

STRUCTURE AND METAMORPHISM

Wind Mountain is a laccolith that rises about 2,500 feet above the Diablo Plateau. It is a nearly circular dome with an asymmetrical extension to the southwest and is denuded of sediments. Talus fans on the lower slopes cover much of the contact. Dikes of several rock types are abundant near the edges of the laccolith and their attitudes are controlled by two sets of fractures. The main set is concentric with respect to the contact and dips inward about 30°; a less well-developed set is radial and vertical. Some dikes occur in the laccolith but most are in the upturned sedimentary rocks; nearly all are within a few hundred feet of the contact. They were observed throughout a vertical range of 500 feet. The dikes are as much as 20 feet thick and fairly regular; some taper to a microscopic thinness.

About 1,200 feet of limestone and shale of Permian age crop out around Wind Mountain. The upper and middle parts are correlated with the Bone Spring limestone and the lower part with the Hueco limestone The three units have not been differentiated on the geologic map (fig. 38). The Hueco limestone, as exposed at several places along the contact of the Wind Mountain laccolith, is typically gray, fine grained, and locally dolomitic. Along the western and southern edges of Wind Mountain, thin-bedded light-colored shales are exposed in the Hueco limestone.

The most prominent structure of the sedimentary rocks is their doming near the laccolith where the beds dip at angles of 50° to 80° and generally are parallel to the contact. The effect of the doming may be detected as far as 2,000 feet from the laccolith.

Metamorphism of the sedimentary rocks next to the intrusive body at Wind Mountain is variable in both extent and intensity. Bleaching and recrystallization of the limestone beds has been developed on the eastern side through a thickness of more than 100 feet (pl. 4), but elsewhere the limestone is unmetamorphosed. The shale beds of the Hueco limestone, where observed near the intrusive mass, are altered to a fine-grained brown to purple hornfels, but probably very little material was added from the intrusive body. At some localities, however, the metamorphism was accompanied by addition of soda and other substances. Narrow bands of aegirite, riebeckite, analcite, and zirconium silicates border many of the dikes. At one area on the south side of Wind Mountain (pl. 3) metasomatism was

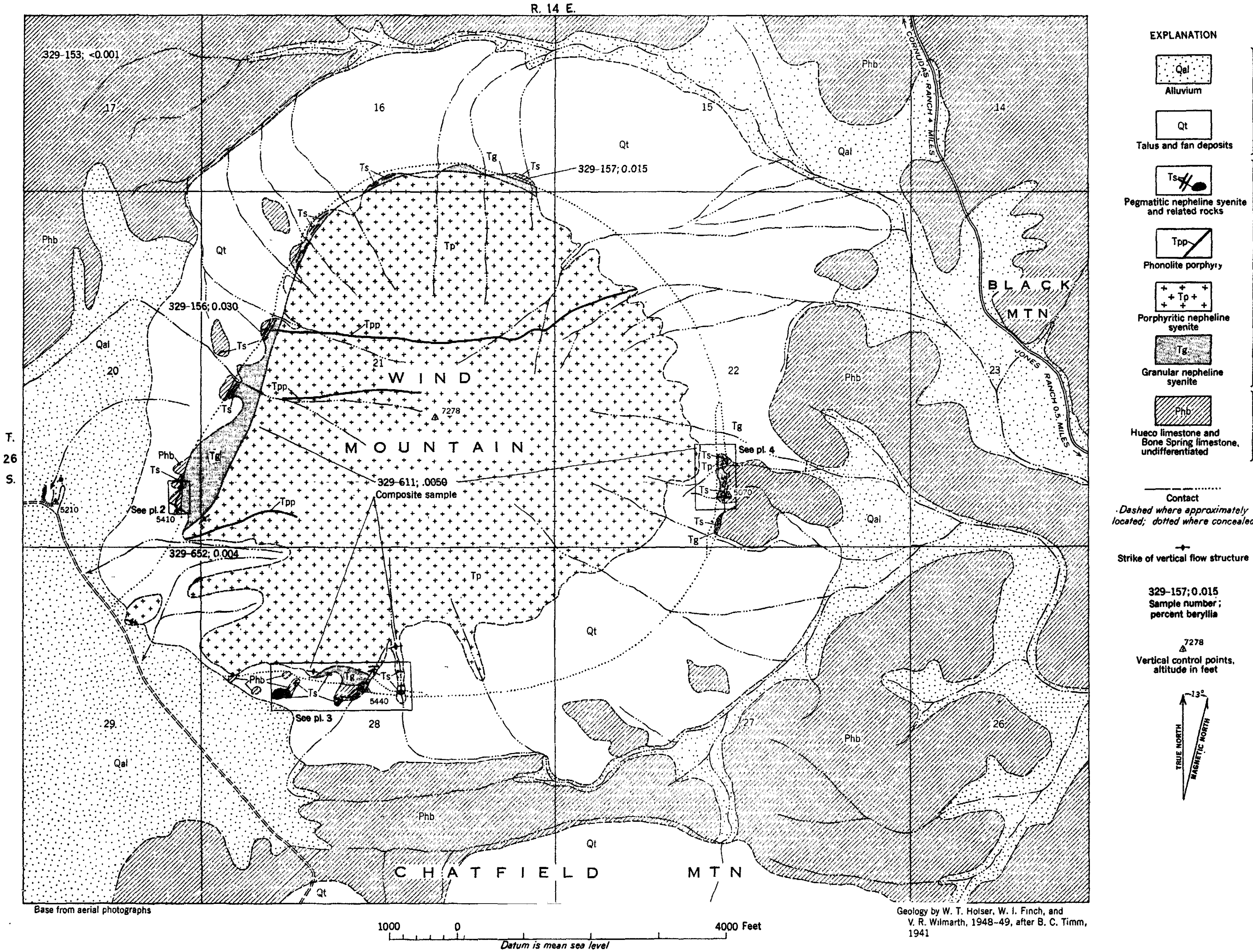


FIGURE 38.—Geologic map of Wind Mountain, Otero County, N. Mex.

intense, and the sedimentary rocks are altered to a coarse tactite of epidote, calcite, and garnet.

IGNEOUS ROCKS

The main mass of Wind Mountain is porphyritic nepheline syenite, containing euhedral to subhedral phenocrysts of nepheline, perthite, and pyroxene in a fine-grained groundmass of 80 to 90 percent feldspar and 10 to 20 percent aegirite. Nepheline phenocrysts constitute as much as 15 percent of the rock and commonly shows large crystal faces. The perthite phenocrysts show a marked flow structure in which their tabular (010) form is parallel to the contact. Adjoining and within a few hundred feet of the contact, the nepheline syenite has a granular texture. Phenocrysts are small or absent, and no alinement of crystals is apparent. Pyroxene, dominantly aegirine-augite, is present in minor quantities and is interstitial to the feldspar crystals. Porphyritic rock having flow structure crop out high on the mountain and within 100 feet seem to grade into the granular syenite of the border facies. No crosscutting relations or sharp contacts between these rock types were seen.

The dikes that border the laccolith are highly variable in composition, but two types predominate. The more abundant is dark-green malignite that consists mostly of aegirite, with some nepheline and feldspar. This rock is generally fine grained, although in places the aegirite crystals are as much as half an inch long, and elsewhere, rectangular phenocrysts of nepheline as much as a quarter inch across are scattered throughout the groundmass. The other main type of dike rock is largely pegmatitic nepheline syenite; it is rich in feldspar and contains some nepheline and aegirite. The rock is coarse grained and in places shows tabular feldspar and prismatic aegirite crystals 1 to 2 inches in length. All gradations between malignite and pegmatitic nepheline syenite may be seen in a single hand specimen. Other dike rocks, similar in composition to the pegmatitic nepheline syenite but finer and more uniformly grained, are designated as fine-grained nepheline syenite. These may be as light-colored as the pegmatitic type, or considerably darker; however, the content of mafic minerals is less than that of malignite. The best exposures of fine-grained nepheline syenite dikes are along the eastern border of the laccolith (pl. 4).

A few dikes with easterly trend occur largely within the laccolith. They are dark green and porphyritic, with fine-grained groundmass, and contain inclusions of limestone and nepheline syenite. The rock is best described as a phonolite porphyry.

Some of the dikes show a pronounced planar structure parallel to the walls, owing to interlayering of malignite, pegmatitic nepheline syenite, and fine-grained nepheline syenite. Commonly there are only a few such layers, but at one locality (sample 329-145, pl. 3) 25 major layers and many minor ones occur in a zone about 12 feet thick. Although some of the layers are continuous for 20 feet or more, the pegmatitic nepheline syenite layers are commonly short and lenticular. In other places masses of pegmatitic nepheline syenite are cut by malignite, and locally the rock resembles a breccia of pegmatitic material "cemented" by malignite. In thin section the malignite layers show a pronounced orientation of aegirite prisms parallel to the layering. The orientation is apparently the result of flow, and the lines of crystals crowd and bend sharply around feldspar phenocrysts. Most of the pegmatitic nepheline syenite dikes lack this structure, but the long axes of feldspar crystals near the dike margins commonly are perpendicular to the walls. Some of the pegmatitic nepheline syenite dikes are zoned. The zoning is mainly textural, although the inner unit commonly is somewhat richer in aegirite. Planar flow structure is well developed in a dark-gray, gneissoid nepheline syenite that crops out on the south side of Wind Mountain (pl. 3). Perthite phenocrysts and albite crystals in the groundmass show orientation.

The junction of a vertical dike and a flat-lying dike is exposed on the Wind Mountain claim (pl. 2). Flow lines show that the dikes were formed at the same time. Malignite and similar rocks are found near contact of both the porphyritic and granular nepheline syenite bodies with the laccolith. Their shape ranges from vague schlieren to sharply bounded dikes, but always in the same orientations. On the southern side of the mountain (pl. 3) near sample 329–622, the granular syenite of the laccolith grades imperceptibly into fine-grained syenite of a dike, and the malignite layers are similarly alined through both rocks. These observations suggest that all the rock types are closely related in age and origin.

The most abundant minerals of the dike rocks are feldspar, aegirite, and nepheline. The feldspars include perthitic orthoclase, albite, and minor quantities of microcline. The aegirite ranges toward augite in composition; the outer zones of the crystals are richer in soda.

Deep red-purple zirconium silicates are important constituents in some dikes and occur both in single crystals 0.5 to 3 mm in diameter and in aggregates. In places they constitute as much as 20 percent of the pegmatitic nepheline syenite. The crystals are grouped in irregular stringers and tend to be most abundant near the edges of pegmatitic layers; a few masses occur in adjacent malignite.

The zirconium silicates are highly variable in optical properties and in chemical composition. Purple-red crystals from the western part of Wind Mountain commonly are color zoned about a light-brown core. Other crystals are entirely light to dark brown, some occurring in the same rock with the purple-red material. Some of the brown material and much of the red material is isotropic and has a refractive index of about 1.59; other brown grains show a small negative optic angle and indices near 1.62. Spectrographic analyses of three specimens from Wind Mountain are compared in table 60 with a chemical analysis of similar material from Kola, U. S. S. R.

TABLE 60.—*Analyses of zirconium silicates, in percent*

	1	*2*	*3*	*4*
BeO	------	0.0051	0.00X	Present
SiO_2	51.6	----------	>1	52.12
Al_2O_3	(1)	----------	.X	.40
Fe_2O_3	------	X.0	>1	.73
Nb	------	.53	.X	-------
TiO_2	.20	.X	--------	1.02
MgO	2.7	.0X	.0X	.76
Mo	------	.00X	--------	-------
Sn	------	.0X	--------	-------
FeO	2.2	(2)	(2)	-------
HfO_2	------	----------	--------	.1
MnO	2.0	X.0	>1	3.46
ZrO_2	11.8	>X.0	>1	16.54
Y	------	.X	.X	-------
Cu	------	.000X	.00X	-------
Na_2O	14.2	----------	.X	3.74
UO_2	------	----------	--------	.2
CaO	14.1	X.0	>1	3.34
La_2O_3	------	.X	.X	} .56
Ce	------	----------	--------	}
SrO	------	.0X	--------	.06
Pb	------	.0X	.00X	-------
K_2O	------	----------	--------	1.90
Ba	------	.00X	--------	-------
H_2O+	------	----------	--------	8.62
H_2O-	------	----------	--------	6.41
Cl	------	----------	--------	None

[1] Included in MgO.
[2] Included in Fe_2O_3.

1. Purple-red eudialite, west side Wind Mountain. Spectrographic analysis by Saratoga Laboratories, courtesy S. E. Clabaugh; Univ. of Texas, Austin.
2. Same mineral, same locality as No. 1 (sample 329–129). Spectrographic analysis by K. J. Murata. Looked for but not found: Ag, As, B, Bi, Cd, Co, Cr, Ga, Ge, In, Ni, P, Sb, Ta, Tl, V, W, Zn.
3. Brown zirconium silicate, south side Wind Mountain (sample 329–145B). Spectographic analysis by K. J. Murata.
4. Lovozerite, Lovozero, Kola, U. S. S. R. (Gerasimovsky, 1939, p. 754; see also Winchell, 1951, p. 454). Chemical analysis by T. A. Burova, spectrographic analyses for U and Hf by I. B. Borovsky, for Be by S. A. Borovick.

X-ray diffraction patterns of the zirconium silicates at Wind Mountain are similar to those of eudialite and eucolite from southern Norway and Greenland. Minerals previously identified as eudialite and eucolite have a wide range of chemical composition (Winchell, 1951, p. 453–454). The Wind Mountain specimens differ from these minerals mainly in containing more calcium and less zirconium, but are probably members of a eudialite-eucolite series.

Other accessory minerals of the dike rocks include sodalite, riebeckite, biotite, apatite, and magnetite. Some of the dikes are intersected by microscopic veins of analcite and other zeolite minerals; these minerals also replace some of the primary minerals.

OCCURRENCE OF BERYLLIUM

The distribution of beryllium in the rocks of Wind Mountain is shown on the detailed geologic maps (pls. 2–4); a few other analyses are shown on the general map of the Wind Mountain area (fig. 38). The samples are described in table 61.

The malignite and pegmatitic nepheline syenite dike rocks of Wind Mountain are richer in beryllium than is the porphyritic nepheline syenite that forms the main part of the laccolith. A channel sample across a typical dike, including both malignite and pegmatitic nepheline syenite layers, probably would contain about 0.007 percent BeO. In some samples no BeO could be detected, and the maximum BeO content obtained was 0.2 percent. This value was reported for a sample (S–150–456) collected for the Mine, Mill, and Smelter Survey in 1944 from the Wind Mountain claim (pl. 2). Reanalysis of the same powder, showed only 0.074 percent BeO. Even this value could not be confirmed in several other samples from the same outcrop (S–150–457 and –458; and 329–195 to –205), which gave a maximum of 0.026 percent BeO and a minimum of <0.001 percent (pl. 2 and table 61).

Although part of the discrepancy may be due to analytical errors, these analyses indicate that the beryllium content of the dikes and the altered rocks that border them is probably quite erratic. This is further indicated in comparing the analyses of samples from given rock types. The BeO content in 5 samples of fine-grained nepheline syenite ranges from 0.001 to 0.022 percent, and in 7 samples of rock that is dominantly malignite the range is from <0.001 to 0.03 percent. Of the 10 samples of metamorphic rocks that were analyzed, those containing detectable amounts of BeO were all taken within a foot of a dike. However, beryllia could not be detected in some samples thus located.

Analytical data for the various minerals indicate that the beryllium in the dike rocks is not contained in any particular mineral but is distributed among the feldspar, nepheline, aegirite, and eudialite. Red-purple eudialite from the west side of Wind Mountain was found to contain 0.0051 percent BeO (table 60, column 2). A sample (329–145) of layered dike rock was separated into mineral components by heavy liquids, and a spectrographic analysis was made for each of the separates. The aegirite separate contained 0.000X BeO, the zirconium silicate 0.00X percent, and the combined nepheline and feldspar 0.003 percent. Two separate quantitative analyses of parts of the sample showed 0.0074 and 0.001 percent BeO, neither

TABLE 61.—*Beryllia in samples from Wind Mountain*

[Key to analysts: KJM, K. J. Murata; JDF, Janet D. Fletcher; JTR, J. T. Rozsa, National Spectrographic Laboratories, Inc.; LWS, L. W. Strock, Saratoga Laboratories, Inc.; MMS: samples collected and analyzed by Mine, Mill, and Smelter Survey. MMSC: gravimetric analysis by Mine, Mill, and Smelter Survey; all other analyses spectrographic]

Sample	*Plate showing locality*	*Description*	BeO (*percent*)	*Analyst*
329–128	2	Specimen of malignite dike with large nepheline phenocrysts	0.014	JTR
129	2	Separate of eudialite from pegmatitic nepheline syenite, near 329–128	.0051	KJM
132	2	4-ft channel sample across hornfels altered to clay	<.004	LWS
135	4	3-ft channel sample across eudialite-bearing fine-grained nepheline syenite dike	.0065	LWS
136	4	1-ft channel sample across thin eudialite-rich pegmatitic nepheline syenite dike and bordering marble	.003	JDF
145	3	3-ft channel sample across lower part of 20-ft dike of banded nepheline syenite pegmatite, fine-grained nepheline syenite, and malignite, containing zirconium silicates	.0074	LWS
145A	3	Separate of aegerite from 329–145	.000X	KJM
145B	3	Separate of brown zirconium silicate from 329–145	.00X	KJM
145C	3	Nepheline and feldspar from 329–145	.003	KJM
149	3	Specimen of malignite dikes in porphyritic nepheline syenite	.018	JTR
150	3	Grab sample from thin serpentine vein in hornfels	<.004	LWS
151	3	4-ft channel sample across magnetite-bearing hornfels, some altered to clay	<.004	LWS
153	(Fig. 38)	Grab sample of alteration zone in limestone near northwest corner of figure 38, containing quartz, chalcedony, siderite, and iron and manganese oxides	<.001	JTR
156	(Fig. 38)	Specimen of 3-in. coarse malignite dike in granular syenite	.030	JTR
157	(Fig. 38)	Grab sample of 6-ft banded dike, predominantly malignite with brown zirconium silicate	.015	JTR
195	2	Channel sample across 15-in. altered shaly limestone	<.001	JTR
196	2	Sample from two 1-ft channels across thin, gray, fine-grained nepheline syenite dike, immediately below 329–195	<.001	JTR
197	2	Sample from three 14-in. channels across black hornfels immediately below 329–196	.026	JTR
198	2	Broad 1-ft channel sample across limestone, from same locality as 329–197	<.001	JTR
199	2	Channel sample across 6 in. of porcelainic limestone, near hanging wall of flat-lying banded dike (329–202)	<.001	JTR
200	2	Chip sample of dark-green aegirite hornfels along hanging wall of same dike as 329–202	<.001	JTR
201	2	Same on footwall	.022	JTR
202	2	Chip sample across flat-lying banded dike, same locality as 329–199 to 201	.012	JTR
203	2	Chip sample of vertical banded dike with some very coarse feldspar. Some hornfels inclusions	.001	JTR
204	2	Specimen of granular syenite	<.001	JTR
205	2	Specimen of anthophyllite asbestos lying between dike rock and aegirite hornfels	.001	JTR
605	2	5-ft channel sample across banded eudialite-bearing dike	.0068	JDF
607	2	----do	.008	JDF
611	(Fig. 38)	Composite of four specimens of porphyritic nepheline syenite from borders of main part of laccolith	.005	KJM
615	3	6-ft channel sample across banded malignite and syenite	.0063	JDF
619	3	2.5-ft channel sample across fine-grained nepheline syenite dike	.022	JDF
620	3	2-ft channel sample across limestone and hornfels at footwall of dike sampled in 329–619	.0013	JDF
622	3	Channel sample across metamorphic rocks at contact porphyritic nepheline syenite, including 10 ft of epidote tactite and 5 ft of calcite marble	.001	JDF
631	4	15-ft channel sample across unaltered limestone	.000X	JDF
632	4	15-ft channel sample across leucocratic fine-grained nepheline syenite	.0072	JDF
633	4	10-ft channel sample across fine-grained nepheline syenite at contact with porphyritic nepheline syenite	.0063	JDF
649	3	Chip sample across 25-ft outcrop of gneissoid nepheline syenite	.004	JDF
652	(Fig. 38)	Specimen of phonolite porphyry with limestone and syenite inclusions	.004	JDF
S–150–456	2	Chip sample across 0.8 ft of hard altered limestone, with two small eudialite-bearing malignite dikes, same locality as 329–195 to 205	.074	KJM
			.14	MMSC
			.2	MMS
457	2	Chip sample across 2 ft of eudialite-bearing malignite dike, same locality	<.001	MMS
458	2	Chip sample across 6 ft of same type of rock, same locality	<.001	MMS

of which can be reconciled with the values obtained for the mineral separates. Although the accuracy of the results may be challenged, some of the discrepancy may have resulted from erratic distribution of beryllium in the minerals. An unsuccessful search was made for the beryllium minerals, such as helvite, eudidymite, meliphenite, and leucophanite, that occur in pegmatitic nepheline syenites in southern Norway.

The dikes range in thickness from less than an inch to as much as 20 feet and in length from 5 feet to at least 300 feet. Though largely covered by talus, they probably are present throughout a zone a few hundred feet wide extending around the 5-mile circumference of the Wind Mountain laccolith. Thus, they would represent a substantial reserve if their beryllium could be recovered.

CAVE PEAK AREA

The intrusive complex at Cave Peak is in the Sierra Diablo, about 35 miles north of Van Horn, Tex., and 2 miles west of State Highway 54 (pl. 1). Though Cave Peak is about 1,300 feet above the alluvial floor of Salt Basin, it is overshadowed by the cliffs on the eastern scarp of the Diablo Plateau.

The intrusive rocks of the Sierra Diablo region were first mapped by Richardson (1914). Later King and others of the Geological Survey mapped the sedimentary formations and structures of the region (King and Knight, 1944; King, 1949). The uncommon igneous rocks of the Cave Peak area collected by King were studied by Charles Milton, Earl Ingerson, and others.

In 1944 the Cave Peak area was sampled by A. L. Slaughter for the Mine, Mill, and Smelter Survey. Two samples from one of the prospect pits contained 0.3 to 0.02 percent BeO. Because of the unusual quantity of beryllium reported in these samples, the geology in the vicinity of Cave Peak was mapped in detail during the present investigation (pl. 5).

GEOLOGY

The igneous rocks of Cave Peak form an intrusive complex that is nearly circular in outline and about half a mile in diameter. The rocks are mainly light and dark rhyolite porphyries and breccias. The central core of the complex is a plug of porphyritic granite about 300 feet in diameter. The complex resembles a volcanic neck but no lavas are found in the region. The ringlike structure of the various rock types around a core of granite (pl. 5) suggests that the pluton intruded almost to the surface.

Porphyritic syenite that is more like the igneous rocks found elsewhere in the Trans-Pecos Region forms the intrusive mass at Marble Canyon, a mile southwest of Cave Peak. The relation of this mass to the complex at Cave Peak is not known.

Most of the sedimentary rocks intruded at Cave Peak are dark-gray, thick-bedded limestones of the Hueco limestone (Permian). Near the southwestern side of the intrusive body, the Hueco limestone grades upward into the black limestone of the Bone Spring limestone (Permian). The formations are similar in appearance and were not differentiated in mapping. The limestone near its contact with the intrusive mass is largely calcite, but some beds are dolomitic. The rocks dip 2° or 3° to the south over much of the area, but are highly deformed within a few feet of the intrusive mass. Where observed, the strike of these deformed beds is approximately parallel to the contact, and dips range from nearly vertical to 35° toward the mass. On the southwest side of Cave Peak there is faulting along the contact, as indicated by a breccia zone several feet thick and slickensides.

IGNEOUS ROCKS

The most abundant rocks are breccias, composed mainly of fragments of rhyolite porphyry. Nonbrecciated felsite, mainly rhyolite porphyry, are less extensive in outcrop. The branches are subdivided on the basis of color into light rhyolite breccia and dark rhyolite breccia. The porphyries are similarly subdivided into light and dark rhyolite porphyry. Field relations suggest that the light rhyolite porphyry is probably the oldest intrusive rock and light rhyolite breccia the youngest, except for a few late porphyry dikes. The dark rhyolite porphyry and breccia are of intermediate age, the breccia being somewhat the younger of the two. The central core of granite appears to be younger than the dark rhyolite.

Light rhyolite porphyry occurs as dikes and irregular masses mainly in a zone about 400 feet wide around the southern end of the intrusive mass (pl. 5). The rock is largely greenish gray and is aphanitic except for scattered phenocrysts of feldspar and quartz as much as 3 mm in diameter. It weathers light gray. In places other varieties of felsite are associated with the light rhyolite porphyry and were undifferentiated from it in the mapping. In several outcrops on the southeastern slope of Cave Peak and in the large outcrop on the western ridge, the rhyolite contains no phenocrysts, but it is otherwise similar to the porphyry and appears to grade into it. Locally the rock contains no quartz and is probably trachyte or andesite porphyry.

The dark rhyolite breccia and porphyry are best exposed in a circular area on the northern slope of Cave Peak. The dark-gray to black, fine-grained rhyolite porphyry contains abundant feldspar and a few quartz phenocrysts about 2 mm in diameter. Microscopic examination by Charles Milton indicates that the feldspar is a slightly albitized orthoclase, and that the groundmass is orthoclase, quartz, biotite, and a little sphene (P. B. King, 1948, written communication). The dark-gray rhyolite breccia is composed largely of randomly oriented angular fragments as much as 2 cm in diameter. Some of the fragments are similar to the dark rhyolite porphyry. The inclusion of porphyry fragments in the breccia indicates that the breccia is younger.

Near the contact of the dark rhyolite porphyry with the porpyhritic granite, the porphyry is brecciated, silicified, highly altered, and crisscrossed by innumerable tiny quartz veins. The resulting rock is hard and medium- to fine-grained; the colors are light shades of pink, gray, and green. Where replacement is complete, parts of the rock closely resemble aplite, but in other places remnants of the rhyolite porphyry texture are preserved. The altered zone forms an aureole around the granite plug, suggesting that the alteration is related to emplacement of the granite.

The porphyritic granite is a dense medium-grained rock of quartz and orthoclase crystals in a fine grained groundmass of similar composition. It contains rare green skeletal crystals, possibly epidotized remnants of biotite; otherwise mafic minerals are lacking. Orthoclase is opaque white from slight alteration, and the rock is partly replaced by manganese and iron oxides.

Light rhyolite breccia underlies most of the main ridge and is the most abundant rock in the area. It crops out in a ringlike zone about 600 feet wide. The rock is pale orange and consists mainly of angular fragments of rhyolite in a felsitic groundmass of quartz and feldspar. Many of the fragments are like the groundmass, others are rhyolite porphyry with conspicuous flow structure, and a few are metamorphosed limestone. The areas of dark breccia that occur near the top of the peak may be large blocks of dark rhyolite breccia like that of the north slope, or a darker phase of the surrounding light rhyolite breccia. Fragment size varies widely from place to place. On the eastern side of the peak near the outer contact the light rhyolite breccia is composed of fragments as much as 2 meters in diameter, but near the inner contact the average diameter of fragments is less than a centimeter. The zones of contact, as well as the character of the inclusions, suggest that the light rhyolite porphyry is the last of the larger intrusive bodies.

METAMORPHIC ROCKS

The limestone on the eastern and southern sides of Cave Peak has been metamorphosed to marble or hornfels in a zone as much as 150 feet wide that has been cut by dikes and irregular masses of light rhyolite porphyry. Nearly all the exposures of rhyolite porphyry are surrounded by an inner zone of hornfels not more than 50 feet wide and by an outer zone of marble. These zones indicate that the metamorphism was related to the intrusion of porphyry.

The mineralogy and petrography of the metamorphic rocks are complex. The limestone is mostly metamorphosed to a white to buff, fine-grained marble that locally contains some fine white needles of tremolite(?). Chert nodules in the marble are altered to a green silicate rock that probably contains diopside.

The areas mapped (pl. 5) as hornfels include a variety of rocks. A common type is a light-gray or white, very fine grained hornfels that according to Charles Milton is principally spurrite ($CaCO_3 \cdot 2Ca_2SiO_4$) and merwinite ($Ca_3MgSi_2O_8$) with a little periclase (MgO). Another type is a greenish-brown hornfels that is at least in part grossularite, idocrase, and wollastonite. The presence of spurrite and merwinite indicates metamorphism at very high temperature (Bowen, 1940, p. 255–264) and comparatively low pressure (Korzhinsky, 1937). The association of wollastonite-garnet-spurrite is also in this same temperature range (Yoder, 1950, p. 249). The principal constituents of the white and gray hornfels are silica, lime, and magnesia, according to chemical analyses (table 62).

TABLE 62.—*Analyses of hornfels from Cave Peak*

[K. J. Murata, analyst]

	1	*2*
Insoluble	5.56	6.28
(SiO_2)	(3.60)	(1.00)
SiO_2	25.38	24.56
R_2O_3	1.62	2.80
MgO	5.93	3.06
CaO	55.00	54.04
CO_2	5.95	7.00
H_2O+	2.03	2.09
H_2O-	.29	.09
F	.21	.05
SO_3	.14	None(?)
	100.11	99.97
$-O=F$[1]	.06	.02
	100.05	99.95

[1] Corrected for oxygen equivalent of fluorine.

1. White hornfels from east side Cave Peak, containing spurrite, merwinite, garnet, wollastonite, idocrase, calcite, etc. P. B. King's specimen 797A.

2. Gray hornfels, principally spurrite, from same locality. P. B. King's specimen 797B.

Both the hornfels and the marble are crisscrossed by thin veins of fine-grained, hard material, ranging from white to light green. Similar material was determined by Charles Milton as thaumasite

$$(CaSiO_3 \cdot CaCO_3 \cdot CaSO_4 \cdot 14.5H_2O)$$

and calcite. Also, he noted the alteration of much spurrite and merwinite to a hydrous silicate that is probably the rare mineral radiophyllite, ($CaO \cdot SiO_2 \cdot H_2O$). These hydrous minerals undoubtedly represent a retrogression from the intense initial metamorphism.

On a weathered surface the metamorphic rocks and their veins are altered further to claylike material.

OCCURRENCE OF BERYLLIUM

The samples analyzed for beryllium are described in table 63 and their localities are shown on plate 5.

On the eastern slope of the peak a 4-foot-thick shear zone at the face of an adit has brought a block of altered light rhyolite porphyry into contact with the light rhyolite breccia. The rock in the shear zone is completely altered to clay, iron oxides, and gypsum. At the portal of the adit a 1-foot shear zone separates the block of porphyry from hornfels.

TABLE 63.—*Beryllia in samples from Cave Peak, in percent*

[All analyses spectrographic except as noted. Analysts: KJM, K. J. Murata; JDF, Janet D. Fletcher; JTR, J. T. Rozsa, National Spectrograhphic Laboratories; LWS, L. W. Strock, Saratoga Laboratories, Inc.; MMS, Samples collected and analyzed by Mine, Mill, and Smelter Survey]

Sample	*Description*	BeO	Mo	Nb	Pb	Sn	Zn	*Analyst*
329-017a	Sample from two 1.5-ft channels across limonite vein with steep westward dip in dark rhyolite porphyry and breccia, at portal	0.004	--------	--------	--------	--------	--------	LWS
020	Channel sample across 7 ft of highly altered, banded rhyolite porphyry dike, some quartz, limonite, and manganese oxide replacement	<.004	--------	--------	--------	--------	--------	LWS
021	Chip sample of 3-ft light rhyolite dike altered to clay and hematite	<.004	--------	--------	--------	--------	--------	LWS
054	Channel sample across 2 ft of hematite-bearing fracture zone in dark rhyolite porphyry, at portal of adit	<.004	--------	--------	--------	--------	--------	LWS
055	Channel sample across 6 ft of hematite-bearing fracture zone in dark rhyolite breccia	<.004	--------	--------	--------	--------	--------	LWS
056	Chip sample across 6 ft of hematite-bearing fracture zones in light rhyolite breccia	<.004	--------	--------	--------	--------	--------	LWS
057	Channel sample across 6 ft of hematite and limonite vein, 20 ft inside adit in light rhyolite breccia	<.004	--------	--------	--------	--------	--------	LWS
062	Channel sample along small fracture zone bearing iron oxides, in prospect shaft in dark rhyolite breccia	<.004	--------	--------	--------	--------	--------	LWS
064	Chip sample across 6-ft wall of adit (35 ft in) veined with iron oxides copper carbonates, fluorite, and minor wolframite in light rhyolite breccia	<.004	--------	--------	--------	--------	--------	LWS
065	Chip sample of 0.3-ft vein similar to 329-064, at portal of adit	<.004	--------	--------	--------	--------	--------	LWS
074	Grab sample of various types of hornfels, near 329-206	<.001	--------	--------	--------	--------	--------	JTR
077	Channel sample across 4 ft of shear zone altered to limonite, clay, and gypsum, at contact of light rhyolite breccia and altered light rhyolite porphyry, near face of adit	.01 (.0096) [1]	0.00X	0.0X	0.X	0.000X	0.0X	JDF LWS
078	Channel sample across 6 ft of altered light rhyolite porphyry, between 329-077 and portal	.004 (.0063) [1]	.00X	.0X	.0X	.000X	.0X	JDF LWS
079	1-ft channel sample across 1-ft shear zone altered to limonite, clay, and gypsum, at portal	.01 (.017) [1]	.00X	.00X	.X	.000X	.X	JDF LWS
080	Channel sample across 3.5 ft of gray hornfels containing grossularite, spurrite, etc., next to portal	<.004	--------	--------	--------	--------	--------	LWS
081	Channel sample across 15 ft of black hornfels containing spurrite, etc., with many greenish-white veins, outward of 329-080	<.004	--------	--------	--------	--------	--------	LWS
084	Specimen of pink hornfels	<.001	--------	--------	--------	--------	--------	JTR
206	Chip sample across hornfels area	.001	--------	--------	--------	--------	--------	JTR
208	Chip sample across feldspar-bearing hornfels	.001	--------	--------	--------	--------	--------	JTR
209	Chip sample across small hornfels inclusion	<.001	--------	--------	--------	--------	--------	JTR
680	Chip sample across 25 ft of grossularite-idocrase-spurrite(?) hornfels	.0005	<.00X	--------	<.000X	<.00X	<.0X	JDF
682	Channel sample across 3 ft of rhyolite breccia near 329-680	.0076	--------	--------	--------	--------	--------	JDF
684	Chip sample of hornfels	<.0001	--------	--------	--------	--------	--------	JDF
685	Chip sample of light rhyolite breccia, near 329-684	.0049	--------	--------	--------	--------	--------	JDF
686	Chip sample of light rhyolite porphyry, near 329-685 and 685	<.0001	--------	--------	--------	--------	--------	JDF

See footnotes at end of table.

TABLE 63—*Beryllia in samples from Cave Peak, in percent*—Continued

Sample	Description	BeO	Mo	Nb	Pb	Sn	Zn	Analyst
S-150-448	Channel sample across 1.5 ft of brecciated contact rock, gypsum-rich and iron-stained (same as 329-077?)	0.3 (.082) [1]	0.02	<0.001	---------	0.003	-------	MMS KJM
449	Chip sample across 12 ft of brecciated gray-green porphyry (same as 329-078 and 079?)	.02	.01	.06	---------	.009	-------	MMS
450	Specimen of purplish-gray porphyry in adit (same as 329-057?)	<.001	.3	.1	---------	.2	-------	MMS
451	Channel sample across 1.0 ft of purplish-gray porphyry with manganese	<.001	.3 (.17) [2]	.04	---------	.02	-------	MMS
452	Channel sample across 1.3 ft manganese-bearing vein	<.001	.3	.03	---------	.09	-------	MMS
516	Grab sample of brown porphyry with manganese stains, from dump, comes with breccia	<.001	--------	<.001	---------	---------	-------	MMS
517	Chip sample of hard siliceous breccia	<.001	--------	<.001	---------	---------	-------	MMS
518	Channel sample across 5.4 ft of light-gray rhyolite porphyry dike	<.001	--------	<.001	---------	---------	-------	MMS
519	Channel sample across 8.0 ft of porphyry	<.001	--------	<.001	---------	---------	-------	MMS
520	Channel sample across 6.0 ft of light-brown fractured porphyry (same as 329-064?)	<.001	--------	<.001	---------	---------	-------	MMS

[1] Analyses in parentheses made on a split of the sample.
[2] Chemical analysis.

Analyses of samples (329-077 and -079) from the shear zones in the adit showed 0.0096 to 0.017 percent BeO and as much as 0.X percent Pb, 0.X percent Zn, and 0.0X percent Nb. The minerals containing these elements were not identified. The altered light rhyolite porphyry (sample 329-078) contains less of these elements. A sample (S-150-448) taken earlier from the shear zone at the adit face was reported to contain 0.3 percent BeO, but reanalysis of the sample showed only 0.082 percent. Samples of the rocks adjoining similar shear zones several hundred feet north (329-685) and southwest (329-682) of the adit contained 0.0049 and 0.0076 percent BeO, respectively.

Beryllium apparently is confined to the shear zones and the rocks adjoining them, as none was found in the many samples of other rocks taken from various parts of the area. Although the average beryllium content of the shear zones appears to be relatively high, the zones can be traced for only a few tens of feet, and their aggregate tonnage is probably small.

UTAH

By L. A. WARNER and V. R. WILMARTH

Information on the BeO content of nonpegmatite rocks in Utah was obtained at 6 localities (see fig. 39). In September 1949 we investigated and sampled the beryl-bearing granite in the Sheeprock Range and the ore deposits associated with contact zones in the Tintic, West Tintic, and Ophir mining districts. Samples from the Little Cottonwood district were furnished by T. S. Lovering. The beryl-bearing rhyolite at Topaz Mountain in the Thomas Range had been sampled previously for the Geological Survey by J. C. Olson.

With the possible exception of the deposits in the Sheeprock Mountains, none of the others investigated seem likely to furnish beryllium. However, the occurrence of beryl in igneous rocks at two widely separated localities in west-central Utah holds some promise that beryllium deposits may be discovered in this region.

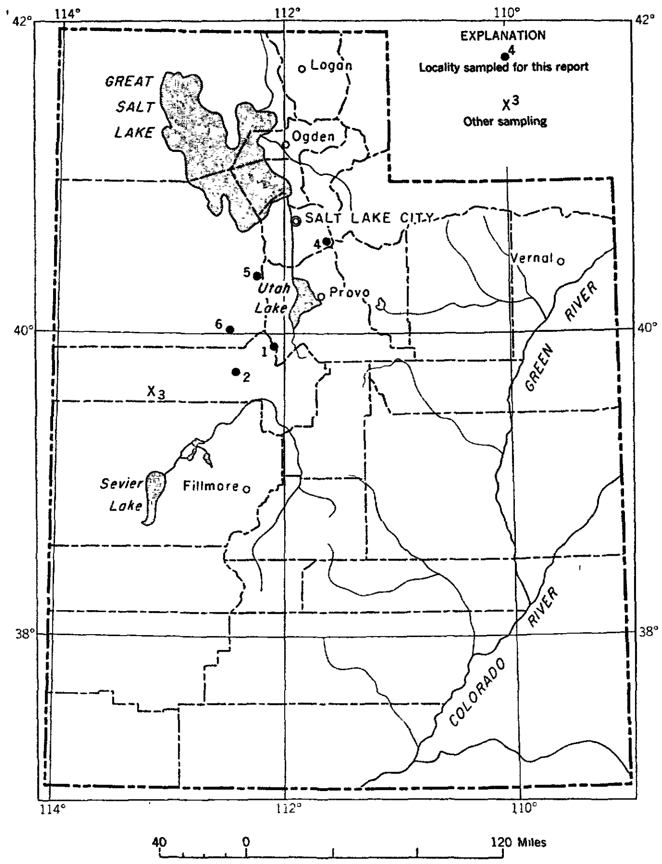
JUAB AND UTAH COUNTIES

TINTIC DISTRICT

The Tintic district is on the boundary between Juab and Utah Counties about 60 miles south of Salt Lake City in the central part of the East Tintic Mountains. Descriptions of the geology and ore deposits of the district have been given by Tower and Smith (1899), Smith, Tower, and Emmons (1900), Crane (1915; 1923), Lindgren (1915), Lindgren and Loughlin (1919), Parsons (1925), Hunt (1928), Farmin (1933), Park (1935), Kildale (1944), and Lovering and others (1949).

A brief examination was made of contact metamorphic deposits at the Black Jack and Dragon Iron mines and near the Carisa stock, all in the central part of the Tintic district and about 1 mile east of Silver City.

The Black Jack mine, half a mile southeast of Mammoth, is in metamorphosed limestone near the contact with an altered monzonite dike. In an opencut a black



DISTRICTS

Juab and Utah Counties
1. Tintic district
2. West Tintic district
3. Topaz Mountain

Salt Lake County
4. Little Cottonwood district

Tooele County
5. Ophir district
6. Sheeprock Mountains

FIGURE 39.—Index map of Utah, showing localities sampled.

manganese-stained siliceous rock is next to a zone of altered monzonite that is composed of clay and quartz. A grab sample (328–929) of the altered monzonite contained less than 0.0001 percent BeO.

The Dragon Iron mine is on the north side of Dragon Canyon about a mile southeast of the Black Jack mine. The mine is in metamorphosed Ajax and Opohonga limestones of Ordovician age near their contact with a monzonite stock. A northwestward-trending zone of altered rock that is rich in limonite extends for about a thousand feet along the contact of the stock and is exposed in a large opencut. The margins of the zone are largely kaolin. Grab samples were taken of iron ore from the dump (328–926) of altered limestone from the north edge of the opencut (328–927) and of kaolin from the south edge of the opencut (328–928). All contained less than 0.0001 percent BeO.

The Carisa stock, a small monzonite body 2,000 feet in diameter, is about half a mile northeast of the Dragon Iron mine. Near the contact, the Bluebell (Silurian and Devonian) dolomite has been changed to a spinel-garnet-pyroxene rock. A grab sample (328–925) of this rock from the southwest side of the stock contained less than 0.0001 percent BeO.

WEST TINTIC DISTRICT

The West Tintic district covers an area of several square miles in eastern Juab County about 25 miles airline southwest of Eureka. The geology and ore deposits were studied by Loughlin (Butler, and others, 1920, p. 432–444) and Stringham (1942).

Precambrian shale, conglomerate, and quartzite are in fault contact with, and unconformably underlie dolomite, limestone, quartzite, and shale of Paleozoic age. These are intruded by granodiorite and monzonite stocks and dikes of Tertiary age. Tertiary rhyolite flows cover the sedimentary rocks east of the district. Contact metamorphic and fissure-vein deposits in the limestone of Paleozoic age are related genetically to the intrusive granodiorite and monzonite. Gold, silver, lead, copper, and tungsten are the principal metals produced. A brief examination was made of the Iron King and Desert Tungsten mines.

The Iron King mine, in the western part of the district, is in a narrow tactite zone in limestone. Magnetite and specularite are the principal ore minerals. Garnet, epidote, diopside, tremolite, and quartz replace the marmorized limestone adjacent to the iron ore. A grab sample (328–930) of monzonite was obtained from an exposure 300 feet west of the mine, and a grab sample (328–931) composed of garnet, epidote, quartz, diopside and magnetite was taken from the mine dump. These samples did not as much as contain 0.0001 percent BeO.

The Desert Tungsten mine, about 1,000 feet east of the Iron King mine, was operated during World War II for tungsten. Scheelite occurs with garnet, magnetite, epidote, and some tremolite, in a fissure vein in limestone. A grab sample (328–932) from the dump did not contain as much as 0.0001 percent BeO.

TOPAZ MOUNTAIN, THOMAS RANGE

By J. C. OLSON

Pink beryl occurs in the topaz-bearing rhyolite of Topaz Mountain in the Thomas Range, Juab County, Utah. The best known locality for topaz and beryl is nearly 2 miles south-southeast of the summit of Topaz Mountain, at an altitude of about 5,700 feet, and is about 40 miles northwest of Delta, Utah, by good dirt road.

The pink beryl on Topaz Mountain was first mentioned by Hillebrand (1905). Patton (1908) described the topaz and bixbyite in the rhyolite, but did not mention the beryl. He states that topaz is scattered through the rhyolite for several miles, but is most abundant on Topaz Mountain. Palache (1934, p. 14) described the beryl as follows:

> Beryl: This mineral, so unfamiliar in such surroundings, has been reported recently from this locality under the name of apatite. A considerable amount of blasting yielded only a small number of specimens. It is in the form of small crystals of a rose-red color attached to the cavity wall or to topaz. The crystals are tabular, simple combinations of prism and base, and rarely reach a diameter of 5 mm and a height of 3 mm. The color is a delicate pink and somewhat variable. Under the microscope the crystals show a zonal structure, the zones having slightly varying optical properties. They enclose tiny quartz crystals.
>
> I am indebted to Mr. Harry Berman for the following optical data. The crushed crystals show a variation in refractive index w=1.580± to w=1.570±. This variation is due apparently to zoning. The average values are w=1.576, e=1.570. These values indicate a beryl low in alkalies. The specific gravity 2.67±.01 likewise indicates a low alkali content.

The topaz is comparatively abundant as clear colorless crystals in cavities in rhyolite that occupies an area at least a mile wide and several miles long. At the principal workings for topaz, about half a mile northwest of the camp maintained by the Utah Geological and Mineralogical Society, the rhyolite has been blasted at about four places over a distance of 1,000 feet. Topaz is common both in the rock quarried and throughout much of the other rhyolite in the area, but beryl is difficult to find.

Beryl occurs as very rare, quarter-inch or less, tabular pink crystals. The richest locality found in a day's reconnaissance is a small pit dug for specimen material. A half-hour search at the pit yielded only 3 tiny crystals. Because the visible beryl is such a minute percentage of the rock, spectrographic analyses were made of 7 samples of rhyolite in which no beryl was visible. A sample of massive rhyolite containing no large cavities, from about 600 feet north-northwest of the camp, contained 0.0011 percent BeO. Samples from three of the localities where rock was blasted for topaz contained 0.0020, 0.0012, and 0.0020 percent BeO. Two samples of rhyolite from the pit dug for specimen beryl contained 0.0039 and 0.0020 percent BeO, and a sample of rhyolite 100 feet northeast of the pit contained 0.0021 percent BeO. The 7 samples range from 0.0011 percent to 0.0039 percent BeO, averaging 0.0020 percent, which appears to be a representative figure for this large mass of rhyolite.

SALT LAKE COUNTY

LITTLE COTTONWOOD DISTRICT

The Little Cottonwood mining district is between the Big Cottonwood and American Fork districts in the central part of the Wasatch Mountains, just southwest of Park City. The geology and ore deposits of the region have been described by Butler and Loughlin (1916). Rocks of the area include Precambrian quartzite and slate that are overlain by formations consisting of limestone, shale, and sandstone of Paleozoic and Triassic ages. These rocks were intruded by stocks and dikes of granodioritic quartz diorite. Tactite deposits formed locally in the limestone beds. The principal ore deposits are lead-silver veins and replacement bodies.

Two grab samples of tactite, containing idocrase, quartz, and garnet, from an unidentified locality in the Little Cottonwood district were furnished by T. S. Lovering. They contained less than 0.0001 percent BeO. The district was not visited by the writers.

TOOELE COUNTY

OPHIR DISTRICT

The Ophir district is on the west side of the Oquirrh Range, about 30 miles southeast of Tooele. Loughlin (1917), Butler (Butler and others, 1920, p. 374–382), Wichman (1920), and Gilluly (1932, p. 139–156) have described the geology and ore deposits of the district. The rocks are largely sedimentary and consist of quartzites, shales, and limestones ranging in age from Cambrian to Carboniferous. The igneous rocks are highly altered and occur as small dikes and sills in the sedimentary formations. Lead and silver, with minor amounts of copper, zinc, and gold are the principal metals recovered, mainly from replacement bodies in limestone. In some places the limestone has been altered and replaced by epidote, quartz, sericite, and orthoclase.

A grab sample (328–924) consisting of marble, epidote, and silicified limestone collected from the dump of the U. S. mine did not contain as much as 0.0001 percent BeO.

SHEEPROCK MOUNTAINS

The Sheeprock Mountains are in southeastern Tooele County and northeastern Juab County about 25 miles west of Eureka, Utah. Beryl-bearing granite occurs in the northern part of the range north of the Erker Ranch. The area is accessible by gravel and dirt road extending northwest from Jericho on U. S. Highway 6, 20 miles south of Eureka. Two days were spent studying the occurrences of beryl and exploring the granite boundary for tactite deposits.

Little detailed work has been done in the Sheeprock Range and the general geology is known. Butler and others (1920, p. 423–426) made a reconnaissance survey of the region, and the Precambrian rocks were described by Eardley and Hatch (1940, p. 823–827).

These rocks appear to constitute the bulk of the range and consist largely of quartzite with some phyllite and a few conglomeratic layers which may be of glacial origin. Limestones and quartzites of Paleozoic age crop out in the West Tintic district at the southern end of the range and in parts of the Columbia and Erickson districts at the northern end. The principal intrusive rock is the beryl-bearing granite stock which extends nearly across the northern part of the range, cutting both Precambrian and Paleozoic rocks. The general geology of the region and locations of the area we investigated are shown in figure 40.

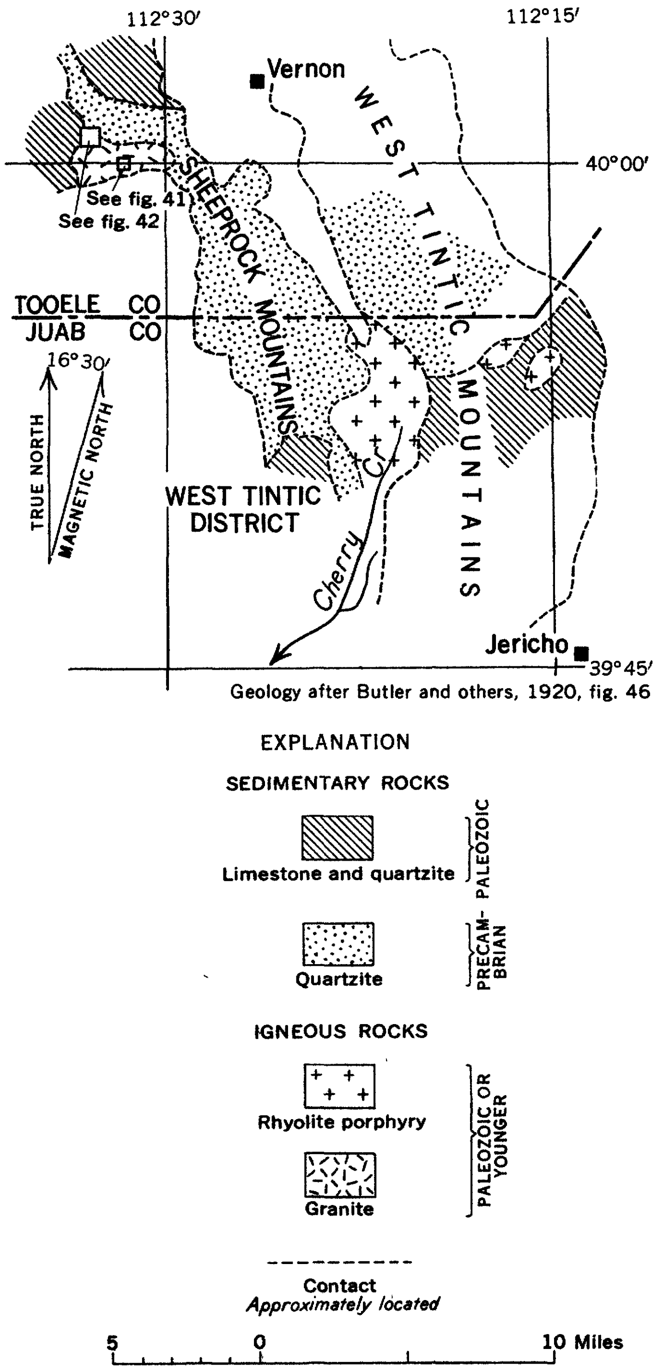


FIGURE 40.—Geologic index map showing locations of areas investigated in Sheeprock Mountains, Utah.

Beryl is sparsely distributed through granite and aplite near the central part of the stock about 1 mile north of the Ekker Ranch house (see fig. 41). The major occurrences are in an irregular zone extending for nearly 2,000 feet along the east side of Hard-to-Beat Canyon. The beryl is a bright blue with index (No) of 1.58, indicating about 13 percent BeO. It occurs as rosettes and single crystals along poorly defined fractures, veinlets, and schlieren which appear to be related to the flow structure in the granite. Rosettes are fairly common and some are as much as 6 inches in diameter, with beryl crystals radiating from the center. One piece of beryl float showed comb structure, with beryl crystals perpendicular to the walls of a fracture filling. Other occurrences consist of small irregular aggregates of beryl with quartz and feldspar which form isolated pods and lenses in the granite. Texturally these aggregates resemble pegmatite, though pegmatite dikes were not noted in the area examined. Much of the beryl, particularly in the aplite, occurs as single crystals or small groups of crystals less than a centimeter in diameter. In most places the beryl aggregates are separated from their nearest neighbors by several feet to several tens of feet of apparently barren granite, and large parts of the zone appear not to contain beryl.

Thin sections of the granite reveal that its mineral composition is approximately 35 percent perthite, 30 percent albite, 25 percent quartz, 5 percent biotite, and 5 percent orthoclase and miscellaneous constituents. The composition of the albite is about Ab_{95}, corresponding to that of the blebs in the perthite. A few grains of albite-antiperthite, containing blebs of microcline, were noted. Perthite was the latest mineral to form, filling interstices between the other minerals. The biotite is pale, highly pleochroic, and strongly birefringent. It contains inclusions of zircon which show well-developed pleochroic halos. Mineral composition of the aplite is similar to that of the granite except that orthoclase is abundant and perthite is absent.

A thin section cut from a specimen of beryl-rich granite, showed beryl interstitial to corroded grains of quartz and albite; perthite and orthoclase were lacking. A section cut from adjoining beryl-free granite showed abundant perthite interstitial to uncorroded grains of quartz and albite. It seems clear that the beryl replaced perthite and orthoclase. This evidence, together with the field relations, suggests that the beryl

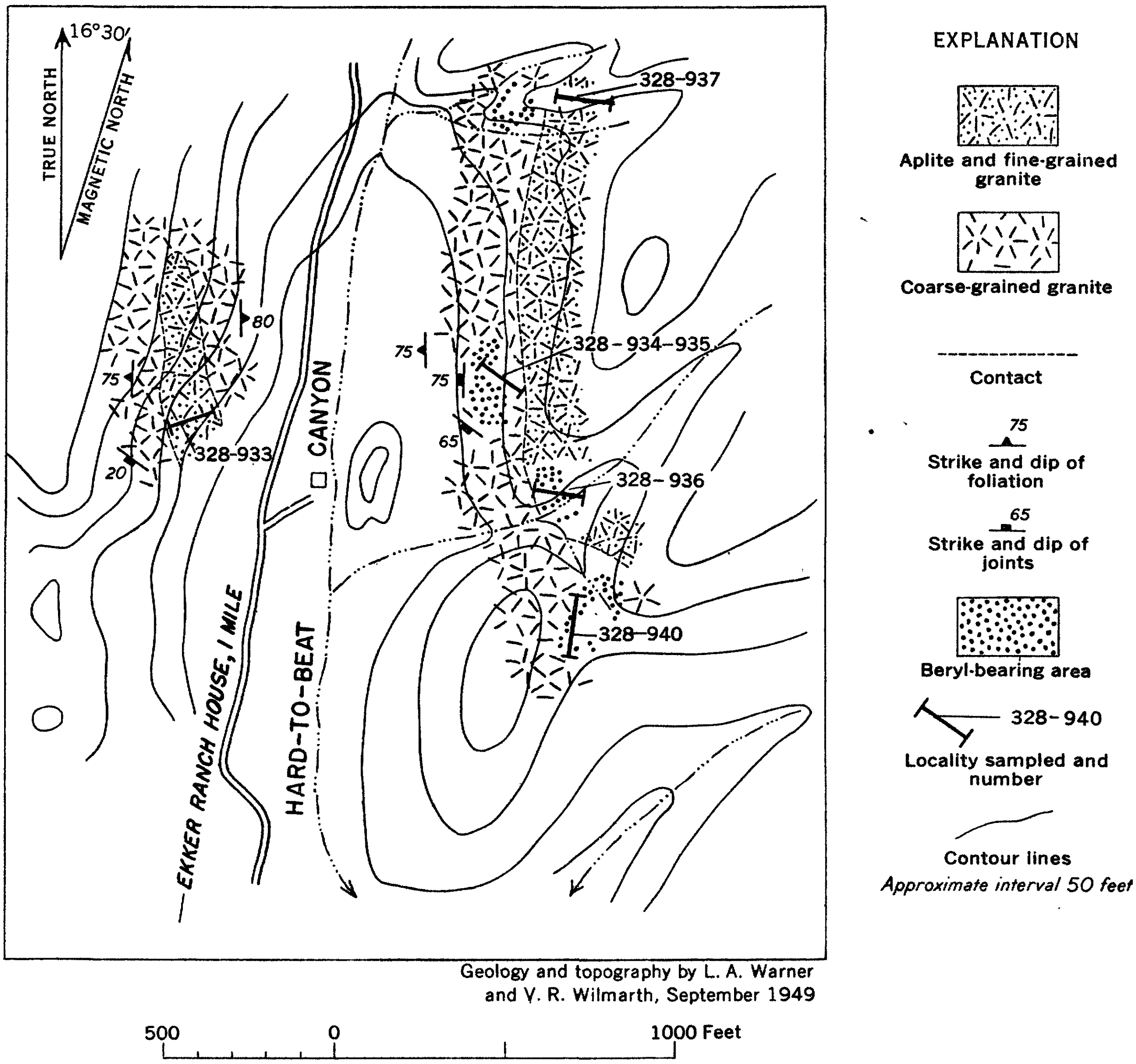


FIGURE 41.—Geologic sketch map showing occurrence of beryl in Hard-to-Beat Canyon, Sheeprock Mountains, Utah.

is of secondary origin, having been introduced by solutions that permeated the rocks after their emplacement.

Samples of granite and aplite were taken, as described in table 64; locations of the samples are shown on figure 41. In sampling, care was taken not to include any of the beryl aggregates, for it was desired to learn whether the rocks might contain disseminated beryl not visible in hand specimen. The relatively low beryllia content of the samples indicates that fine-grained beryl, if present at all, is probably not abundant. Without more detailed mapping and sampling the tonnage of beryl-bearing granite cannot be estimated. Parts of the granite may be rich enough in beryl to constitute an ore of milling grade.

TABLE 64.—*Beryllia in samples of granite and aplite from Hard-to-Beat Canyon*

Sample	*Description*	BeO (percent)
328–933	Chip sample across aplite dike; little or no beryl visible	0.0049
934	Chip sample across beryl-bearing granite	.0052
935	Chip sample of beryl-bearing granite	.0050
936	Chip sample across beryl-bearing aplite	.0033
937	Chip sample across aplite next to beryl-bearing granite at north end of zone	.0033
940	Chip sample across beryl-bearing granite, south end of zone	.0024

Along its northwestern margin, the granite stock invades limestones of Paleozoic(?) age. The contact in this area was investigated for about a mile (see fig. 42) in a search for tactite deposits that might contain beryllium. The limestone has been silicified and mar-

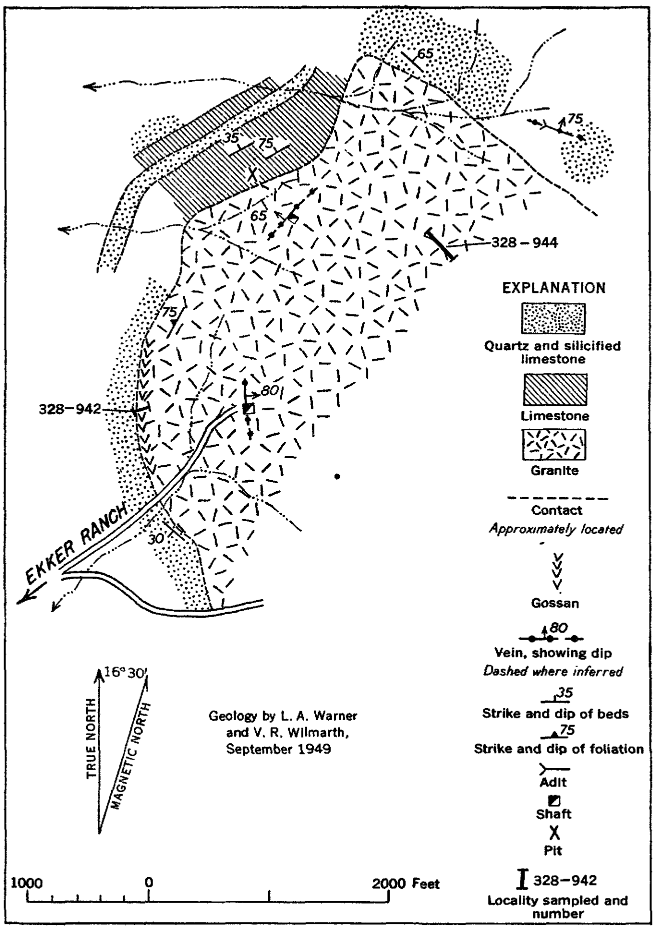


FIGURE 42.—Geologic sketch map of northwest contact of granite stock, Sheeprock Mountains, Utah.

morized, but no tactite was found. A few fissure deposits containing quartz, pyrite, chalcopyrite, limonite, and in places magnetite, were formed in the granite and adjoining rocks. A veinlike deposit along the west margin of the granite has been oxidized to a gossan that was traced for more than 1,000 feet. A sample of this material (328–942) showed no detectable beryllium. No beryl was observed in the granite in this area, and a chip sample of the granite (328–944) contained only 0.0008 percent BeO. Along its northern and eastern boundaries the granite stock is in contact with Precambrian quartzite, and the southern boundary is largely covered by alluvium. The probability that further search might reveal beryllium-bearing deposits along the granite boundary seems small.

MONTANA

By L. A. WARNER and V. R. WILMARTH

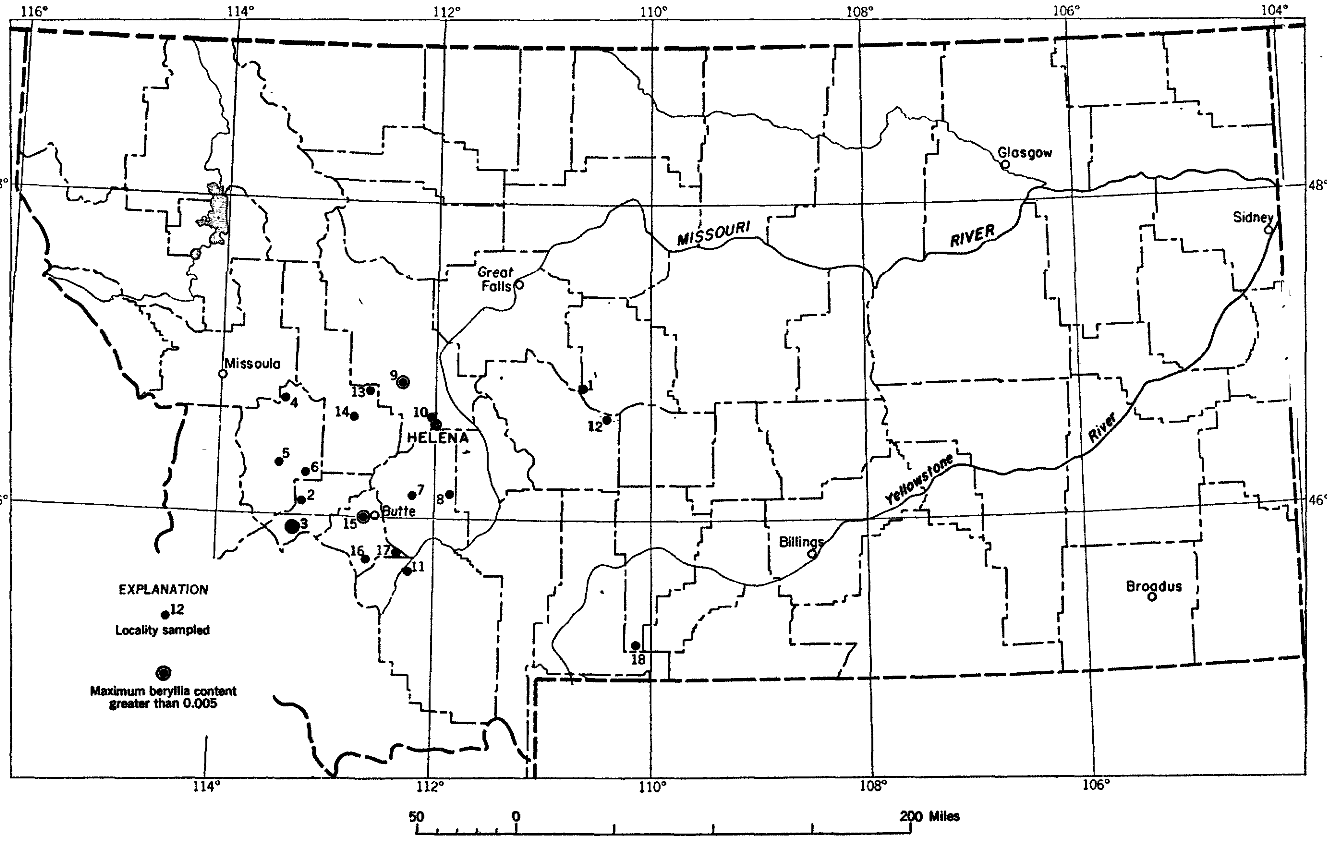
Beryllium investigations in Montana were carried on during September 1949, in 18 districts and localities (fig. 43). A variety of samples of igneous rocks and ore deposits was obtained. Principal attention was devoted to the Butte district, where helvite had been reported in rhodonite veins. The veins apparently do not contain enough helvite to make them a likely source of beryllium. A sample of tactite from the Mill Creek area, southwest of Anaconda, and a sample of mill tailings taken at the Drumlummon mine in the Marysville district contained 0.022 percent and 0.011 percent of BeO, respectively. There is no assurance that the samples are representative and further investigations at these localities are needed to determine the nature and quantity of the beryllium-bearing material.

CASCADE AND JUDITH BASIN COUNTIES

LITTLE BELT MOUNTAINS

In the central part of the Little Belt Mountains, near Neihart, alkalic igneous rocks intrude limestones of Paleozoic age, and locally contact metasomatism has taken place. Metamorphosed limestone is exposed in a road cut on U. S. Highway 89, about 10 miles south of Neihart (fig. 44). The sedimentary rocks are part of the Barker formation of Weed (1899a) (Cambrian) and consist of altered limestone, quartzite, and shale. The igneous rocks are part of the group mapped by Weed as diabase, basalt, minette, vogesite, and kersantite. The igneous rocks exposed in the road cut include a lamprophyre dike and a light-colored aphanitic rock which may have been separately intruded or is an extremely altered part of the lamprophyre. The limestone adjacent to the lamprophyre has been marmorized and partially replaced by silicate minerals. Taylor (1935) identified 27 minerals in the contact zone. A grab sample (328–919) was taken from the contact zone on the east side of the road cut and a chip sample (328–920) was taken across the altered limestone and shale exposed on the west side of the cut. Beryllium was not found in these samples; the lower limit of detection being 0.0001 percent BeO.

Yogo Peak is a prominent topographic feature in the Little Belt Range about 6 miles east of Neihart. It is formed by a Tertiary stock of shonkinite that cuts limestones, shales, and sandstones of Paleozoic age. Talus covers most of the contact on the west slope of Yogo Peak, and little or no metamorphism was found where the contact was exposed. On the east and northeast sides of the peak, massive limestone beds have been marmorized and locally replaced by garnet, actinolite, and diopside. A grab sample (328–921) of these contact minerals from a tactite zone, 3 miles by road northeast of the top of Yogo Peak, did not contain as much as 0.0001 percent BeO.



LOCALITIES

Cascade and Judith Basin Counties

1. Little Belt Mountains

Deer Lodge County

2. Georgetown district
3. Mill Creek area

Granite County

4. Garnet district
5. Philipsburg district
6. Red Lion district

Jefferson County

7. Basin district
8. Elkhorn district

Lewis and Clark County

9. Marysville district
10. Spring Hill mine

Madison County

11. Silver Star district

Meagher County

12. Gordon Butte

Powell County

13. Ophir district
14. Priest Pass

Silver Bow County

15. Butte district
16. Highland district
17. Toll Mountain area

Sweet Grass County

18. Haystack stock

FIGURE 43.—Index map of Montana, showing localities sampled.

DEER LODGE COUNTY

GEORGETOWN DISTRICT

By W. T. HOLSER

The Georgetown district is in the vicinity of Georgetown Lake, where U. S. Highway 10A crosses the summit of the Flint Creek Range. It was sampled in June 1948 in connection with other geological work in the area.

The geology of the district was described by Emmons and Calkins (1913, p. 221–242) and Holser (1950, p. 1063–1067). A stock of granodiorite 2 miles in diameter intrudes a faulted anticline of sedimentary rocks of Paleozoic age. Shaly limestones are metamorphosed to garnet-diopside and hornblende-magnetite tactites as far as 1,200 feet from the contact, and dolomite is recrystallized and irregularly replaced by massive magnetite near the stock. Later deposited pyrite, chalcopyrite, pyrrhotite, arsenopyrite, and gold are widespread in the contact zone.

The recrystallized and replaced limestones were sampled at several places along the northern edge of the stock as follows:

329–003 22-ft channel sample of magnetite-dolomite-olivine rock, from open pits of Pomeroy mine.

329–004 25-ft channel sample of dolomite marble partly altered to limonite, from opencuts on the Uncle Billy claim.

329–005 10-ft channel sample of dolomite marble at contact of granodiorite, from northeast crosscut of tunnel level, Cable mine.

329–006 10-ft channel sample of brecciated dolomite marble, from main tunnel near third crosscut, Cable mine.

329–007 15-ft channel sample of dolomite marble breccia and magnetite from tunnel level just north of Nowlan raise, Cable mine.

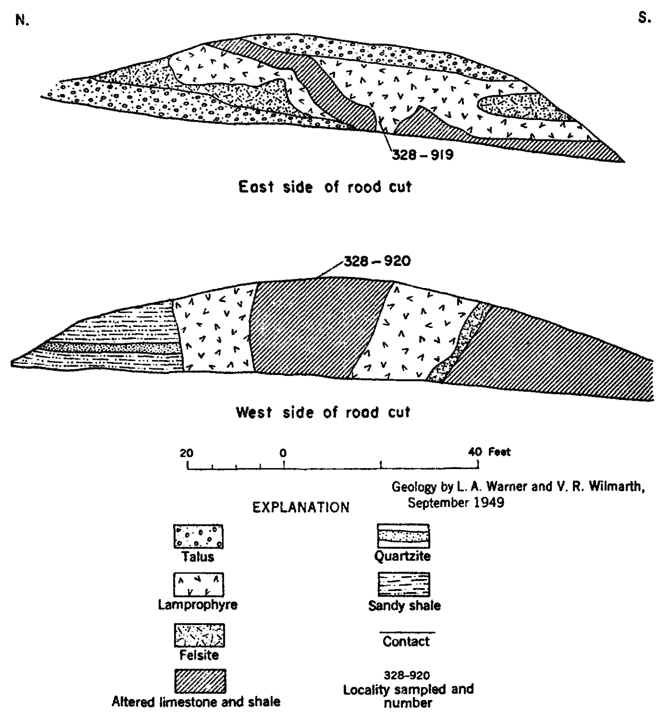


FIGURE 44.—Sketches showing geology in road cut on U. S. Highway 89, in T. 12 N., R. 8 E., about 10 miles south of Neihart, Mont.

Magnetite deposits near the contact of a granite stock at Olson Gulch (Holser, 1950, p. 1067, Emmons and Calkins, 1913, p. 244) were sampled as follows:

329–008 40-ft channel sample of magnetite-actinolite tactite in limestone, from northern open pits of the Bung-Your-Eye claim.

329–009 15-ft channel sample across a hematite-clay shear zone, same locality as sample 329–008.

Beryllium was not detected in these samples, the lower limit of sensitivity being 0.001 percent BeO.

MILL CREEK AREA

Mill Creek rises in a valley that heads a short distance west of Mount Haggin, a prominent peak about 30 miles southwest of Anaconda. The area is in the southeast part of the Philipsburg quadrangle, the geology of which was described by Emmons and Calkins (1913) and Calkins and Emmons (1915). The western part of the quadrangle is underlain by rocks of the Belt series which in most places have been thrust over complexly folded and faulted formations of Paleozoic and Mesozoic age that lie to the east. The latter have been intruded by stocks, dikes, and sills ranging in composition from granite to diabase.

On the north side of Mill Creek, near its headwaters, shaly limestone in the Silver Hill formation of Cambrian age has been contact metasomatized next to a granodiorite stock. A geologic sketch map of the contact zone exposed near the head of a northeast-trending gulch on the southeast side of Mount Haggin is shown in figure 45.

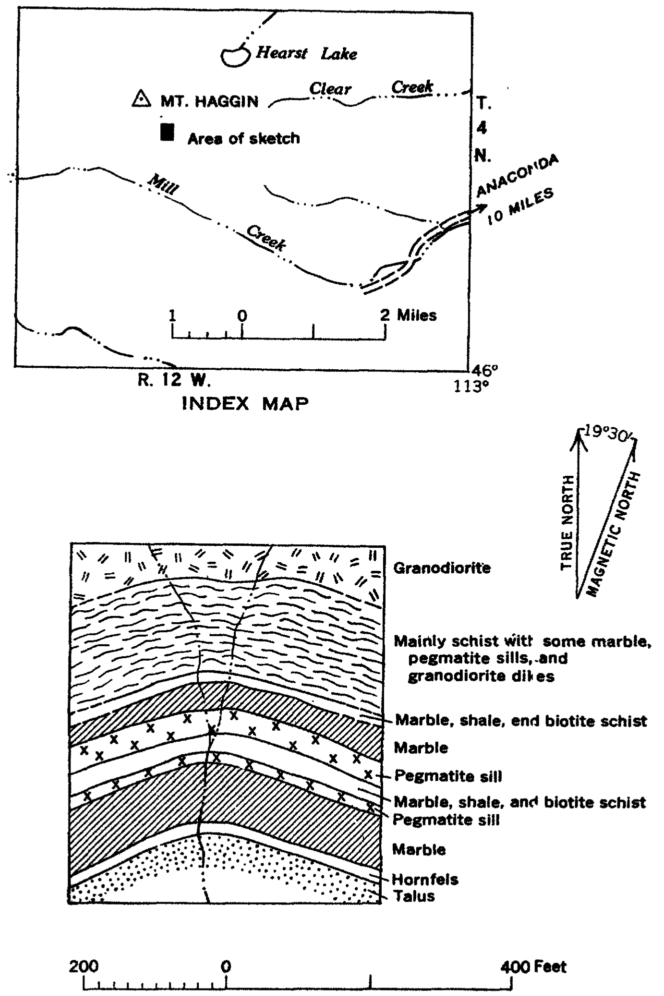


FIGURE 45.—Index and sketch maps of contact zone near Mount Haggin, Anaconda Range, Dear Lodge County, Mont.

The rocks exposed in the contact zone are biotite schist, hornfels, marble, pegmatite sills, and narrow dikes of granodiorite. In places the marble and hornfels have been replaced by idocrase and garnet.

A composite sample (328–905) of idocrase-bearing rock from this locality contained 0.022 percent beryllium oxide. A mineralogical study of rock specimens from the contact zone was made by J. J. Glass, of the U. S. Geological Survey, in an effort to isolate and identify the beryllium-bearing mineral. The specimens were composed chiefly of idocrase, fluorite, calcite, biotite, spessartite, diopside-hedenbergite, hydrobiotite, quartz, and albite. The results of spectrographic analyses of these minerals for beryllium are shown in table 65.

TABLE 65.—*Beryllia in minerals from contact zone, Mill Creek area, Montana*

[Qualitative spectrographic analyses by A. A. Chodos]

Description	BeO (*percent*)
Idocrase from idocrase-fluorite-marble rock	0.0X
Fluorite from idocrase-fluorite-marble rock	.00X
Calcite from idocrase-fluorite-marble rock	Not found.
Biotite from idocrase-fluorite-marble rock	Not found.
Garnet from quartz-feldspar-garnet rock	Not found.
Diopside-hedenbergite from hornfels	.00X
Hydrobiotite from marble	.000X
Quartz and albite from veinlets	.0X

Idocrase occurs chiefly in the relatively thin shaly limestone layers, in which it is an abundant constituent. J. J. Glass of the U. S. Geological Survey made the following optical determinations on the idocrase: uniaxial negative; N_e=1.700; N_o (variable) 1.707 to 1.717; birefringence (variable) 0.007 to 0.015; distinctly pleochroic in thick grains, colorless to yellowish green. A quartz-feldspar-garnet rock was found in float but was not observed in place. The garnet is spessartite (N=1.80 to 1.81) and is associated with microcline, albite, and quartz. Bands rich in diopside-hedenbergite occur in hornfels near the pegmatite sills. Veinlets and stringers of quartz and albite presumably are related to the pegmatite.

The contact zone in this area is extremely complex, and detailed sampling would be needed as a basis for estimating tonnage. There is no assurance that the material collected at the locality visited is at all typical of the zone. Calkins' map (Emmons and Calkins, 1913, pl. 1) shows the Silver Hill formation extending for more than 2 miles along the southern margin of the granodiorite stock in the vicinity of Mount Haggin. The mineral assemblage in the contact zone is one which commonly includes helvite, though none was found.

GRANITE COUNTY

By W. T. HOLSER

GARNET DISTRICT

The Garnet district, including the Top O'Deep district, is along the crest of the Garnet Range, about 50 miles east of Missoula, and about 10 miles north of U. S. Highway 10. The area was visited in July 1948. The geology of the district has been described by Pardee (1917) and Holser (1950, p. 1067). A northwestward-trending anticline of limestones and shales of Paleozoic age is intruded by granodiorite of the Garnet batholith. Although recrystallization is widespread, contact metasomatism is confined to a narrow zone near the granodiorite where shaly beds are replaced by diopside, garnet, epidote, and magnetite. An eastward-trending fracture zone in the metamorphic rocks contains local concentrations of quartz, barite, pyrite, tetrahedrite, chalcopyrite, galena, gold, telluride minerals, and molybdenite.

A 4-foot channel sample (329–014) was cut from a surface exposure of garnet-diopside tactite at the Shamrock mine in the town of Garnet. At the Boston mine, a 15-foot channel sample (329–015) was taken across garnet and garnet-magnetite tactite in limestone. Spectrographic analyses of these samples showed no beryllium, the limit of detection being 0.001 percent BeO.

PHILIPSBURG DISTRICT

The Philipsburg district, which is on U. S. Highway 10A midway between Butte and Missoula, was visited in July 1948. The geology was studied by Emmons and Calkins (1913) and by Holser (1950). A northward-plunging anticline of sedimentary rocks of Paleozoic age is intruded by granodiorite of the Philipsburg batholith. Limestones are partly recrystallized, and shaly or sandy limestones are replaced by garnet-diopside tactite. Much of the tactite is replaced by magnetite, hornblende, and scapolite. East-trending veins contain quartz, rhodochrosite, pyrite, galena, sphalerite, and argentiferous tetrahedrite; the oxide zones are rich in manganese.

Samples were taken from the contact zone as follows (for localities see Holser, 1950, pl. 1):

329–010 Channel sample across 15 ft of phlogopite-bearing marble, 235-ft level of Marie mine, 400 ft from shaft.

329–011 Channel sample across 20 ft of marble containing pyrolusite and quartz at headframe of True Fissure shaft.

329–012 Channel sample across 15 ft of dolomite marble containing serpentine and magnetite, from end of south drift, main level, Climax mine.

Beryllium was not detected in the samples, the lower limit of sensitivity being 0.001 percent BeO.

RED LION DISTRICT

In the Red Lion district, about 10 miles southeast of Philipsburg, sedimentary rocks of Paleozoic age, mainly limestones, have been metamorphosed adjacent to the Philipsburg batholith. The metamorphism is less intense than in the Philipsburg and Georgetown districts nearby. Fracture fillings and replacement bodies in the limestone contain quartz, calcite, pyrite, hematite, magnetite, and gold.

A prospect on the Modoc claim (Emmons and Calkins, 1913, p. 239) is on the contact between granodiorite and marble. Two channel samples were taken at this prospect, one (329–001) across 5 feet of granodiorite and the other (329–002) across 12 feet of marble. The samples contain no beryllium, the lower limit of sensitivity being 0.001 percent BeO.

JEFFERSON COUNTY

BASIN DISTRICT

The Basin mining district, centering around the town of Basin, is about 8 miles west of Boulder and 20 miles south of Helena in the northern part of Jefferson County. The geology and ore deposits were described by Knopf (1913, p. 120–128) and Pardee and Schrader (1933, p. 285–299). The rocks exposed in the Basin district are quartz monzonite, dacite, and andesite of Late Cretaceous and Tertiary age. The ore deposits include gold placers, and lodes that are valuable for silver, lead, zinc, and copper. Some composite lodes were worked chiefly for gold and silver. Samples were obtained at the Eva Mae and Hattie Ferguson mines.

The Eva Mae mine and mill are 8 miles north of Basin. The country rock is quartz monzonite that has been cut by tourmaline-bearing quartz veins containing scheelite, galena, chalcopyrite, sphalerite, and pyrite. Grab samples of mill tailings (328–906) and ore from the mine dump (328–907) contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

The Hattie Ferguson mine is on Cataract Creek, about 6 miles north of Basin. The now abandoned mine was on a quartz vein in aplite. Galena, sphalerite, and auriferous pyrite are the principal ore minerals. A composite sample (328–908) of vein material from the dump contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

ELKHORN DISTRICT

The Elkhorn mining district, centering around the town of Elkhorn, is about 12 miles northeast of Boulder, in the eastern part of Jefferson County. The geology and ore deposits were described by Weed (1901), Stone (1911), Knopf (1913, p. 128–139), and Pardee and Schrader (1933, p. 299–303). The sedimentary rocks are limestones, shales, and quartzites of Paleozoic age unconformably overlain by sandstones, shales, and impure limestones of Mesozoic age; all have been much altered by contact metamorphism. Tertiary andesite breccia, tuff, and lava overlie the sedimentary rocks of Mesozoic age. Intrusive igneous rocks of Cretaceous or Tertiary age range in composition from gabbro to granite. Samples were obtained from the Elkhorn and Sourdough mines and the Quartz Lode claim.

The Elkhorn mine at the town of Elkhorn explores a lead-zinc-silver replacement deposit in indurated limestone and shale. A composite grab sample (328–909) of dump material contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

The Sourdough mine, a mile northwest of Elkhorn, is developed on a small pyrrhotite deposit in limestone near a quartz monzonite intrusive. Minor quantities of scapolite and epidote were noted on the dump. A grab sample (328–910) of dump material composed of epidote, scapolite, pyrrhotite, and limestone contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

A grab sample (328–911) of garnet from a small prospect pit on the Quartz Lode mining claim, one-fourth mile below the Sourdough mine, contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

LEWIS AND CLARK COUNTY

MARYSVILLE DISTRICT

The Marysville mining district is in Lewis and Clark County, about 17 miles northwest of Helena. The geology and ore deposits of the district were discussed by Barrell (1907), Knopf (1913, p. 61–76; 1950), and Pardee and Schrader (1933, p. 63–76). The rocks of the Marysville district include a small quartz diorite stock that intrudes limestones and shales of the Belt series. Younger intrusive rocks are aplite, pegmatite, and diorite porphyry. The ore deposits are steeply dipping veins in the metamorphosed sedimentary rocks and the quartz diorite. Gold and silver are the principal metals produced.

Only the Drumlummon mine (Clayton, 1888; Goodale, 1915), on the north side of Marysville, was visited. The dump material consisted chiefly of indurated shales, marble, and hornfels, with very little garnet and epidote; the mine workings were inaccessible. A grab sample (328–913) of mill tailings from the Rainbow mill at the Drumlummon mine contained 0.011 percent BeO. A mineralogical study of this sample by J. J. Glass of the U. S. Geological Survey was undertaken to identify the beryllium-bearing mineral. The material was too fine for separation of individual mineral species; a magnetic fraction and three heavy mineral fractions were separated. The minerals recognized in the fraction with specific gravity greater than 3.3 are hematite, limonite, biotite, garnet, zoisite, epidote, and pyroxene. In the fraction with specific gravity between 2.8 and 3.3 chlorite, diopside, and carbonate were identified. The fraction with specific gravity less than 2.8 contains chiefly quartz and feldspar. Magnetite is the chief constituent in the magnetic separation. The results of spectrographic analysis for beryllium of the separate fractions are as follows:

Fraction	BeO (*percent*)
Specific gravity >3.3	0.00X
Specific gravity >2.8<3.3	.00X
Specific gravity <2.8	.00X
Magnetic	.00X

These analyses, though qualitative, cast some doubt upon the higher quantitative BeO value obtained for the bulk sample. No beryllium minerals were recognized in any of the fractions and the analyses suggest that the beryllium probably is dispersed in the various silicates.

SPRING HILL MINE

The Spring Hill mine is 4 miles southwest of Helena on the east side of Grizzly Gulch. The geology of the mine has been described by Knopf (1913, p. 101) and by Pardee and Schrader (1933, p. 207–209). The ore deposit is at the contact of a small body of diorite that intrudes Madison limestone (Mississippian). A dense gray-green rock composed of diopside and tremolite contains gold and some pyrite, pyrrhotite, and chlorite. In places, garnet, olivine, scapolite, sphene, and epidote replace the limestone. A grab sample (328–918) of ore and tactite minerals from the dump contained no beryllium, the lower limit of detection being 0.0001 percent BeO.

MADISON COUNTY

SILVER STAR DISTRICT

The Silver Star mining district is northwest of the town of Silver Star, about 25 miles airline southeast of Butte, in the northern part of Madison County. The geology and ore deposits of the district have been described by Winchell (1914, p. 139–144). The rocks exposed in this district are Tertiary granite, Cambrian (?) limestone, and Precambrian schist, slate, and quartzite. The limestone is metamorphosed and replaced by garnet, epidote, magnetite, and pyrrhotite at its contact with granite. Gold, silver, copper, and lead occur in tactite deposits and a quartz vein.

The Broadway mine, about 2 miles northwest of Silver Star, is on a tactite zone in the Cambrian limestone near the granite contact. A small glory hole exposes a U-shaped sulfide ore body composed mainly of gold-bearing pyrrhotite surrounded by tactite and hornfels containing magnetite, garnet, and epidote. The tactite zone extends northeast from the glory hole for about 700 feet, through two smaller opencuts, and southwest for about 500 feet. Ore deposition appears to have been controlled by a northeast-trending fault that approximately parallels the limestone-granite contact. A composite sample (328–896) of tactite from the workings and a grab sample (328–897) of tailings from the mill contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

A grab sample (328–899) of garnet rock was collected from the dump of the Reconstruction Lode No. 3 mine, which is about 1 mile northwest of the Broadway mine. A quartz vein was mined for gold at this locality. The garnet contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

MEAGHER COUNTY

GORDON BUTTE

Gordon Butte, in the eastern part of Meagher County, is an eroded laccolith at the north end of the Crazy Mountains, geology of which was described by Wolff (1938). The rock composing the butte is theralite, an alkalic basalt containing augite, olivine, biotite, nepheline, sodalite, and feldspar. A grab sample (328–892) of theralite from the north side of the butte contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

POWELL COUNTY

OPHIR DISTRICT

The Ophir mining district, centering around the abandoned town of Ophir, is about 24 miles airline northwest of Helena in the eastern part of Powell County. The geology and ore deposits of the district were described by Pardee and Schrader (1933, p. 29–34). Limestones, shales, and quartzites of early Paleozoic age occupy most of the area. East and west of Ophir are small masses of intrusive quartz monzonite of Tertiary age. The ore deposits are mainly gold and silver veins that are genetically related to the quartz monzonite. The sedimentary rocks have been partly altered to marble, garnet tactite, and hornfels. The limestones adjacent to the intrusive bodies have been replaced by garnet, specularite, epidote, hornblende, diopside, calcite, tourmaline, sericite, and hematite. A composite sample (328–914) of tactite from the dump of the Maybe mine near Ophir contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

PRIEST PASS AREA

The road over Priest Pass, a short route across the Continental Divide from Helena to Blossburg, turns off U. S. Highway 10-N about 1 mile west of Spring Creek on the east side of MacDonald Pass. Near the top of Priest Pass, a prospect pit explores the contact of Tertiary quartz monzonite with the Quadrant quartzite (Pennsylvanian). A limestone layer in the quartzite has been partly replaced by brown garnet. A grab sample (328–917) of garnet from the pit contained no beryllium, the lower limit of sensitivity being 0.0001 percent BeO.

SILVER BOW COUNTY

BUTTE DISTRICT

A brief visit was made to the Butte district to investigate the occurrence of helvite reported by Hewett (1937) at the Lexington mine. According to Hewett, the helvite occurs as sparse lemon-yellow grains as much as 2 millimeters in diameter and as veinlets about 1 millimeter wide in rhodonite and rhodochrosite with minor amounts of galena, sphalerite, and pyrite.

Through M. H. Gidel, chief geologist for the Anaconda Copper Mining Co., permission was obtained to sample the Lexington mine. Helvite was noted in a mass of rhodonite as much as 3 feet wide and 30 feet long on the 200-foot level of the mine, 300 feet west of the shaft. A chip sample (328–902) taken across the rhodonite mass contained 0.00057 percent BeO. Similar rhodonite bodies have been found on the lower levels of the mine. They appear to be lenticular and to occur generally on the hanging wall of the vein.

Analyses of composite grab samples from mine dumps in the Butte district are shown in table 66. Helvite was found in rhodonite on the dumps at the Moulton, Niagara, Alice, Magna Charta, and Lexington mines. Rhodonite was virtually lacking in dump material at the Emma mine, rhodochrosite being the dominant gangue mineral, and no helvite was found. At all other dumps where samples were taken rhodonite was present and rhodochrosite rare or absent. The sample containing the most BeO (0.007 percent) was obtained at the Niagara mine where fluorite occurs in the gangue. Although analytical data on the BeO content of the Butte ores are too meager for speculation, further sampling of rhodonite veins in which fluorite is a constituent may reveal local concentrations of helvite. It is doubtful that such occurrences would be large or of high grade, but in view of recent advances in flotation of nonmetallic minerals, recovery of helvite from relatively low-grade material may be possible in a large mining operation.

TABLE 66.—*Beryllia in samples from mine dumps at Butte, Mont.*

Sample	Mine	BeO (percent)
328–890	Lexington	0.0016
891	Moulton	.0023
891A	do	.0015
892	Alice	.0042
893	Magna Charta	.0030
894	Emma	n. d. [1]
903	Alice (vein outcrop, east of shaft)	.0005
904	Niagara	.0070

[1] Not detected, lower limit of sensitivity being 0.0001 percent.

In the course of sampling the mines of the Anaconda Copper Mining Co. at Butte a visit was made to the company's smelter at Anaconda. Company officials kindly provided samples of the mill and smelter products of ores from several localities. Twelve of the samples were selected for spectrographic analysis and are described in table 67. In connection with the Mine, Mill, and Smelter Survey, 12 samples of mill and smelter products were obtained in 1945 from the Washoe Reduction Works at Anaconda. The ores treated were from various mines in the Butte district. Analytical data for these samples are given in table 67. Results of analyses indicate that very little beryllium is contained in the ore minerals at Butte. Presumably most of it occurs in helvite associated with the gangue and is lost in beneficiating the ore.

TABLE 67.—*Beryllia in samples from Washoe Reduction Works, Anaconda, Mont.*

[nd not detected; lower limit of sensitivity is 0.0001 percent BeO. Samples 310-ACM-1 to -20 collected in 1945 by Mine, Mill, and Smelter Survey and analyzed by K. J. Murata and E. W. Claffey]

Sample	Description	BeO (percent)
328–952	Third shift, Sept. 1, 1949, Agitair tails, Butte Copper ore	nd
963	Final tails bulk float, zinc ores, Butte, Mont	0.0004
966	Third shift, Aug. 15, 1949, manganese concentrate	nd
973	Lot No. B–64, copper concentrate, Cooke City, Mont	nd
974	Lot No. 981, waste slag ferromanganese	.0001
975	Second shift, Aug. 28, 1949, manganese tails	.0001
975A	Conda phosphate footwall rock	.0004
975B	Conda phosphate hanging-wall rock	nd
977	Lot No. FM–7, ferromanganese metal	nd
981	Black sand, Rock Creek district, Mont	nd
988	Third shift, Sept. 1, 1949, Agitair concentrate, Butte Copper ores	nd
989	Zinc concentrates, Butte ores	nd
310–ACM–1	Sulfide concentrate, Emma mine (Pb-Zn-Ag ore, rhodochrosite gangue)	.0002
ACM–2	Sulfide tailings, Emma mine	.0002
ACM–3	Copper flotation tailings, Butte mines	.0002
ACM–4	Copper concentrate, Butte mines	nd
ACM–5	Arsenic roaster residue, Butte mines	.0002
ACM–6	Granulated reverberatory slag (copper), Butte mines	.0002
ACM–8	Iron table concentrates, Butte mines	nd
ACM–9	Flue dust (copper), Butte mines	nd
ACM–17	Zinc concentrates, Butte mines	nd
ACM–18	Lead concentrates, Butte mines	nd
ACM–19	Zinc-lead tailings, Butte mines	.0008
ACM–20	Zinc concentrates, Butte mines	nd

HIGHLAND DISTRICT

The Highland district is in the southern part of Silver Bow County, about 25 miles south of Butte. According to Winchell (1914, p. 87–90), the rocks of this district consist of a series of slates and quartzites of Belti age underlying a thick limestone bed, probably Paleozoic in age, all of which are intruded by quartz monzonite, diorite, granite, and aplite, presumably of Tertiary age. Garnet, epidote, magnetite, diopside, and actinolite replace the limestone at its contacts with igneous rocks.

The Highland mine, at the head of the main fork of Fish Creek, is on the north side of a large limestone inclusion or roof pendant in granite. The ore body has been described by Newcomb (1941). The ore is chiefly pyrrhotite, pyrite, and chalcopyrite, in a gangue of coarsely crystalline tremolite, epidote, and diopside. A composite grab sample (328-901) from the dump contained less than 0.0001 percent BeO.

Approximately 2 miles west of the Highland mine is a tactite zone 50 feet wide and several hundred feet long in the limestone. A composite grab sample (328-900) of garnet, diopside, magnetite, and epidote from the tactite zone did not contain as much as 0.0001 percent BeO.

TOLL MOUNTAIN AREA

Toll Mountain is 19 miles southeast of Butte near the boundary between Silver Bow and Jefferson Counties. At this locality, sedimentary rocks of Paleozoic age consisting of slate, marble, and quartzite appear to form a roof pendant in a Tertiary intrusive granite body. The sedimentary rocks strike N. 45° E. and dip steeply northwest. A garnet tactite zone can be traced northeast for several hundred feet along the contact between granite and marble, beginning at an outcrop about 800 feet north of the Toll Mountain Ranger Station. The garnet zone locally contains thin lenses of diopside. The granite adjacent to the sedimentary rocks has been endomorphosed. A composite grab sample (328-895) of the garnet rock did not contain as much as 0.0001 percent BeO.

SWEET GRASS COUNTY

HAYSTACK STOCK

Haystack stock, about 55 miles south of Big Timber, is 1 mile south of the old mining camp of Independence in Sweet Grass County. The geology has been described in detail by Emmons (1908). We made a brief visit to the area to sample the contact zone on the west side of the stock. The intrusive body, according to Emmons, ranges in composition from quartz monzonite to olivine gabbro and extends from Haystack Peak to Baboon Mountain, a distance of 3 miles. Limestones, shales, and sandstones of Cambrian age have been metamorphosed and replaced by tactite at the contact with the intrusive rock. Garnet, epidote, quartz, and actinolite are the principal tactite minerals. A composite grab sample (328-923) of tactite from the contact zone did not contain as much as 0.0001 percent BeO.

WYOMING

By L. A. Warner and V. R. Wilmarth

Beryllium investigations at 15 localities in Wyoming (fig. 46) were made during October 1948 and August 1949. The BeO content of 31 samples selected for spectrographic analysis ranged from less than 0.0001 percent to 0.003 percent. The samples represent many types of nonpegmatite rocks and mineral deposits. Present information does not appear to warrant further sampling at any of the localities.

ALBANY COUNTY

CENTENNIAL DISTRICT

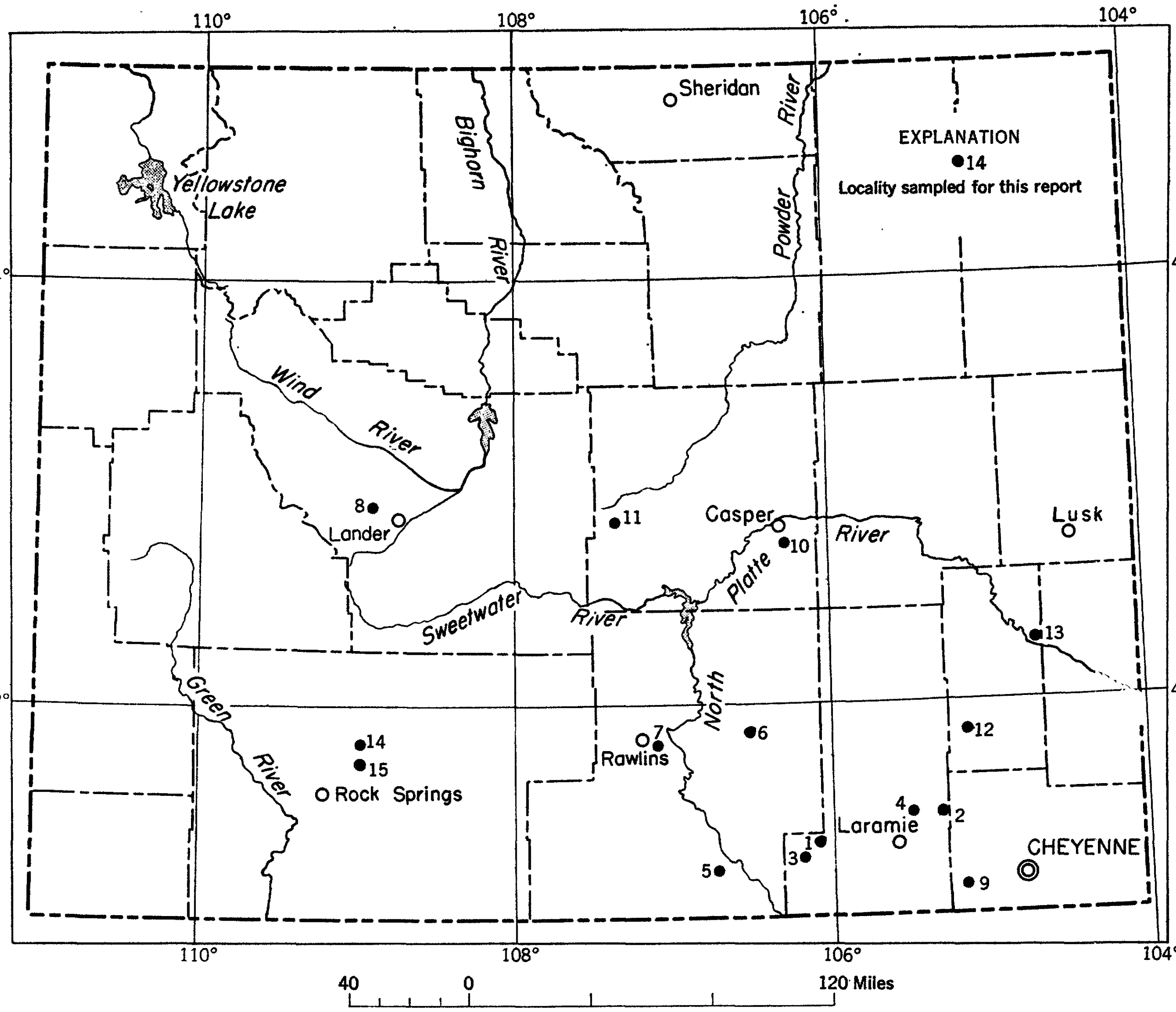
The Centennial district centers around the town of Centennial in the eastern part of the Medicine Bow quadrangle. The geology of the area was described briefly by Darton and Siebenthal (1909, p. 49-50). The ore deposits consist of gold-bearing quartz veins in Precambrian schist, gneiss, and granite. Samples were collected from two mines, the Utopia and the Independence.

The Utopia mine is 1 mile northwest of Centennial on the east side of Centennial Ridge. Gold is found in a 3-foot wide, west-trending quartz vein in hornblende schist. Additional vein materials are calcite, pyrite, sericite, limonite, and garnet. A composite sample (328-877) of dump material showed no beryllium, the limit of sensitivity being 0.0001 percent BeO.

The Independence mine is 2 miles west of the Utopia mine on the west side of Centennial Ridge. The mine is developed on eight narrow pegmatite stringers in hornblende schist. A 6-foot channel sample (328-878) across the back of the adit, 10 feet from the portal, did not contain as much as 0.0001 percent BeO.

IRON MOUNTAIN

Iron Mountain is on the eastern flank of the Laramie Mountains in secs. 22, 23, and 27, T. 19 N., R. 71 W., about 40 miles northeast of Laramie. Geology of the area has been described by Diemer (1941, p. 6-11), and is shown on figure 47. A north-trending dikelike body of titaniferous magnetite 50 to 350 feet wide can be traced for nearly a mile. The adjacent rock is Precambrian anorthosite with some gabbro. Near the center of the ore body, a small plug of granite cuts the magnetite and anorthosite. The anorthosite and gabbro are fractured and hydrothermally altered on either side of the ore body at its southern end, where the contacts are exposed on Chugwater Creek.



ALBANY COUNTY

1. Centennial district
2. Iron Mountain
3. Rambler mine
4. Strong mine

CARBON COUNTY

5. Encampment district
6. Hanna district
7. Rawlins area

FREMONT COUNTY

8. Fort Washakie area

LARAMIE COUNTY

9. Silver Crown district

NATRONA COUNTY

10. Casper Mountain
11. Garfield Peak

PLATTE COUNTY

12. Halleck Creek area
13. Welcome mine

SWEETWATER COUNTY

14. Leucite Hills
15. Superior district

FIGURE 46.—Index map of Wyoming, showing localities sampled.

Samples were taken as follows (see fig. 47 for locations):

328–206 Chip sample across 25 ft of gabbroic anorthosite with some magnetite.

207 Chip sample across 30 ft of altered anorthosite and gabbro.

209 Chip sample across 6-ft gabbro dike.

210 Chip sample across magnetite body at top of Iron Mountain.

212 Grab sample from outcrop of granite plug.

Spectrographic analyses showed no beryllium in the samples, the limit of detection being 0.001 percent BeO.

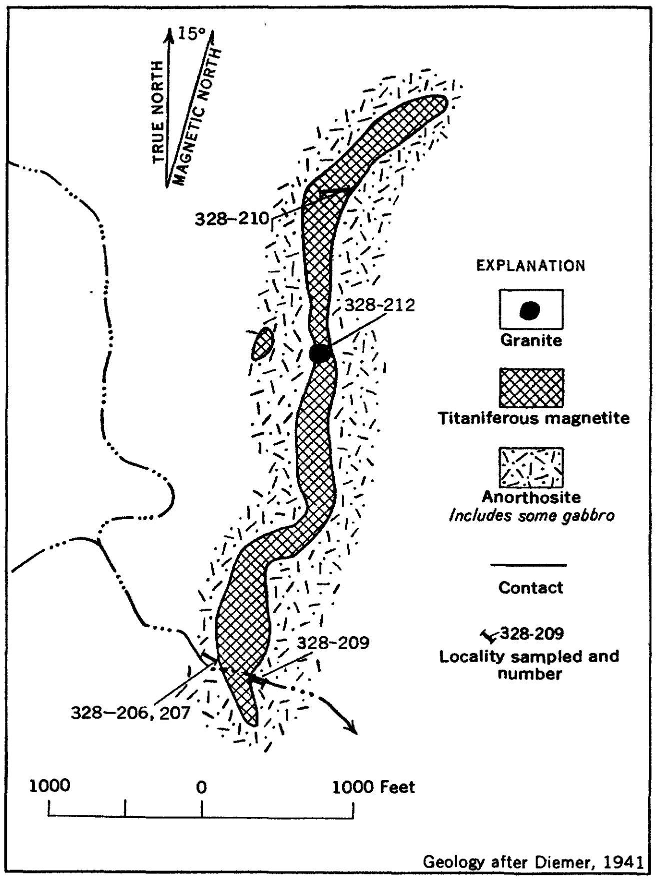


FIGURE 47.—Geologic map of Iron Mountain magnetite deposit, Albany County, Wyo.

RAMBLER MINE

The Rambler mine is half a mile west of the abandoned mining camp of Holmes, about 12 airline miles southwest of Centennial. The geology and ore deposits have been discussed by Knight (1902), Emmons (1903), Read (1903), Hess (1926), Coulton (1936) and Osterwald and Osterwald (1952, p. 28).

The mine is developed in an altered zone in Precambrian pyroxenite. A sample from the dump containing covellite, azurite, malachite, quartz, and altered pyroxenite and a grab sample (328–879) of the mill tailings were obtained. These showed no beryllium, the limit of detection being 0.001 percent BeO.

STRONG MINE

The Strong mine is 12 airline miles northeast of Laramie in sec. 4, T. 16 N., R. 71 W. (Osterwald and Osterwald, 1952, p. 29). Chalcopyrite, tetrahedrite, molybdenite, azurite, and malachite—the principal ore minerals—are associated with pegmatite in Precambrian anorthosite. A sample (328-200) of ore from the dump showed no beryllium, the limit of detection being 0.001 percent BeO.

CARBON COUNTY

ENCAMPMENT DISTRICT

The Encampment mining district is in the Sierra Madre range near the southern boundary of Wyoming. The town of Encampment, from which most of the mines can be reached by road, is in the northeast corner of the district. The geology and ore deposits of the area have been described by Spencer (1903 and 1904) and Platt (1947). Copper deposits related to Precambrian diorite and gabbro intrusive masses occur as small lenses and fracture fillings in Precambrian schist, slates, and quartzites. The Doane-Rambler and the Hidden Treasure mines were sampled.

The Doane-Rambler mine is at the abandoned mining town of Rambler about 18 miles southwest of Encampment. The ore minerals, chalcocite, chalcopyrite, covellite, bornite, malachite, and azurite, occur as fracture fillings in quartzite. A composite sample (328–882) of dump material contained 0.002 percent BeO. Heavy liquid separations were made and the fractions were analyzed for beryllia. The heavy fraction (specific gravity greater than 2.60), composed of chalcopyrite, chalcocite, pyrite, bornite, and covellite, contained 0.001 percent BeO. The fraction with specific gravity less than 2.60 was mainly quartz and malachite and contained 0.003 percent BeO. No beryllium minerals were identified.

The Hidden Treasure mine is about 2 miles east of the Doane-Rambler mine on the main road to Encampment. The mine explores a narrow, northeast-trending vein at the contact of Precambrian quartzite and diorite. Chalcopyrite, chalcocite, calcite, specularite, and siderite are the principal vein minerals. A grab sample (328–885) of dump material showed no beryllium, the limit of detection being 0.0001 percent BeO.

HANNA DISTRICT

A grab sample (328–248) of coal was collected from the dump of an open pit mine half a mile east of Hanna on U. S. Highway 30. The coal is in the Hanna formation of Tertiary age. The ash was found to contain 0.002 percent gallium, 0.0003 percent beryllium and 0.01 percent vanadium.

RAWLINS AREA

Two chip samples (328–246, –247), mainly limestone taken across the Phosphoria formation (Permian) at exposures on U. S. Highway 287 near Rawlins were found to contain no beryllium, the limit of detection being 0.001 percent BeO.

FREMONT COUNTY

FORT WASHAKIE AREA

Samples of a Tertiary lamprophyre dike and altered sandstone of the Wind River formation adjoining the dike were collected at an outcrop on U. S. Highway 287 about 10 miles north of Fort Washakie, Wyo. The dike is vertical and strikes N. 45° E.; the average width is about 20 feet. The sandstone is baked and altered for about 2 feet on either side of the dike. A chip sample (328–235) across the dike and a grab sample (328–237) of baked sandstone contained no beryllium, the limit of detection being 0.001 percent BeO.

LARAMIE COUNTY

SILVER CROWN DISTRICT

The Silver Crown district (Osterwald and Osterwald, 1952, p. 41–42) is near Hecla, about 20 miles west of Cheyenne on the east slope of the Laramie Mountains. Gold and silver-bearing veins and shear zones in Precambrian schist and granite gneiss contain chalcopyrite, bornite, azurite, malachite, quartz, pyrite, and limonite.

The Copper King mine, 1 mile southwest of the Hecla post office in sec. 36, T. 14 N., R. 70 W., was the only mine visited. Chalcopyrite, pyrite, quartz, and limonite are disseminated in a nearly vertical northwest-trending zone of shattered Precambrian granite gneiss 20 to 75 feet wide and 600 feet long. A 20-foot chip sample (328–202) taken across the mineralized zone in a small opencut contained no beryllium, the limit of detection being 0.001 percent BeO.

NATRONA COUNTY

CASPER MOUNTAIN

Casper Mountain, in the westernmost part of the Laramie Range, forms a prominent ridge 9 miles south of Casper in the east-central part of Natrona County. Beeler (1911), Diller (1911a, p. 512–516, and 1911b), Beckwith (1939, p. 822–832), and Stephenson (1941) have described the geology and ore deposits of the area. Casper Mountain is a westward-trending asymmetrical anticline with steeply dipping sedimentary rocks of Paleozoic age on the north side. Large masses of Precambrian serpentine, granite-gneiss, hornblende schist, and metadiabase are cut by later metadiabase and granite pegmatite dikes. Small areas of quartzite of unknown age occur in the northeast part of the mountain. Asbestos-bearing serpentine and chromite-bearing schist have been prospected.

A grab sample (328–226) of a metadiabase dike was obtained from an outcrop at the abandoned town of Eadsville on the north slope of the mountain. A large pegmatite dike is exposed in altered serpentine approximately 3,000 feet east of Eadsville. A chip sample across 50 feet of altered serpentine and a grab sample of pegmatite and altered serpentine were taken east of the dike. None of the samples contained as much as 0.001 percent BeO.

GARFIELD PEAK

Garfield Peak, the highest mountain in the Rattlesnake Range, is about 6 miles southeast of Ervay. Carboniferous limestone has been silicified at the contact of a Tertiary monzonite stock. A grab sample (328–234) of silicified limestone from the contact zone on the northeast side of the peak contained no beryllium, the limit of detection being 0.001 percent BeO.

PLATTE COUNTY

HALLECK CREEK AREA

Rock specimens from a prospect on Halleck Creek, a tributary to North Sybille Creek, about 30 miles airline southwest of Wheatland, were rumored to contain more than 1.0 percent BeO. Information obtained from Mr. A. B. Bartlett of Wheatland, former State Geologist of Wyoming, enabled the writers to locate the prospect, which is on McGill ranch in the northeast corner of T. 21 N., R. 72 W. A ranch road leading westward to the area joins State Highway 26 just southwest of the bridge across Blue Grass Creek; the distance from the highway to the prospect is about 6 miles.

The regional geology has been described by Fowler (1930). A sketch map of part of the prospect area is shown in figure 48. A quartz pegmatite and four

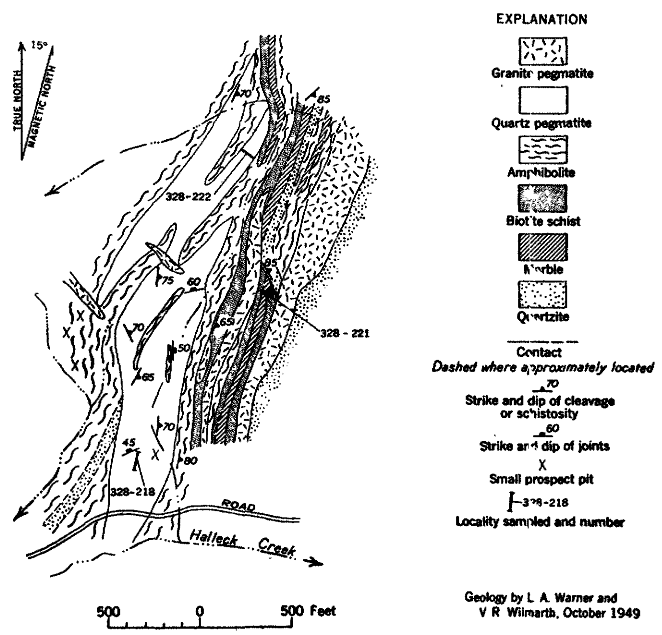


FIGURE 48.—Geologic sketch map of part of Halleck Creek area, Platte County, Wyo.

granite pegmatite bodies have intruded quartzite, marble, biotite schist, and amphibolite; all the rocks are Precambrian. The intruded rocks show pronounced schistosity that strikes N. 25°–30° E. and dips steeply southeast. A pronounced plane of cleavage in the quartz pegmatite is parallel to the schistosity and the cleavage surfaces are coated with a greenish mica. The granite pegmatites show no cleavage and in places cut across the schistosity of the intruded rocks. The marble adjoining the pegmatites contains diopside, actinolite, and yellow garnet. Several prospect pits have been excavated in the quartz pegmatite and altered marble.

Six samples from the area were analyzed spectrographically and are described in table 68. Locations of three samples are shown on figure 48; the others were obtained at prospect pits a short distance north of the mapped area. Petrographic studies did not reveal any beryllium minerals in the rocks.

TABLE 68.—*Beryllia in samples from Halleck Creek area*

Sample	Description	BeO (percent)
328–218	Chip sample across 100 ft of quartz pegmatite body, near center	0.001
221	Chip sample across 50 ft of marble containing thin layers of schist, quartzite, and amphibolite	.001
222	Chip sample across quartz pegmatite body	.001
873	Channel sample across 10 ft of marble and schist containing actinolite, serpentine, mica, and idocrase	.0011
875	Channel sample across 10 ft of marble containing diopside and garnet	.0010
876	Channel sample across 8 ft of marble containing actinolite and garnet	.0013

WELCOME MINE

The Welcome mine, half a mile east of Guernsey, explores a small replacement body of hematite in a limestone bed of the Guernsey formation of Devonian and Mississippian age. A 6-foot channel sample (328–872) of hematite taken across the face of the lower adit at the mine contained no beryllium, the limit of detection being 0.001 percent BeO.

SWEETWATER COUNTY

LEUCITE HILLS

The Leucite Hills, in southwestern Wyoming, are a series of buttes and mesas formed from Tertiary volcanic rocks of extraordinary composition. They extend from Pilot Butte, near Rock Springs, northeastward for 30 miles to Steamboat Mountain. The geology of the region has been described by Cross (1897), Kemp and Knight (1903), and Schultz and Cross (1912). The fine-grained volcanic rocks of the Leucite Hills rest on or cut through Cretaceous and Eocene sedimentary rocks, being in part flows and in part intrusive sheets and plugs. They are composed chiefly of the rare alkali-rich rocks madupite, orendite, and wyomingite.

The rock at Pilot Butte, 7 miles northwest of Rock Springs, is madupite and consists of phlogopite and diopside in a potash-rich glass base. A grab sample (328–240) from the north side of Pilot Butte showed no beryllium, the limit of the detection being 0.001 percent BeO.

Orenda Mesa, a remnant of one of the larger lava flows, is 26 miles airline northeast of Rock Springs. Orendite, named for the mesa, is a vesicular rock composed of sanidine, leucite, diopside, and mica. A grab sample (328–244) from the northeast side of the mesa showed no beryllium, the limit of detection being 0.001 percent BeO.

Wyomingite, a porphyritic rock composed of leucite, diopside, and brown mica forms much of Zirkel Mesa, which is 3 miles south of Orenda Mesa. A sample (328–242) collected from the north wall of the mesa showed no beryllium, the limit of detection being 0.001 percent BeO.

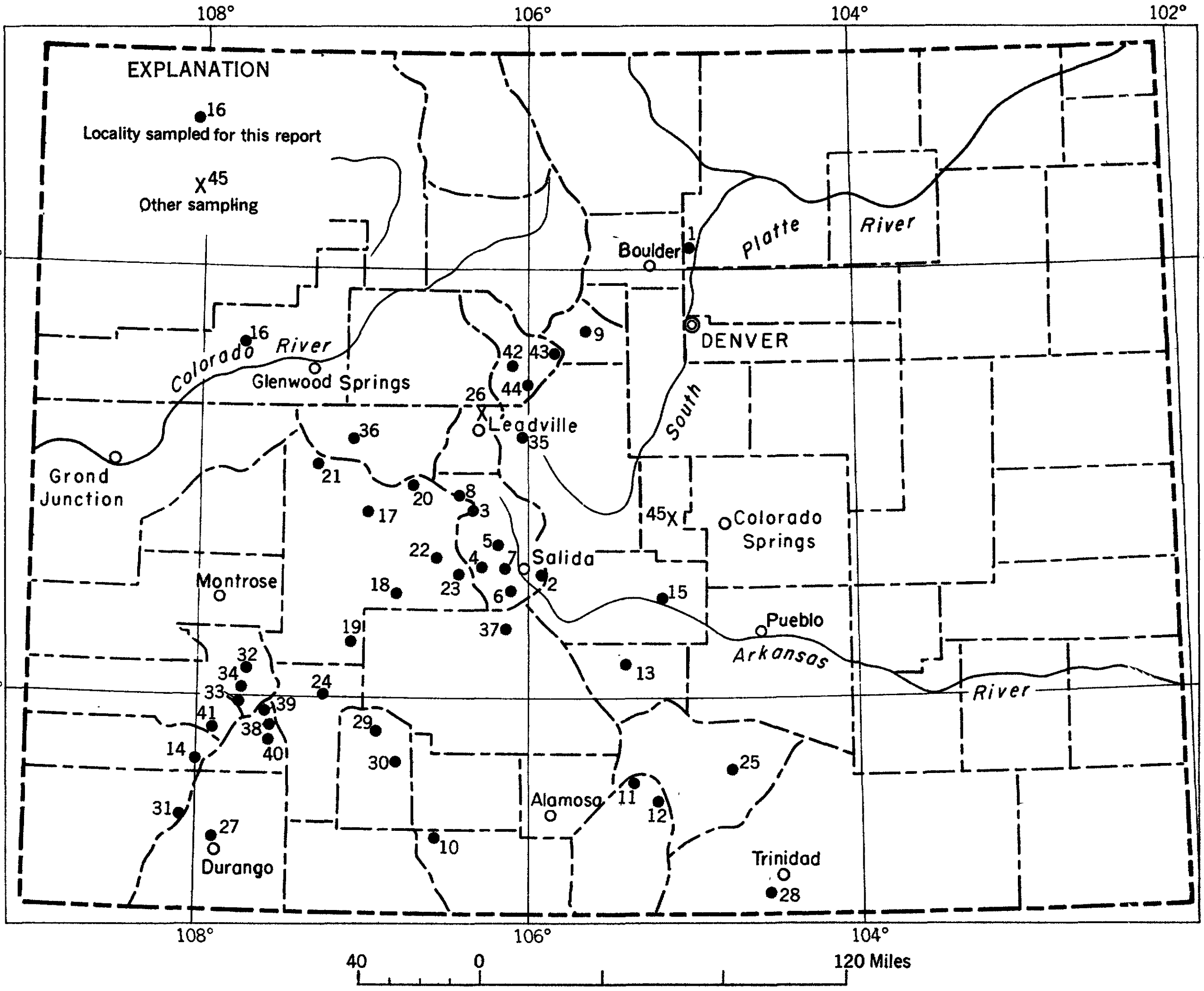
SUPERIOR DISTRICT

Coal is mined from Cretaceous rocks in the vicinity of Superior, about 15 miles northeast of Rock Springs. The geology of the district has been described by Schultz (1909). A grab sample (328–245) of coal was obtained from the bunker at the Copenhagen mine in Superior. The ash contained 0.004 percent gallium, 0.0004 percent beryllium, and 0.008 percent vanadium.

COLORADO

By L. A. WARNER and V. R. WILMARTH

Field investigations of the occurrence of beryllium in nonpegmatite rocks and mineral deposits in Colorado were carried on during the fall of 1948 and the summer of 1949. Forty-five localities were examined, (see fig. 49) and about 550 samples of rocks and minerals were collected for laboratory studies. Most of the localities are in mining districts in central and southwestern Colorado, and the samples are primarily from ore deposits; some samples of sedimentary, igneous, and metamorphic rocks also were obtained. Particular attention was paid to manganiferous vein deposits in the San Juan region, because helvite had been reported in such veins at the Sunnyside mine near Eureka. The alkalic rocks of Iron Hill in Gunnison County, from which beryllium had been reported, also were studied in detail. The occurrence of beryl in quartz veins at Mount Antero, Chaffee County, had



Boulder County

1. Lafayette area

Chaffee County

2. Calumet mine
3. Geneva claim
4. Monarch district
5. Mount Antero
6. Ouray Peak
7. Sedalia mine
8. Winfield district

Clear Creek County

9. Georgetown district

Conejos County

10. Platoro-Summitville district

Costilla County

11. Grayback district
12. La Veta area

Custer County

13. Querida district

Dolores County

14. Rico district

Fremont County

15. Florence-Canon City area

Garfield County

16. Rifle-Silt area

Gunnison County

17. Crested Butte district
18. Gold Brick district
19. Iron Hill
20. Italian Mountain
21. Snowmass Mountain
22. Tincup district
23. Tomichi district

Hinsdale County

24. Lake City district

Huerfano County

25. Walsenburg area

Lake County

26. Climax mine

LaPlata County

27. Durango area

Las Animas County

28. Morley area

Mineral County

29. Creede district
30. Wagon Wheel Gap

Montezuma County

31. Rush Basin

Ouray County

32. Ouray district.
33. Red Mountain district
34. Upper Uncompaghre district

Park County

35. Tarryall district

Pitkin County

36. Redstone area

Saguache County

37. Bonanza district

San Juan County

38. Eureka-Animas Forks district
39. Mineral Point district
40. Silverton district

San Miguel County

41. Ophir district

Summit County

42. Breckenridge district
43. Montezuma district
44. Upper Blue River district

Teller County

45. Cripple Creek district

FIGURE 49.—Index map of Colorado, showing localities sampled.

been previously investigated by J. W. Adams of the Geological Survey. A brief summary of his findings is included in this report. None of the deposits sampled in Colorado are of present commercial interest for their beryllium content.

BOULDER COUNTY

COAL DEPOSITS

Coal is mined in southeastern Boulder County, principally in the vicinities of Louisville and Lafayette, from the lower part of the Laramie formation of Late Cretaceous age. The regional geology of the coal deposits has been discussed by Martin (1910).

Samples of coal from the Black Diamond and Washington mines were collected and the ashes were analyzed for beryllium. Ash of coal from the Black Diamond mine at Lafayette (sample 328–357) contained 0.004 percent gallium, 0.01 percent vanadium, and no beryllium, the limit of detection being 0.0001 percent beryllium. Ash from a grab sample of coal (328–358) collected at the Washington mine, 7 miles northeast of Lafayette, contained 0.0003 percent beryllium, 0.003 percent gallium, and 0.01 percent vanadium.

CHAFFEE COUNTY

CALUMET MINE

The Calumet iron mine (Behre, Osborn, and Rainwater, 1936) is about 8 miles airline northeast of Salida. A geologic map of the immediate vicinity of the mine is shown in figure 50.

Mississippian limestone has been marmorized, and partially replaced by magnetite, epidote, actinolite, tremolite, garnet, pyrite, and chalcopyrite at or near its contact with a Tertiary granodiorite sill. Much of the rock in the contact zone is banded magnetite-bearing tactite. In the northern opencut, a zone 25 feet wide composed of alternating layers, as much as 6 inches thick, of actinolite and magnetite, occurs in the limestone below the granodiorite. The actinolite-magnetite zone is bounded on the west by a fault zone 5 feet wide that contains abundant kaolinite. In the southern opencut adjoining the granodiorite sill is an epidote-rich rock containing stringers and bands of magnetite, several of which are more than 1 foot thick. A small body of low-grade massive magnetite ore is exposed between the two cuts.

Six samples were collected at the mine (see fig. 50) as follows:

328–001 Chip sample across 20 ft of banded epidote-actinolite rock in the Weber formation above granodiorite sill.
002 Chip sample across 4 ft of magnetite ore containing epidote.
004 Chip sample across garnetized inclusion of Weber formation in sill.
007 Chip sample across 25 ft of banded epidote-magnetite tactite.
008 Chip sample across 25 ft of magnetite ore and diopside-epidote tactite.
009 Chip sample across 15 ft of banded actinolite-magnetite tactite.

Spectrographic analyses showed no beryllium in any of the samples, the limit of detection being 0.001 percent BeO.

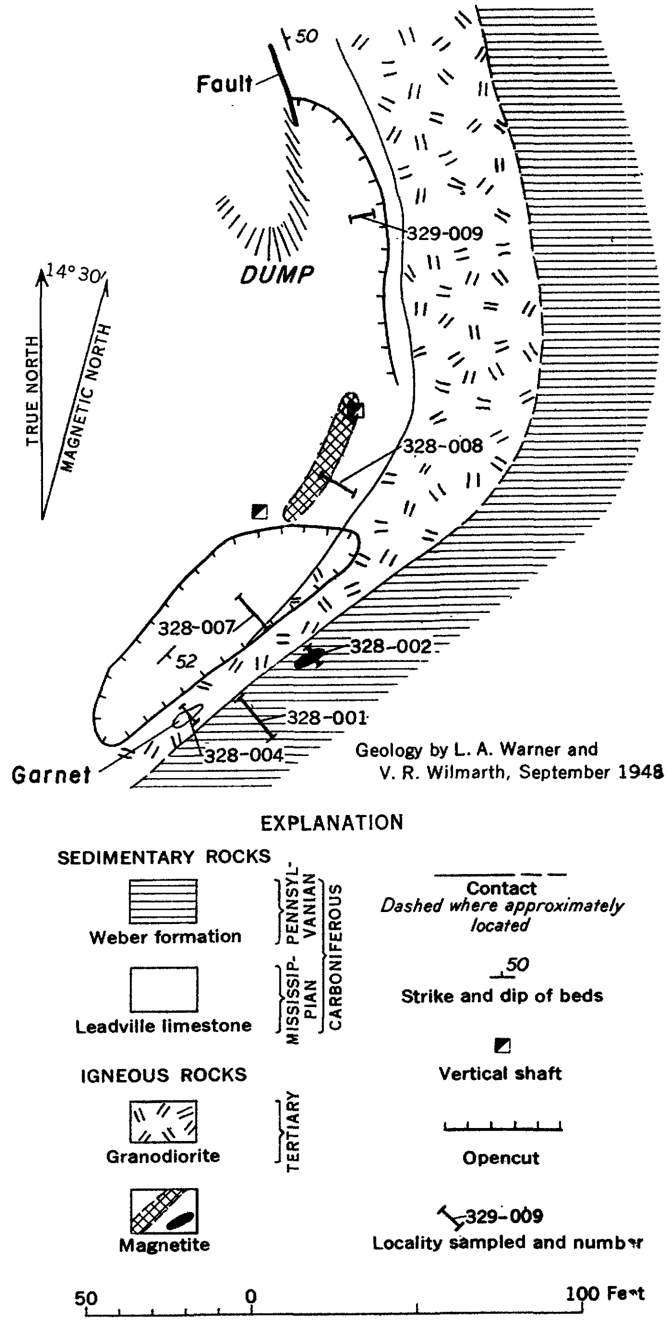


FIGURE 50.—Geologic map of Calumet mine, Chaffee County, Colo.

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GENEVA CLAIM

The Geneva claim is about 18 miles airline southwest of Buena Vista on the north side of South Cottonwood Canyon. According to Worcester (1919, p. 46), a block of dolomitic limestone about one-eighth mile wide and more than a mile long has been tilted into a vertical position between granite walls along a large fault. The limestone has been extensively brecciated and altered adjacent to the granite. It grades from coarsely crystalline marble into tactite containing serpentine, grossularite, diopside, phlogopite, and minor quantities of chalcopyrite, pyrite, and molybdenite. The tactite grades into a zone 15 feet wide of black hornfels that formed next to the granite contact. Narrow veins of secondary calcite fill fractures in the marble. Adjacent to the contact the granite shows well-developed foliation which parallels the limestone bedding.

Three samples collected at the main workings are as follows: (328–711) a chip channel across the black quartzitic rock, (329–709) a channel sample across the tactite zone, and (328–712) a grab sample of metallic minerals from the dump. None of the samples contained as much as 0.0001 percent BeO.

MONARCH DISTRICT

The Monarch district is in the southwestern part of Chaffee County, on the east slope of the Sawatch Range, and joins the Tomichi district on the west. Mines and prospects in the Taylor Gulch, Cree Camp, and Hoffman Park areas were investigated briefly. Crawford (1913, p. 195–283) has described the geology of the region in detail. The Tomichi limestone (Ordovician) of former usage, Ouray limestone (Devonian), and Garfield formation of Crawford (1913) (Pennsylvanian) are folded into a north-trending syncline. Precambrian granite crops out east of Taylor Gulch and intrusive Tertiary quartz monzonite cuts off the sedimentary rocks to the north and west.

The New York mine, on the west side of Taylor Gulch, is at an altitude of 12,000 feet. An adit was driven on an oxidized zone in the Garfield formation of Crawford (1913) near its contact with the Ouray limestone. The dump rock consists of indurated sandstone and some limestone containing actinolite, garnet, and epidote. A small pile of ore, mainly sphalerite, galena, and chalcopyrite, was noted on the dump. A composite grab sample (328–011) from the dump showed no beryllium, the limit of detection being 0.001 percent BeO.

About 500 feet east of the New York mine, several prospect pits and shallow shafts expose a northeast-trending vein in the Ouray limestone. The vein ranges from 2 to 4 feet in width and can be traced along the strike for about 1,500 feet. It contains mainly limonite, pyrite, galena, and sphalerite in a gangue of quartz. A composite grab sample (328–012) of the vein material showed no beryllium, the limit of detection being 0.001 percent BeO.

Figure 51 is a generalized geologic sketch map of the area near the head of Taylor Gulch. The Tomichi limestone of former usage has been marmorized and partially replaced by garnet, actinolite, and epidote near a Tertiary quartz monzonite dike and along the contact of the limestone with Precambrian granite. Two veins containing magnetite, quartz, and tactite minerals cut the limestone in the area between the dike and the granite. The contacts of the veins, dike, and granite all trend north, parallel to the strike of the limestone.

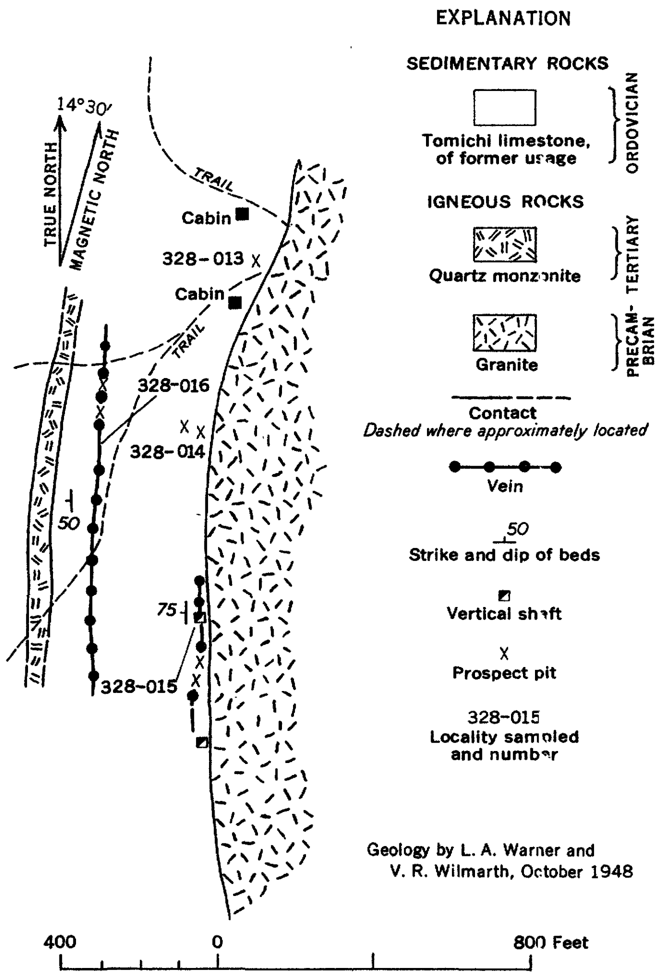


FIGURE 51.—Geologic sketch map of area near head of Taylor Gulch, Chaffee County, Colo.

None of the four samples described below contain as much as 0.001 percent BeO.

328–013 Grab sample of tactite from pit near base of Tomichi limestone.
014 Grab sample of tactite from pits near contact with granite.
015 Grab sample of tactite and vein material from dump of shaft.
016 Chip sample of magnetite and tactite from vein outcrop.

In the Cree Camp area, the Garfield formation of Crawford (1913) has been metamorphosed to quartzite, hornfels, marble, and tactite. A composite chip sample (328–020) collected from Crawford's Garfield formation on the cliff west of Cree Camp represents tactite zones 1 to 10 feet wide which are separated by wider zones of marble and hornfels. A grab sample (328–021) was taken of dark-brown garnet, graphite, epidote, idocrase(?), and quartz from near the base of Crawford's Garfield formation just west of Cree Camp. None of the samples contain as much as 0.001 percent BeO.

The Royal Purple and Nest Egg claims in Huffman Park, a large glaciated valley about 4 miles northwest of Garfield, were also visited. The rock in this area is quartz monzonite, of the large Princeton batholith of Tertiary age. Worcester (1919, p. 38–39) briefly described the ore deposits. The abandoned workings on the Royal Purple claims are at an altitude of 11,850 feet, about 2,000 feet northeast of a cabin at the end of the road. Two vertical quartz veins strike N. 50° E. The southern vein, where exposed in a shaft, is 8 feet wide and contains molybdenite in small pockets, flakes, and stringers along the walls. Pyrite is locally abundant. A channel sample (328–699) across the vein in the shaft contained 0.0005 percent BeO. The other vein was not sampled.

The Nest Egg claims are 2,000 feet northwest of the Royal Purple claims. The main opencut is at the junction of two faults; one strikes N. 25° E. and dips 27° NW., the other strikes N. 35° E. and dips 85° NW. Molybdenite occurs as small clots and stringers in the hanging walls of the two faults. It impregnates the quartz monzonite for as much as 2 feet beyond the faults. A grab sample (328–700) of molybdenite-bearing material from the dump showed no beryllium, the limit of detection being 0.0001 percent BeO.

MOUNT ANTERO AREA

By J. W. Adams

Pegmatites commonly containing beryllium minerals occur in a granite stock in the vicinity of Mount Antero and White Mountain, Chaffee County, Colo. (Adams, 1953). These pegmatites have been known for many years as a source of fine specimens of aquamarine, phenakite, and bertrandite, but they do not appear to be of sufficient size to be of interest as a commercial source of beryllium.

At the California mine, 2 miles southwest of Mount Antero, a quartz vein containing molybdenite and beryl occurs in a quartz monzonite stock. Mineralogical study shows that some of the beryl was deposited with molybdenite. Molybdite is closely associated with molybdenite. Brannerite, an oxide of titanium and uranium, was identified in the material collected. The mine was operated on a small scale during World War I, but the surface cuts were caved and the mine workings were inaccessible in June 1948. Where exposed, the vein at the California mine is 1½ to 3 feet thick, is nearly vertical, and strikes N. 72°–75° E. Early reports of the mining and the material seen on the dump indicate that rich molybdenite ore was accompanied by considerable beryl, but no accurate appraisal of the beryl reserves can be made without reopening the mine workings and trenching the surface.

A channel sample taken across the vein at the California mine contained 0.016 percent BeO. A composite sample of granite from the north slope of White Mountain and one of greisen from an outlying granite mass contained 0.018 and 0.015 percent BeO, respectively. The results obtained for these samples were not verified by analyses of 14 additional samples of granite and greisen from the main stock and outlying bodies. The 14 samples had BeO contents ranging from less than 0.0003 percent to a maximum of 0.0006 percent, indicating that the average BeO content of the granite is probably very low.

OURAY PEAK

A large granite pegmatite dike, about a mile long and 500 to 1,500 feet wide, intrudes Precambrian quartz-muscovite-biotite schist at Ouray Peak, 15 miles airline southwest of Salida. Grab samples of the schist (328–707) and the pegmatite (328–704 and –706) taken near the contact showed no beryllium, the limit of detection being 0.0001 percent BeO.

SEDALIA MINE

The Sedalia mine is 8 miles northwest of Salida on the east side of the Arkansas Valley at an altitude of 7,500 feet. Lindgren (1908, p. 161–166) described the ore deposit as a thick bed of actinolite schist, 800 feet long and 150 feet thick, richly impregnated by copper minerals. The most productive part of the deposit is above a pegmatite dike that cuts the schist. A grab sample (328–600) of dump material containing almandite, actinolite, chlorite, idocrase, epidote, and copper minerals contained 0.0004 percent BeO.

WINFIELD DISTRICT

The Winfield district is on Clear Creek, 14 miles west of Granite. The largest mines are west and southwest of Winfield. The geology and ore deposits of the district have been described by Worcester (1919, p. 40–43) and Vanderwilt (1947, p. 48). Small veins in the Twin Lakes quartz monzonite porphyry of Howell (1919) which is of Tertiary age, have been mined for gold, silver, lead, and copper. Quartz veins containing molybdenite and bismuthinite are also present. A brief examination was made of the Swiss Boy mine and the Banker Tunnel, which represent the two types of mineralization in the district.

The Banker Tunnel is 2 miles south of Winfield on the South Fork of Clear Creek. The mine was operated in 1948 and a small quantity of silver ore was produced. Molybdenite and bismuthinite, with minor amounts of pyrite, clay, and sericite, occur as streaks and pockets along the walls of quartz veins. A grab sample of silver ore (328–715) was found to contain 0.0008 percent BeO. A sample (328–716) of molybdenite and bismuthinite ore contained 0.0011 percent BeO.

The Swiss Boy mine is 3 miles east of Winfield on the north side of Clear Creek valley. The upper adit is on a narrow quartz vein which strikes north and dips 70° E. The ore minerals are galena and sphalerite. The lower adit is on a brecciated fault zone that parallels the quartz vein. Galena, sphalerite, pyrite, and tetrahedrite fill small fractures in the fault breccia. A grab sample (328–719) of ore from the bin showed no beryllium, the limit of detection being 0.0001 percent BeO.

A sample (328–720) of pale-green crystalline fluorite from a small vein southeast of the Swiss Boy mine did not contain as much as 0.0001 percent BeO.

CLEAR CREEK COUNTY

GEORGETOWN DISTRICT

The geology of the Georgetown quadrangle has been described by Spurr, Garrey, and Ball (1908) and by Lovering and Goddard (1950, p. 138–153). Except for small stocks and dikes of Laramide age, the rocks of the district are Precambrian and consist of schists and gneisses of the Idaho Springs formation that have been intruded by granitic batholiths. At many places calcareous lenses in the Idaho Springs formation have been altered to tactite, containing garnet, diopside, epidote, hornblende, and locally pyrite and magnetite. A grab sample (328–111) of tactite from talus slopes east of Clear Lake, 6 miles south of Georgetown, showed no beryllium, the limit of detection being 0.0001 percent BeO.

CONEJOS COUNTY

PLATORO-SUMMITVILLE DISTRICT

The Platoro-Summitville district is in an eastern extension of the San Juan Mountains in the northern part of Conejos County and the southern part of Rio Grande County. Del Norte, the nearest railhead, is 30 miles to the northeast. The geology and ore deposits were described by Patton (1917), and Vanderwilt (1947, p. 63, 184–186). Only igneous rocks are exposed in the district. The extrusive rocks, part of the Hinsdale formation and Potosi series of Tertiary age, include rhyolite, latite, andesite, basalt, and biotite latite. Near the center of the district, monzonite and monzonite porphyry stocks are exposed, and in the northern part is a small stock of biotite-augite diorite. Large areas of intensely altered volcanic rocks occur near Stunner in the central part of the district. The principal alteration processes are kaolinization, sericitization, and alunitization. Gold-bearing veins that also yield small quantities of lead-zinc-silver ores have been mined near a monzonite intrusive body.

The Miser mine is about half a mile west of Jasper in the northeast part of the district. The caved mine workings were reported to have been developed on gold- and silver-bearing quartz veins in altered biotite latite. The ore consists of galena, chalcopyrite, sphalerite, and minor amounts of pyrite. A grab sample (328–594) of ore was taken from the dump.

The Red Mountain No. 1 mine is about 1 mile northeast of Stunner on the north side of the Alamosa River. The mine is altered in quartz monzonite porphyry. A 2-foot wide quartz vein containing pyrite, chalcopyrite, and a minor amount of galena is exposed at the face of the adit. A channel sample (328–595) was taken across the vein.

At Summitville the Reynolds mine and mill were sampled. The mine was inaccessible, and only a grab sample (328–597) of ore from the ore bunkers was obtained. Galena, chalcopyrite, pyrite, covellite, and sphalerite in a quartz gangue make up the ore. A sample of mill tailings (328–598) was taken from the Reynolds mill.

None of the 3 samples obtained from this area contain as much as 0.0001 percent BeO.

COSTILLA COUNTY

GRAYBACK DISTRICT

The Grayback mining district is in the northern part of Costilla County, about 5 miles north of the village of Russell. The geology of the area was described by Patton, Smith, Butler, and Hoskin (1910). Limestones, sandstones, and shales of Carboniferous age overlie Precambrian gneiss and schist that crop out in the southwestern part of the district. Tertiary intrusive rocks ranging in composition from diorite to felsite cut the sedimentary rocks. The principal ore deposits of the district are narrow low-grade gold veins in the Carboniferous sedimentary rocks. Small bodies of magnetite occur in tactite adjoining a monzonite porphyry intrusive body at the Star of the West claims in the southwest slope of Grayback Mountain (fig. 52).

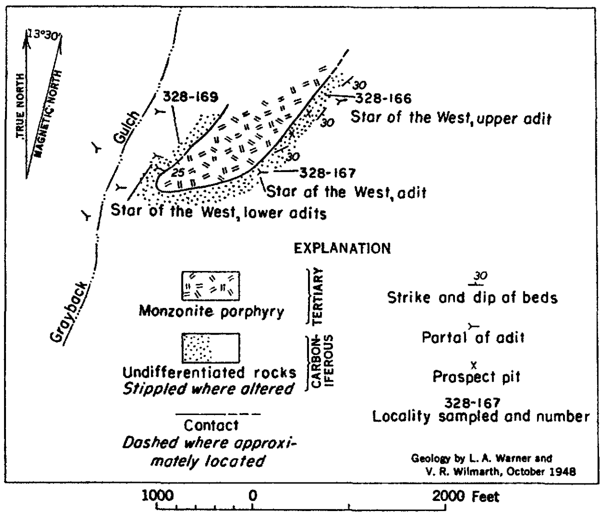


FIGURE 52.—Geologic sketch map of vicinity of Star of the West workings, Grayback district, Costilla County, Colo.

The Upper Star of the West adit is near the top of Grayback Mountain, about 1,000 feet vertically above Grayback Gulch. Magnetite has replaced a limestone bed near the monzonite porphyry body. Overlying the ore body is a 10-foot thick zone of silicified limestone and shale which have been partially replaced by epidote, andradite, chlorite, and actinolite. A channel sample (328–166) across the altered sedimentary rocks showed no beryllium, the limit of detection being 0.001 percent BeO.

The Star of the West adit, 150 feet vertically below the Upper Star of the West, is developed on a 6- to 10-foot-thick magnetite body that strikes N. 75° E., and dips 35° to the south. A 15-foot-thick zone of tactite is exposed above the ore in the adit. No beryllium was found, limit of detection being 0.001 percent BeO, in a channel sample (328–167) across the tactite zone.

About 1,000 feet west of the Star of the West adit, a group of workings on the Lower Star of the West claim explores the contact zone. Magnetite ore, averaging 5 feet in thickness, and a tactite zone 12 feet thick are exposed along the northwest side of the monzonite porphyry body. A chip sample (328–169) across the tactite zone showed no beryllium, the limit of detection being 0.001 percent BeO.

LA VETA AREA

A grab sample of coal was obtained at a mine 5 miles west of La Veta on U. S. Highway 160. The ash of the sample contained 0.0004 percent beryllium, 0.004 percent gallium, and 0.01 percent vanadium. The coal is from the Vermejo formation of Late Cretaceous age.

CUSTER COUNTY

QUERIDA DISTRICT

The Querida (Rosita) district is in the Rosita Hills about 14 miles east of Silver Cliff and 25 miles southwest of Canon City. The Rosita Hills are a series of eroded andesite and rhyolite flows and agglomerates resting on Precambrian granite and schist. The flows are presumed to be from a local source and pipes of agglomerate in the area may be the necks of volcanoes. Veins containing silver, with some lead, copper, and gold, occur chiefly in the volcanic rocks. Galena, pyrite, and barite are the principal minerals.

A grab sample (328–173) of mill tailings was collected from an abandoned mill on State Highway 96 near Querida. The BeO content of the sample was 0.0005 percent.

DOLORES COUNTY

RICO DISTRICT

The Rico district centers around the town of Rico in the eastern part of Dolores County. The principal articles relating to the geology and ore deposits of the district are those by Cross, Howe, and Ransome (1905), Cross and Spencer (1900), McKnight (1932), Ransome (1901a), and Varnes (1944). Sedimentary rocks ranging in age from Proterozoic to Jurassic are intruded by sills of hornblende monzonite porphyry and a stock of quartz monzonite. The sedimentary formations, especially the Ouray limestone (Devonian), have been metamorphosed adjacent to the stock. Silver, lead, zinc, and gold ores have been produced from fissure veins and blanket-type deposits.

Considerable tactite is exposed in the Smuggler mine on the west side of the Dolores River at Rico. The Ouray limestone has been replaced in part by chlorite, specularite, epidote, and garnet. Galena, sphalerite, and chalcopyrite are the ore minerals. A grab sample (328–157) of tactite from the dump showed no beryllium, the limit of detection being 0.001 percent BeO.

FREMONT COUNTY

FLORENCE-CANON CITY AREA

Samples of coal were obtained at two mines, the Brookside and the Double Dick, in the Florence-Canon City area. The coal is in the Vermejo formation of Late Cretaceous age. The geology of the area and the occurrence of the coal were described by Washburne (1910).

Ash of the coal sample (328–171) from the Brookside mine contained 0.0006 percent beryllium, 0.004 percent gallium, and 0.007 percent vanadium. Ash of the sample (328–172) from the Double Dick mine contained 0.0002 percent beryllium, 0.004 percent gallium and 0.01 percent vanadium.

GARFIELD COUNTY

RIFLE AND SILT AREA

Three coal mines in the Grand Hogback coal field (Gale, 1910, p. 109–136) north of Rifle and Silt were sampled. The coal is in the Mesaverde formation of Late Cretaceous age. Ash from a grab sample (328–093) of coal obtained at an abandoned mine 10 miles north of Silt contained 0.0009 percent beryllium, 0.004 percent gallium, and 0.02 percent vanadium. Ash of a coal sample (328–095) from a mine 7 miles northeast of Rifle contained 0.0009 percent beryllium, 0.005 percent gallium, and 0.01 percent vanadium. A channel sample (328–096) was obtained from a 3-foot-thick coal bed exposed in the lower adit of a coal mine near the reservoir, 8 miles north of Silt. The ash contained 0.0004 percent beryllium, 0.005 percent gallium, and 0.008 percent vanadium.

GUNNISON COUNTY

CRESTED BUTTE DISTRICT

The Crested Butte coal mining district centers around the town of Crested Butte in the northern part of Gunnison County. Subanthracite and anthracite coal is mined from the Mesaverde formation of Late Cretaceous age. The geology of the coal field was described by Lee (1912, p. 168–198). A grab sample (328–091) of coal was obtained from an abandoned mine on the east side of Slate Creek, 4 miles north of Crested Butte. The ash contained 0.0004 percent beryllium, 0.004 percent gallium, and 0.01 percent vanadium.

GOLD BRICK DISTRICT

The Gold Brick mining district is 4 miles north of Ohio City on the west side of the Sawatch Range. Most of the ore deposits are small, relatively rich gold-silver-lead veins in Precambrian granite and schist. Small quantities of lead-zinc ore have been produced from one contact metamorphic deposit in limestone. The geology and ore deposits of the district were discussed by Hill (1909, p. 32–34), and Crawford and Worcester (1916). Two mines—the Carbonate Camp and the Gold Links—were visited.

The Carbonate Camp mine is near the head of Alder Creek, about 5 miles airline northwest of Ohio City. The abandoned mine is in Leadville limestone (Mississippian) that has been replaced in part by magnetite, garnet, and diopside. Small quantities of calamine were noted on the dump. A grab sample (328–664) of dump rock showed no beryllium, the limit of detection being 0.0001 percent BeO.

Lead, zinc, and gold were the principal metals produced from vein deposits at the Gold Links mine, about 5 miles north of Ohio City. A grab sample (328–666) of mill tailings from the Gold Links mill showed no beryllium, the limit of detection being 0.0001 percent BeO.

IRON HILL AREA

A small composite stock of alkalic rocks occurs at Iron Hill in the southern part of Gunnison County, near Powderhorn post office. A 3-mile gravel road connects this area with County Highway 149, a gravel road that leads to Iola, a distance of 20 miles. Gunnison, the nearest city, is 22 miles airline to the northeast and can be reached from Iola by way of paved U. S. Highway 50.

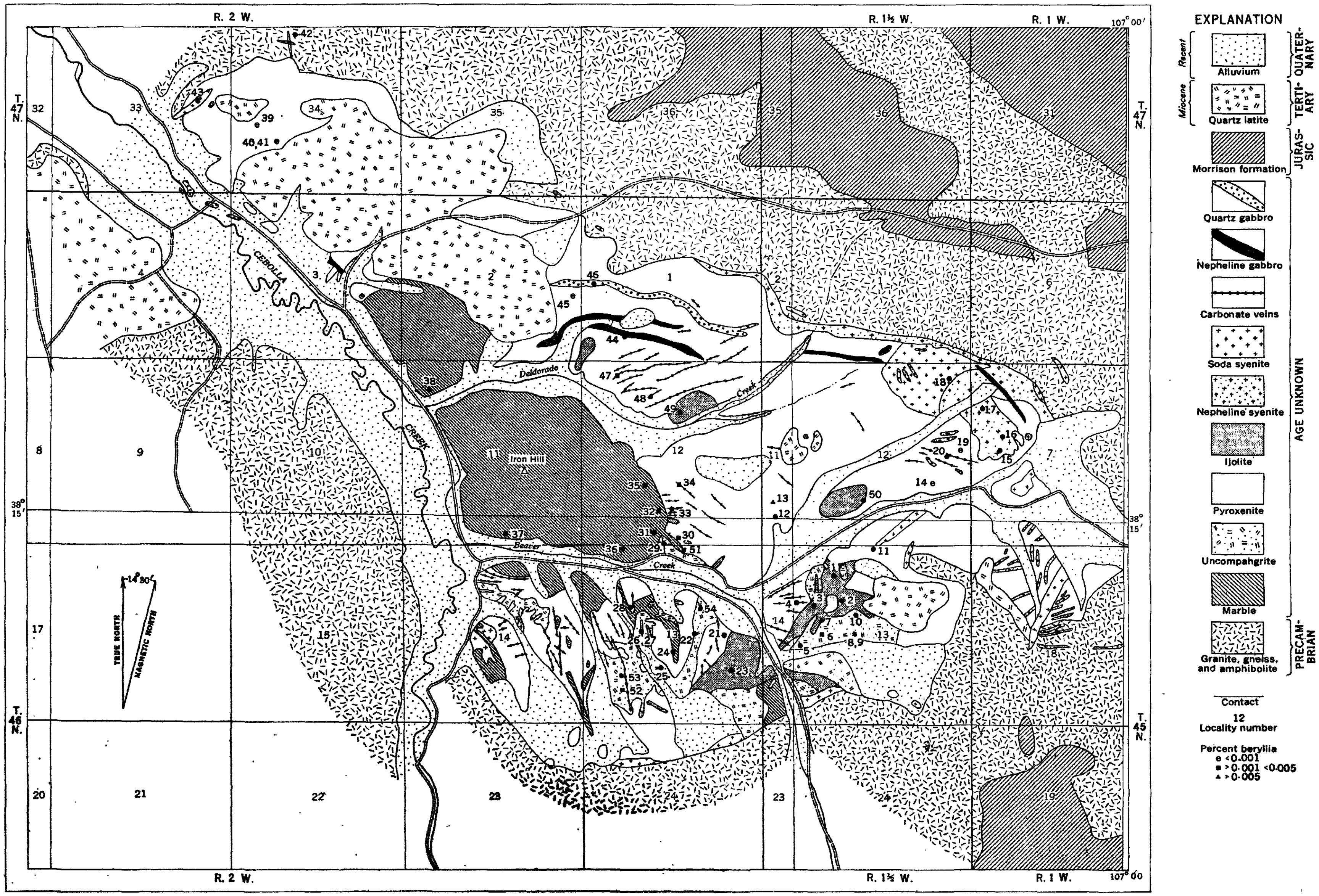
The Iron Hill area has been described in detail by Larsen (1942), who mapped the geology and made extensive laboratory studies of the rocks. In connection with this work spectrogaphic analyses of many rock and mineral specimens were made by George Steiger and E. K. Gedney, who reported BeO in amounts as much as 0.28 percent.

The writers visited the area in September 1948 and again in June 1949. A total of 6 days was spent in systematic sampling, and 116 samples of the various rock types were collected. In view of the detailed nature of Larsen's work no additional mapping was undertaken.

GEOLOGY

The oldest rocks in the Iron Hill area are Precambrian granite, gneiss, and amphibolite. These rocks are overlain in places by sandstones and shales of the Morrison formation of Late Jurassic age. The Jurassic rocks are overlain by volcanic flows and tuffs of the Potosi volcanic series of Miocene age. Rocks of the Iron Hill stock are younger than the latest Precambrian formations and are overlain unconformably in several places by the Potosi volcanic series.

The Iron Hill stock (fig. 53) is a composite intrusive of triangular shape, 6 miles long (in a northwesterly



Map after E. S. Larsen, Jr., 1942, pl. 1

FIGURE 53.—Geologic map of Iron Hill area, Gunnison County, Colo.

direction) and 4 miles wide at its widest part. Iron Hill, in the central part of the stock, is a mass of dolomitic marble that rises about 1,000 feet above the Cebolla Creek valley. In an irregular and discontinuous aureole along the contact with intrusive rocks, the marble contains aegirite, phlogopite, and soda amphibole. The marble closely resembles later carbonate veins which cut it and the surrounding intrusive rocks. Larsen favors a hydrothermal origin for the marble, and presumes that it may have been deposited in the open throat of an old volcano.

The oldest intrusive rock of the stock is uncompaghrite, a coarse-grained rock which occurs in irregular bodies and dikelike masses that have been cut by later intrusive rocks. It underlies an area of about 0.6 square mile in the southern part of the basin of Beaver Creek. The average specimen contains about 70 percent melilite, 15 percent diopside-hedenbergite, and 10 percent magnetite, the remainder being chiefly apatite, perovskite, phlogopite, and calcite. The composition varies considerably from place to place, and the color in hand specimen ranges from light gray for the melilite-rich variety to dark greenish for specimens rich in pyroxene. In places the uncompaghrite has been altered by a series of complex hydrothermal reactions to a rock containing diopside, colorless garnet, idocrase, and calcite.

Pyroxenite is the most abundant rock of the complex and is later than the marble and uncompahgrite. It underlies about 9.4 square miles, the largest exposure being east of Iron Hill in the drainage basins of Deldorado and Beaver Creeks. The rock is quite variable, both in texture and in mineral composition. The dominant variety contains about 60 percent pyroxene, 15 percent biotite, and 10 percent each of magnetite, and perovskite, with lesser amounts of apatite and ilmenite. Other varieties contain nepheline, orthoclase, or albite and locally as much as 30 percent sphene. In places dikelike bodies consisting of magnetite and perovskite, with apatite, biotite, and pyroxene, cut the other rocks; some small dikes contain as much as 90 percent apatite. Magnetite and perovskite in lenslike bodies are commonly associated with the apatite- and biotite-rich rocks. Masses of biotite pyroxenite containing as much as 98 percent biotite were mined during World War II for mica.

Ijolite occurs as dikelike and irregular masses that cut the uncompahgrite and pyroxenite. It makes up about 3 percent of the intrusive rocks. The largest area of outcrop, about 0.1 square mile, is west and south of the main forks of Beaver Creek. The chief mineral constituents are nepheline, titaniferous garnet, and dark diopside, but the proportions vary greatly. Cancrinite, calcite, and zeolites are common and owe their origin to alteration of the nepheline.

Soda syenite makes up about 2½ percent of the intrusive rocks and is later than the ijolite. It occurs as dikes and irregular masses, generally near the periphery of the stock. The syenite is a light-gray medium- to coarse-grained rock consisting chiefly of microperthite, with small amounts of aegirite or soda amphibole and some apatite, fluorite, and sphene. Much of the syenite is banded or streaked from granulation during or immediately after intrusion.

Nepheline syenite underlies an area of 0.3 square mile along the northeastern border of the stock. It occurs as dikes and irregular bodies intruded into pyroxenite, soda syenite, and Precambrian rocks. The rock consists predominantly of albite and microcline. Other minerals recognizable in hand specimen are nepheline, apatite, sphene, biotite, magnetite and aegirite. Locally the nepheline syenite has been altered and contains cancrinite and zeolites.

The latest intrusive rocks consist of dikes of nepheline gabbro and quartz gabbro which are most abundant in the valley of Deldorado Creek north of Iron Hill. The nepheline gabbro is a dark coarse-grained rock containing tabular crystals of labradorite, interstitial pyroxene, and smaller amounts of nepheline and olivine. The quartz gabbro is finer grained and consists of labradorite and pink titaniferous augite and small amounts of intergrown quartz and orthoclase.

Hydrothermal activity accompanied and followed intrusion, and alteration products are widespread in the various rock types. The more common hydrothermal minerals include aegirite, sodic amphibole, phlogopite, apatite, garnet, idocrase, diopside, zeolites, albite, orthoclase, carbonates, quartz, fluorite, and sulfides. Veins are common in the intrusive rocks of the stock and some occur in the central mass of marble and in the surrounding Precambrian rocks. The major veins are a few feet wide and can be traced for nearly a mile, but many are smaller. Many of the veins are similar in composition to the central carbonate mass and consist largely of dolomite, with some calcite and ankerite. Locally they contain sulfides, limonite, apatite, and silicate minerals; in places they have been prospected for silver. In some veins lime-silicate minerals are dominant and the vein filling closely resembles the material in the contact-metasomatic aureole of the Iron Hill marble. Other veins consist largely of martite and apatite, with small amounts of limonite and carbonates. These grade into veins and irregular bodies rich in iron oxides and chalcedony or opal. Manganese oxides are present locally, and rarely piedmontite. The martite-apatite veins and siliceous iron-oxide veins are best developed in the marble mass of Iron Hill, where they have been prospected for iron.

OCCURRENCE OF BERYLLIUM

Fifty-four samples of various rock types in the Iron Hill area were analyzed spectrographically for BeO. Descriptions of the samples and analytical results are given in table 69. The locality numbers refer to sample locations shown on figure 59. The BeO content ranges from 0.0098 percent to less than 0.0001 percent. For most samples the lower limit of detection was 0.001 percent, and fewer than half the samples contained as much as 0.001 percent. For a few samples the lower limit of determination was 0.0001 percent and for still fewer it was 0.004 percent. Distribution of beryllium in the various rock types is shown in table 70.

TABLE 69.—*Beryllia in samples from Iron Hill, Colo.*

[Analyses by National Spectrographic Laboratories, Cleveland, Ohio, and Saratoga Laboratories, Saratoga Springs, N. Y.]

Locality No. n fig. 58	*Sample*	*Description*	BeO (*percent*)
1	328-34	Ijolite	<0.001
2	35	do	<.001
3	36	do	<.001
4	36A	Vein (mainly calcite-dolomite)	<.001
5	38	Altered uncompahgrite	<.001
6	39	Uncompahgrite	.003
7	40	Uncompahgrite (pyroxene-rich)	.0098
8	41	Vein (siliceous iron oxide)	.002
9	42	Vein (lime-silicate type)	<.001
10	43	Uncompahgrite	.000X
11	44	Pyroxenite	.000X
12	45	Biotite pyroxenite	<.001
13	46	Altered biotite pyroxenite	.0075
14	49	Pyroxenite	<.001
15	50	Vein (mainly quartz)	<.001
16	51	Nepheline syenite	<.004
17	52	do	<.001
18	53	Soda syenite	.000X
19	54	Altered pyroxenite	<.001
20	55	Vein (mainly calcite-dolomite)	<.001
21	56	Altered pyroxenite	<.001
22	57	Altered uncompahgrite	<.001
23	60	Ijolite	.000X
24	61	Marble (mainly calcite-dolomite)	<.001
25	62	Uncompahgrite (melilite-rich)	<.001
26	63	Vein (mainly calcite-dolomite)	<.001
27	64	Vein (lime-silicate type)	.0009
28	65	Marble (lime-silicate rock)	<.001
29	68	Vein (lime-silicate type)	<.001
30	69	Altered marble (siliceous iron oxide)	.0035
31	70	Marble (calcite-dolomite rock)	<.001
32	71	Altered marble (lime-silicate rock at pyroxenite contact)	.0033
33	72	Vein (lime-silicate type)	<.001
34	73	Vein (siliceous iron oxide)	.004
35	74	Marble (lime-silicate rock)	.0006
36	75	do	<.001
37	76	Marble (calcite-dolomite with bands of lime-silicate rock)	<.001
38	77	Altered marble (siliceous iron oxide)	.0097
39	500	Pyroxenite	<.0001
40	504	Apatite-rich dike in pyroxenite	<.0001
41	505	do	<.0001
42	506	Granite gneiss (Precambrian country rock)	.0005
43	508	Soda syenite	.0005
44	510	Nepheline gabbro	<.0001
45	512	Pyroxenite	<.0001
46	513	Quartz gabbro	<.0001
47	516	Carbonate vein	.001
48	518	do	.001
49	520	Altered ijolite	.001
50	529	Ijolite	<.0001
51	535	Altered uncompahgrite	.001
52	539	do	.002
53	545	do	.002
54	564	Uncompahgrite	.002

TABLE 70.—*Distribution of beryllia in rock types at Iron Hill, Colo.*

Rock type	*Number of samples analyzed*	BeO (*percent*) *High*	*Low*	*Average*
Marble and carbonate veins:				
Calcite-dolomite type	8	0.001	−0.001	−0.001
Lime-silicate type	9	.0033	−.001	±.001
Siliceous iron-oxide type	4	.0097	.002	.0048
Uncompahgrite:				
Unaltered	5	.0098	−.001	.0035
Altered	5	.002	−.001	±.001
Pyroxenite:				
Normal pyroxenite:				
Unaltered	4	−.001	−.001	−.001
Altered	2	−.001	−.001	−.001
Biotite pyroxenite:				
Unaltered	1			−.001
Altered	1			.0075
Ijolite:				
Unaltered	5	−.001	−.0001	−.001
Altered	1			.001
Soda syenite	2	.000X	.0005	±.0005
Nepheline syenite	2	−.004	−.001	−.001
Granite gneiss	1			.0005
Nepheline gabbro	1			<.0001
Quartz gabbro	1			<.0001
Apatite-rich dikes	2	<.0001	<.0001	<.0001

The analytical data indicate that beryllium is concentrated mainly in the siliceous iron oxide veins. The BeO content of 4 samples of these veins ranges from 0.002 percent to 0.0097 percent, the average being 0.0048 percent, which is higher than the content of any other rock type for which a comparable number of samples was obtained. The average BeO content for other vein types is 0.001 percent or less. The nature of the beryllium-bearing material in the veins has not been determined. The siliceous iron oxide veins appear to resemble somewhat the ocherous beryllium-bearing material in the manganese-tungsten deposits of Golconda, Nev., in which beryllium and tungsten are presumed to be adsorbed in colloidal masses of silica and manganese-iron oxides or hydroxides. The deposits at Golconda, Nev., are thought to be underlain at depth by high-temperature veins or tactite bodies containing tungsten and beryllium from which these metals may have been leached by ascending thermal solutions and deposited at or near the surface. Ocherous veins, similar to those at Iron Hill, occur in the Golconda area.

In the igneous rocks beryllium is found chiefly in uncompahgrite. The BeO content in 5 samples of fresh uncompahgrite ranged from 0.0098 percent to less than 0.001 percent, the average being about 0.0035 percent.

In the samples analyzed the BeO content appears to be in direct proportion to the percentage of diopside-hedenbergite present, and it is concluded that most of the beryllium in the uncompahgrite is contained in the pyroxene. On this basis it might be assumed that beryllium would be more abundant in the pyroxenite and ijolite, as those rocks, in general, contain more pyroxene than the uncompahgrite, and according to Larsen (1942, tables 18 and 19), the pyroxenes of the three rock types are very similar. Analytical data indicate, however, that the average BeO contents of the igneous rocks younger than uncompahgrite are less than 0.001 percent. In general the altered igneous rocks appear to contain less BeO than their unaltered counterparts. This applies especially to uncompahgrite, of which the largest number of samples were analyzed, and suggests that beryllium was leached from uncompahgrite during hydrothermal alteration. Possibly the beryllium in the veins may be accounted for in this way. An exception to the generalization is noted in 1 sample of altered biotite pyroxenite (328–046) that contained 0.0075 percent BeO.

COMMERCIAL POSSIBILITIES

Because of the extremely variable character of the Iron Hill rocks, much more detailed sampling and hundreds of analyses would be needed to obtain a reasonably accurate knowledge of the grades and tonnages of beryllium-bearing material at this locality. At least several million tons of uncompahgrite averaging 0.003 percent or more of BeO and a smaller amount of ocherous vein material averaging about 0.005 percent BeO are present. Even if accurate figures could be given, it is doubtful, however, that these materials should be regarded as beryllium resources, because of the extremely low grade and apparent mode of occurrence. Analytical data seem to indicate that most of the beryllium is contained as an accessory constituent in the rock-forming minerals rather than in true beryllium minerals, such as helvite or beryl. Detailed laboratory study of many samples revealed no beryllium minerals. If such minerals are lacking, recovery of the beryllium would be difficult or impractical.

Some interest has been shown in the rocks at Iron Hill for the relatively high content of iron, titanium, gallium, indium, and other metals. In the event mining of these metals is undertaken, further studies on the occurrence of beryllium at Iron Hill might be warranted in the hope of finding at least small deposits of material from which beryllium might be recovered as a byproduct.

ITALIAN MOUNTAIN AREA

Italian Mountain, comprised of North Italian, Italian, and South Italian Peaks, is along the eastern edge of the Crested Butte quadrangle in the northern part

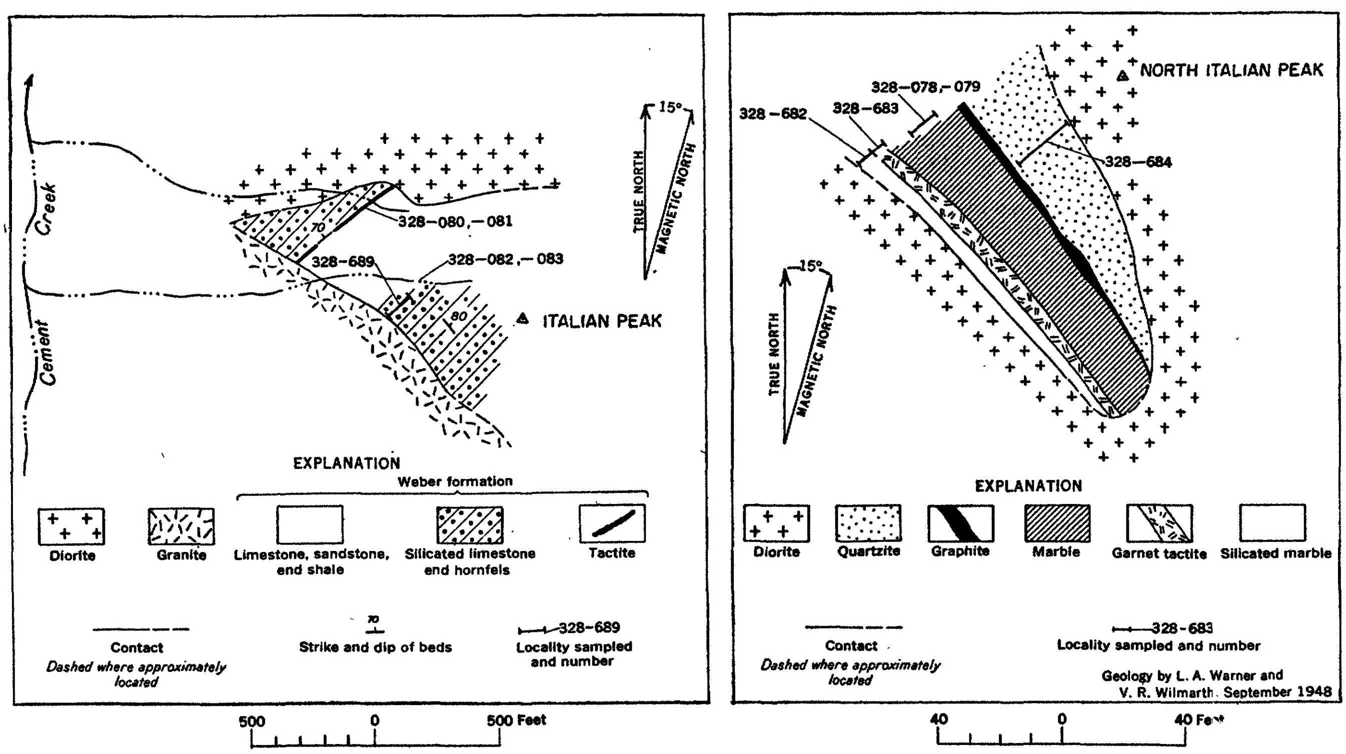


FIGURE 54.—Geologic sketch maps of parts of Italian Mountain area, Gunnison County, Colo.

of Gunnison County. The geology of the Italian Mountain area was described by Emmons, Cross, and Eldridge (1894, p. 5) and by Cross and Shannon (1927). North and South Italian peaks are formed by masses of intrusive rock that range in composition from diorite to granite. Sedimentary rocks of the Weber formation (Pennsylvanian) crop out on the flanks of North and South Italian Peaks, and form Italian Peak. Near their contacts with intrusive bodies the sedimentary rocks have been metamorphosed and replaced locally by tactite (fig. 54). Shannon (*in* Cross and Shannon, 1927, p. 9) described 28 minerals from the tactite zones.

A wedge-shaped body of limestone, shale, and sandstone in the Weber is exposed on the west flank of Italian Peak between the northern and southern intrusive masses. A limestone bed has been replaced by a tactite layer 15 feet thick containing brown and yellow grossularite-andradite garnet, actinolite, sphene, idocrase, magnetite, and epidote. Southwest of North Italian Peak is a smaller wedge-shaped mass of intensely altered Weber formation consisting of interlayered quartzite, hornfels, marble, tactite, and some graphite.

Ten samples were taken as follows (see also fig. 54):

328–078 Grab sample of marble containing epidote, garnet, and diopside, North Italian Peak.
079 Do.
080 Grab sample of tactite containing garnet, diopside, and actinolite, Italian Peak.
081 Grab sample of tactite containing garnet, diopside, and epidote, Italian Peak.
082 Grab sample of garnet tactite float, Italian Peak.
083 Grab sample of epidote tactite float, Italian Peak.
682 Chip sample across 6 ft of silicated marble containing magnetite, phlogopite, garnet, and actinolite, North Italian Peak.
683 Chip sample across 12 ft of garnet tactite, North Italian Peak.
684 Chip sample across 25 ft of quartzite with thin layers of hornfels, North Italian Peak.
689 Chip sample across 100 ft of silicated limestone and hornfels containing tremolite and garnet, Italian Peak.

No sample contained as much as 0.001 percent BeO.

SNOWMASS MOUNTAIN AREA

The Snowmass Mountain area is in the Elk Mountains in the extreme northern part of Gunnison County. The geology and mineral deposits were described by Vanderwilt (1937). Sedimentary rocks ranging in age from Cambrian to Cretaceous have been metamorphosed for several thousand feet outward from their contact with a Tertiary albite granite mass that forms Treasury Mountain. Zinc, lead, and silver are the major metals produced from quartz veins in faulted sedimentary rocks.

In the area at the head of Yule Creek (fig. 55) garnet tactite bodies as much as 25 feet thick occur near the top of the Leadville limestone (Mississippian). Thin bands of epidote, garnet, diopside, and quartz replace limestone layers in the Hermosa group (Pennsylvanian).

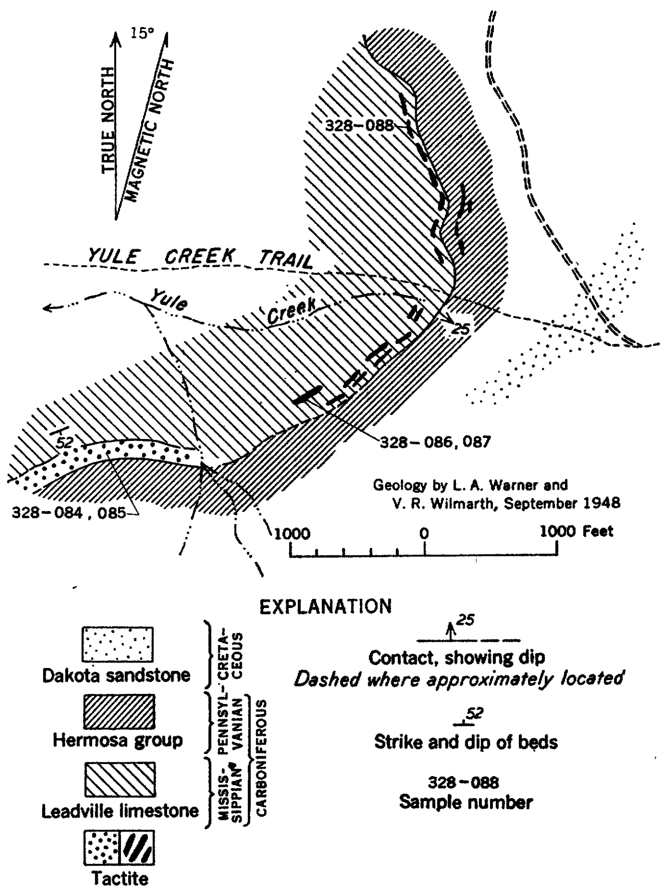


FIGURE 55.—Geologic sketch map of tactite zone near head of Yule Creek, Snowmass Mountain area, Gunnison County, Colo.

Five samples from the tactite layers in this area were taken, as shown on figure 55, and are described below.

328–084 Grab sample of garnet-bearing rock from north side of tactite zone.
085 Same, from south side of tactite zone.
086 Chip sample across 25 ft of garnet tactite.
087 Chip sample along outcrop of tactite layer for 200 ft.
088 Grab sample from outcrop of garnet tactite layer.

None of the samples contained as much as 0.001 percent BeO.

In the Rock Creek area, near Schofield Pass 12 miles northwest of Gothic, quartz veins containing pyrite, epidote, specularite, tourmaline, galena, and sphalerite occur along north-trending faults. A chip sample (328–692) across a 10-foot-wide quartz vein contained less than 0.0001 percent BeO, if any. The Niobrara limestone (Cretaceous) has been replaced by garnet, epidote, calcite, diopside, and actinolite at the contact of a Tertiary lamprophyre dike. Two channel samples (328–693 and –695) across altered limestone adjacent to the dike showed no BeO.

TINCUP DISTRICT

The Tincup district is in the Sawatch Range, a few miles south and southeast of the village of Tincup. The formations include Precambrian granite gneiss and sedimentary rocks of Paleozoic age, chiefly limestone, ranging in age from Cambrian to Pennsylvanian. Tertiary quartz monzonite sills, dikes, and small stocks cut the sedimentary rocks. The sedimentary formations trend northwesterly and dip 10°–35° NE.

The ore deposits of the district are of four types (Goddard, 1936, p. 565); silver-lead-gold blanket deposits, silver-lead-gold veins, molybdenum-tungsten veins, and pyrometasomatic iron deposits. The silver-lead-gold deposits account for most of the production. The blanket deposits and pyrometasomatic deposits are in limestone; the veins cut all rock but were most productive in limestone. Several mines in the district were visited, and the samples taken are described in table 71.

TABLE 71.—*Beryllia in samples from the Tincup district*

Sample	*Description*	BeO (*percent*)
328–669	Grab sample from 2-ft quartz vein containing huebnerite, molybdenite, pyrite, chalcopyrite, sphalerite, and galena, Ida May mine, 5 miles south of Tincup at Cumberland Pass	<0.0001
670	Channel sample across 3-ft quartz vein containing molybdenite and pyrite, Emma H mine, 1 mile west of Cumberland Pass	.0013
671	Grab sample from 6-ft quartz vein containing molybdenite at Mammoth mine, ¾ mile west of Ida May mine	<.0001
673	Grab sample containing galena, pyrite, chalcopyrite, limonite, and quartz from dump of Jimmy Mack mine, 5 miles south of Tincup	<.0001
675	Channel sample across 6-ft zone of garnet tactite, Cumberland mine opencut on Gold Hill, 4 miles south of Tincup	<.0001
676	Channel sample across 10-ft layer of magnetite containing some garnet, Cumberland opencut	<.0001
677	Channel sample across altered quartz monzonite sill, Cumberland opencut	<.0001
681	Grab sample containing molybdenite, pyrite, and quartz from dump of Bon Ton mine, 3 miles south of Cumberland Pass	.0005

TOMICHI DISTRICT

The Tomichi, or Whitepine, mining district is in the eastern part of Gunnison County on the west slope of the Sawatch Range. Most of the mines are east and north of the mining camp of Whitepine. The geology and ore deposite of the district were described by Harder (1909, p. 194–198), and Crawford (1913, p. 284–310). Sedimentary rocks ranging in age from Ordovician to Pennsylvanian are in fault contact on the east with Precambrian granite and are bounded on the west by Princeton quartz monzonite of Crawford (1913) of Tertiary age. The ore deposits are replacement bodies in limestone and dolomite, contact deposits, and fissure veins. The principal metals produced are lead, zinc, and silver. Contact deposits and veins near the Iron King mine, northeast of Whitepine, were sampled (fig. 56).

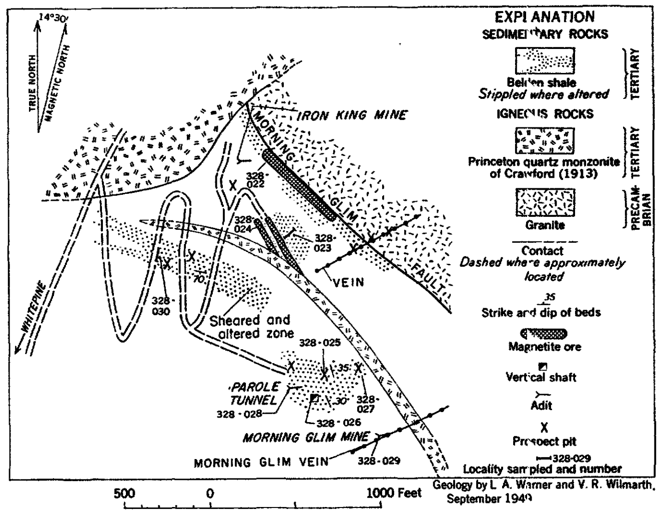


FIGURE 56.—Geologic sketch map of part of northern Tomichi district, Gunnison County, Colo.

The samples collected in the Tomichi district (see fig. 56 for some localities) are listed below. None showed as much as 0.0001 percent BeO.

328–022	8 ft channel sample across tactite on hanging wall of magnetite body.
023	Chip sample across silicified limestone between magnetite zones.
024	Grab sample of magnetite.
025	Grab sample of epidote, garnet, and silicified limestone.
026	Grab sample of silicified limestone.
027	Grab sample of silicified limestone with garnet, epidote, and magnetite.
028	Grab sample of limonite-stained silicified limestone.
029	Grab sample of sulfide ore from vein.
030	Grab sample of altered shale and limestone containing magnetite.
031	Grab sample of epidote-garnet rock from dump of Erie mine.
033	Grab sample of tailings from Callahan Zinc-Lead Co. mill at Whitepine.
033A	Grab sample of mill heads from Callahan Zinc-Lead Co. mill at Whitepine.
033B	Garnet-epidote rock from level 4, Erie mine.
033C	Garnet-epidote, galena, and sphalerite, main drift, Erie mine.
033D	Galena and sphalerite from main drift, Erie mine.
033E	Ore from main drift, Erie mine.

The Iron King mine is about 2 miles by road northwest of Whitepine near the Morning Glim fault. Magnetite ore in a zone 65 feet wide extends along the fault for several hundred feet. Masses of serpentine and quartzite interlayed with magnetite are exposed at the Iron King opencut. Adjacent to a quartz monzonite dike the limestone and shaly layers of the Belden shale have been heavily impregnated with epidote, chlorite, actinolite, garnet, pyrite, and magnetite. Tactite minerals partly replace the shaly layers of the Belden shale near the Parole tunnel.

Samples of tactite from the underground workings of the Erie mine at Whitepine were obtained through the courtesy of C. S. Robinson of the U. S. Geological Survey. Samples of mill products were obtained from the Callahan Zinc-Lead Co. mill at Whitepine.

HINSDALE COUNTY

LAKE CITY DISTRICT

The mining district near Lake City, in the western part of Hinsdale County, includes two major mining camps: Galena (Henson Creek) camp west of Lake City along Henson Creek and the Lake Fork camp at the north end of Lake San Cristobal about 5 miles south of Lake City. The geology and ore deposits of the Lake City district have been described by Irving and Bancroft (1911), Brown (1926), and Burbank (*in* Vanderwilt, 1947, p. 439–443).

The rocks of the district are mainly of the Silverton volcanic series of Tertiary age. Intrusive bodies of rhyolite, latite, and quartz monzonite in places cut the volcanic rocks. The ore deposits are chiefly fissure veins containing lead-zinc ores and a little gold, silver, and copper. The principal gangue minerals are rhodochrosite, quartz, and barite.

The veins in the Lake City district are similar to helvite-bearing veins in the Eureka area nearby, except that the latter contain rhodonite. Samples obtained at seven mines in the district are described in table 72. No helvite was noted in any of the veins.

TABLE 72.—*Beryllia in samples from the Lake City district*

Sample	*Description*	BeO (*percent*)
328–573	Grab sample containing rhodochrosite, quartz, galena, sphalerite, and altered rhyolite from dump of Ulay tunnel, on Henson Creek 3.5 miles west of Lake City	0. 0002
576	Grab sample of ore from dump of Hidden Treasure mine, 2,000 ft northwest of Ulay tunnel (tetrahedrite, galena, sphalerite, quartz, rhodochrosite, and jasper)	<. 0001
579	Grab sample containing tetrahedrite, galena, sphalerite, pyrite, chalcopyrite, and quartz from dump of Wave of the Ocean mine, on Henson Creek 7 miles west of Lake City	. 0002
580	Grab sample of ore from bunker at Yellow Medicine mine, 2 miles northeast of Capitol City in Yellowstone Gulch (galena, sphalerite, chalcopyrite, and quartz)	<. 0001
581	Grab sample of lead-zinc ore from dump of Capitol mine, one-quarter mile southwest of Yellow Medicine mine	<0. 0003
586	Grab sample of ore from dump of Golden Fleece mine, 1,200 ft west of north end of Lake San Cristobal (galena, pyrite, and gold telluride, with rhodochrosite and quartz)	<. 0003
588	Grab sample containing galena, pyrite, sphalerite, and quartz from dump of General Sherman mine, in Slumgullion Gulch 1 mile north of Lake San Cristobal	<. 0001

HUERFANO COUNTY

WALSENBURG AREA

By W. T. HOLSER

Near Walsenburg, flat-lying Cretaceous and Tertiary sedimentary rocks are cut by small intrusive bodies that are probably related to the Tertiary igneous complex of the Spanish Peaks to the southwest. The principal bodies are northeasterly trending vertical dikes several miles long and as much as 50 feet thick; they range in composition from basalt to granite. There are a few sills and plugs. Details of the geology were described by Hills (1900).

One of the plugs forms Huerfano Butte, on the east side of U. S. Highway 85–87 and south of Huerfano Creek (Knopf, 1936, p. 1776). The rock is an alkali gabbro composed mainly of labradorite, augite, biotite, olivine, and potassium feldspar. A sample (329–251) from the top of the butte on the north side contained 0.002 percent BeO.

An olivine basalt dike containing titanaugite crosses the highway about 3 miles south of Huerfano Butte. A 12-foot channel sample across the dike contained 0.0008 percent BeO.

Seventeen samples of various rocks collected by Knopf were analyzed chemically and also were tested spectrographically for beryllium with negative results, the limit of sensitivity being 0.0X percent (Knopf, 1936, p. 1779).

Although the beryllium contents of the samples from the Walsenburg area are much too low to be of commercial interest, the 0.002 percent BeO in gabbro at Huerfano Butte is considerably above the average for mafic rocks. Theoretically, some of the silicic and alkalic rocks in the Spanish Peaks region might be expected to contain appreciably more beryllium.

LAKE COUNTY

CLIMAX MINE

Ten samples of mill products furnished to the Geological Survey by the Climax Molybdenum Co. in 1950 were analyzed for BeO. Descriptions of the samples and analytical results are given in table 73. Details of the geology of the Climax mine are given by Butler and Vanderwilt (1933).

TABLE 73.—*Beryllia in samples of mill products from Climax, Colo.*

Sample	Description	BeO (percent)
CMC 1	Molybdenite concentrate	<0.0001
1A	Quartz tailings	.0005
3	Huebnerite concentrate	.0004
4	Quartz tailings	.0005
6	Pyrite concentrate	<.0001
7	Huebnerite concentrate	<.0001
8	Topaz concentrate	<.0003
12	Monazite concentrate	<.0003
14	Cassiterite concentrate	.0005
762	Molybdenite mill heads	.0006

LA PLATA COUNTY

DURANGO AREA

Coals of Late Cretaceous age occur in the Durango area, principally in the Mesaverde and Fruitland formations. The deposits have been described by Gardner (1909). Samples were obtained from the Castle, O. K., and Yellow Jacket coal mines and from coal outcrops east of Durango.

Ash from a grab sample (328–158) of coal from the Castle mine, 5 miles northwest of Durango, contained 0.0003 percent beryllium, 0.006 percent germanium, 0.004 percent gallium, and 0.02 percent vanadium. Ash of coal (328–163) from the Yellow Jacket mine, east of Bayfield on U. S. Highway 160, contained 0.0003 percent beryllium, 0.005 percent gallium, and 0.008 percent vanadium.

LAS ANIMAS COUNTY

MORLEY AREA

By W. T. HOLSER

Two mafic dikes are exposed in a road cut on the east side of U. S. Highway 85–87 at Morley station, a few miles north of the New Mexico State line. The rock is greenish black, fine grained, and rich in augite. A 6-foot channel sample (329–254) across the northern dike showed no BeO; the limit of sensitivity for the spectrographic analysis was 0.0004 percent.

An intrusive body of basalt about half a mile in diameter crops out 2 miles east of Morley. The rock consists of augite and olivine phenocrysts in a groundmass of plagioclase, augite, and magnetite (Hills, 1899, p. 3). At the southwestern margin of the intrusive, the rock is light gray and probably more silicic than basaltic. A sample (329–257) of this rock showed no beryllium, the limit of sensitivity being 0.0004 percent BeO.

MINERAL COUNTY

CREEDE DISTRICT

The Creede district is near the eastern edge of the San Juan Mountains in the northern part of Mineral County. The principal mines are a few miles northeast of the town of Creede. The geology and ore deposits of the district were were discussed by Emmons and Larsen (1923). The ore deposits are silver-lead veins in Tertiary rhyolite and in quartz latite flows. The principal ore minerals are galena, pyrite, chalcopyrite, and sphalerite in a gangue of amethyst, quartz, chlorite, and fluorite. Samples of the mill products were obtained at the Emperius Mill in Creede. Analyses of both mill heads and mill tails (samples 328–591, –592) showed 0.002 percent BeO.

WAGON WHEEL GAP

Fluorspar veins occur in Miocene rhyolite tuffs and breccias about 1 mile south of Wagon Wheel Gap station on the Denver and Rio Grande Western Railroad. The geology and ore deposits of the area were described by Aurand (1920, p. 61–67) and Emmons and Larsen (1913). The main deposit is on the east side of Goose Creek, across the valley from Mineral Hot Springs. It is owned and operated by the Colorado Fuel and Iron Corp. at Pueblo. A grab sample (328–593) of white fluorite from the ore bin contained no beryllium.

MONTEZUMA COUNTY

RUSH BASIN

Rush Basin is a large erosional valley at the head of the East Mancos River in the La Plata mining district. A description of the geology of the area is given in a comprehensive report on the La Plata district by Eckel, Williams, and Galbraith (1949, p. 110–115). Many dikes, sills, and small stocks of diorite monzonite, and syenite porphyry cut metamorphosed sedimentary rocks of Jurassic and Cretaceous age. Several mines in the area exploit gold-bearing breccia deposits, blanket or replacement deposits, and fissure veins. A 1-foot-wide tactite zone composed of brown garnet, epidote, actinolite, calcite, quartz, and a minor amount of pyrite is exposed about 700 feet N. 80° E. of a cabin at the entrance to Rush Basin. The tactite zone is in a limestone member of the Wanakah formation of Jurassic age. A grab sample (328–155) of the tactite showed no beryllium, the limit of sensitivity being 0.0001 percent BeO.

OURAY COUNTY

OURAY DISTRICT

The Ouray district centers around the town of Ouray in the San Juan Mountains of southwestern Colorado. The geology and ore deposits of the Ouray district have been described by Irving (1905); Cross, Howe, and Irving (1907); and Burbank (1930; 1940). The rocks exposed in the Ouray district include 8,000 feet of Precambrian quartzites and slates and about 5,000 feet of limestones, shales, and sandstones of Paleozoic and Mesozoic ages. Unconformably overlying the strata of Mesozoic age is a thick series of Tertiary volcanic rocks, consisting chiefly of andesite flows and latite tuff and breccia. The principal ore deposits occur in strata of Paleozoic and Mesozoic age near Tertiary granodiorite and quartz monzonite porphyry intrusive bodies. Pyrometasomatic deposits, fissure veins, and flat-lying replacement deposits are represented. Beryllium was not detected spectrographically in any of the samples, the limit of detection being 0.001 percent BeO.

These are samples collected in the district:

328–119 Grab sample containing chalcopyrite, pyrite, diopside, epidote, and quartz from dump of Bright Diamond mine, 1 mile north of Ouray.

120 Channel sample across 8-ft tactite zone at portal of Bright Diamond adit, 500 ft southeast of Bright Diamond mine. (Tactite is chiefly garnet, epidote, actinolite, and chlorite; ore minerals are pyrite, chalcopyrite, galena, sphalerite, and magnetite.)

123 Grab sample from dump of Portland mine, 1.5 miles east of Ouray (calcite, siderite, rhodochrosite, and quartz, with minor amounts of galena and sphalerite).

861 Mill heads, American Zinc, Lead, and Smelting Co. mill at Ouray.

862 Mill tails from same place.

RED MOUNTAIN DISTRICT

The Red Mountain district is along Red Mountain Creek in the southern part of Ouray County, between Ironton Park on the north and Red Mountain on the south. The geology and mineral deposits have been described by Ransome (1901b, p. 214–250), Collins (1931), and Burbank (*in* Vanderwilt, 1947, p. 428–431). The Silverton volcanic series of Tertiary age several thousand feet thick, constitutes the major part of the exposed bed rock. These rocks are intruded by porphyritic latite and rhyolite plugs that range from a few feet to more than 2,000 feet in diameter. Much fracturing accompanied intrusion, and the volcanic rocks were altered to clay minerals, alunite, diaspore, and quartz along vertical pipelike zones. Ore deposits containing sulfides of copper, silver, lead, and zinc are associated with the siliceous pipes. Samples collected in the district are described in table 74; none contained as much as 0.001 percent BeO.

TABLE 74.—*Beryllia in samples from the Red Mountain district*

Sample	*Description*	BeO (*percent*)
328–127	Grab sample of altered volcanic rock containing galena and sphalerite from dump of Mountain King mine, 2 miles northeast of Red Mountain Pass	0.0004
128	Chip sample across 125 ft of silicified volcanic material near ore bin at Guston mine, 1.5 miles north of Red Mountain Pass	<.001
130	Composite grab sample of silicified volcanic material from dump of Guston mine	<.001
132	Chip sample across southwest end of silicified pipe at National Belle mine at Red Mountain Pass	<.001
134	Grab sample of sericitized volcanic rock at southwest end of shaft house, National Belle mine	<.001
137	Chip sample across northeast end of silicified pipe, National Belle mine	<.001
859	Mill heads from Idorado mill at Treasury Tunnel, 1 mile north of Red Mountain Pass	<.0001
860	Mill tails from Idorado mill	<.0001

UPPER UNCOMPAHGRE DISTRICT

The Upper Uncompahgre district includes the mines along Uncompahgre Canyon, and along Red Mountain Creek between Ironton Park and the junction with Uncompahgre River. The geology and mineral deposits were described by Burbank (*in* Vanderwilt, 1947, p. 437–439), and Kelley (1946, p. 355–385). The rocks in Uncompahgre Canyon are Precambrian quartzites and slates that are uncomformably overlain by sandstones, shales, conglomerates, and limestones of Devonian to Jurassic age. Tertiary volcanic tuff, breccia, andesite, and latite, of the Silverton volcanic series and the San Juan tuff, overlie the older rocks. Prevolcanic intrusive rocks consist of quartz monzonite and diabase dikes. The ore deposits in this area are vein and chimney deposits in the altered volcanics. Two types of vein deposits are found: pyrite-gold-quartz, and tungsten-quartz. Chimney deposits are characterized by lead, zinc, and copper-silver minerals. We took samples from the seven mines we visited in this area, and one from another mine was supplied us. None of the samples contained as much as 0.0001 percent BeO. They are described below.

328–800 Channel sample across 6-ft vein at portal of lower adit at Gertrude mine, 2 miles south of Ouray (quartz, fluorite, pyrite, galena, and sphalerite).

802 Chip sample across iron-copper deposit at Dunmore mine on Silver Creek 1 mile south of Ouray (circular chimney deposit 200 ft in diameter containing hematite, chalcopyrite, quartz, barite, chlorite, and rhodochrosite).

804 Chip sample across tungsten deposit at Dunmore mine (chimney 20 by 50 ft containing huebnerite, galena, sphalerite, and milky quartz).

806 5-ft channel sample across vein at North Star mine, 1,000 ft southeast of Dunmore mine (quartz, pyrite, rhodochrosite, rhodonite, galena, and sphalerite).

807 Grab sample from dump of Chrysolite mine, 1,500 ft east of Dunmore mine (galena, sphalerite, quartz, rhodonite, rhodochrosite, and calcite).

810 Grab sample of galena and sphalerite in quartz gangue from dump of Connie mine, 1,600 ft east of North Star mine.

811 Channel sample across vein at portal of lower adit, Daniel Bonanza mine, on west side of Uncompahgre Canyon, 3,000 ft southwest of Bear Creek falls (galena, sphalerite, pyrite, quartz, rhodonite, and rhodochrosite).

814 2-ft channel sample across vein at Natalie mine, 800 ft northeast of Daniel Bonanza mine (galena and sphalerite in gangue of quartz and rhodochrosite).

------- Lead-zinc ore from Mountain Monarch mine, about 1 mile up Uncompahgre River from U. S. Highway 550. Sample furnished by Sherman Comstock of Golden, Colo.

PARK COUNTY

TARRYALL DISTRICT

The Tarryall district is on the east slope of Mount Silverheels about 5 miles west of Como in the northwest part of Park County. The mines are accessible by roads up Tarryall Creek and its tributaries. Descriptions of the geology and ore deposits are given by Muilenburg (1925), and Singewald (1942). The sedimentary rocks are a series of conglomerates, shales, sandstones, and limestones that range in age from Pennsylvanian to Cretaceous. Monzonite porphyry of Tertiary age occurs as sills, dikes, and small stocks in the sedimentary rocks of Paleozoic age, which are metamorphosed near the intrusive bodies. The ore deposits are chiefly in the contact zones and consist of veins and replacement bodies that formed at relatively high temperature. The deposits have been mined for their gold content but production has been small. Several mines were visited in Australia, Montgomery, and French Gulches; the samples obtained are described in table 75.

TABLE 75.—*Beryllia in samples from the Tarryall district*

Sample	*Description*	BeO (*percent*)
328–603	Grab sample of tactite containing garnet, epidote, and magnetite from dump of Links mine, at head of Australia Gulch 3 miles east of Mount Silverheels	0.001
606	Grab sample of epidote rock containing pyrite, chalcopyrite, and magnetite from dump of Iron mine in small gulch between Little French Gulch and Deadwood Gulch	<.0001
608	Grab sample of garnet-epidote tactite with a little pyrite from altered limestone bed, north side of Little French Gulch, about 1,500 ft west of Iron mine	.0004
611	Grab sample of garnet-epidote tactite containing magnetite and pyrite from dump at abandoned adit half a mile west of junction of north and south forks of Little French Gulch	<.0001
612	5-ft channel sample across lime silicate rock containing phlogopite, near contact of quartz monzonite sill exposed at portal of adit (same locality as for 328–611)	.001
614	Grab sample from dump of abandoned mine at east edge of Johnson village, near head of Montgomery Gulch (garnet, epidote, diopside, quartz, pyrite, and chalcopyrite)	<.0001

PITKIN COUNTY

REDSTONE AREA

A grab sample of coal from the Mesaverde formation of Late Cretaceous age was collected at a mine 4 miles south of Redstone on State Highway 327. The coal ash contained 0.0005 percent beryllium, 0.004 percent gallium, and 0.01 percent vanadium.

SAGUACHE COUNTY

BONANZA DISTRICT

The Bonanza district centers around the mining camp of Bonanza in the northern part of the Cochetopa Hills 15 miles north of Saguache. A basement complex of Precambrian granites, schists, and gneisses contains infolded and infaulted, limestones, sandstones, and shales that range from Ordovician to Permian in age. Several thousand feet of Tertiary rhyolites, andesites, latites, and breccias unconformably overlie the older rocks. Two types of veins are present in the district: quartz veins containing lead, zinc, silver, and gold, and quartz-rhodochrosite-fluorite veins with minor quantities of sulfides, mined primarily for silver. The geology and ore deposits were described by Patton (1916) and Burbank (1932).

A grab sample (328–112) of dump rock was taken at the Eagle mine, 2 miles southeast of Bonanza. The mine is abandoned, and the workings are inaccessible. The most conspicuous gangue minerals on the dump are fluorite, quartz, rhodochrosite, and manganese oxide; the ore minerals are galena, sphalerite, and chalcopyrite. The sample did not contain as much as 0.001 percent BeO.

A chip sample (328–114) was taken across several hundred feet of zunyite-bearing altered volcanic rocks from the north side of Greenback gulch. Analysis of the sample did not show as much as 0.001 percent BeO.

SAN JUAN COUNTY

EUREKA-ANIMAS FORKS DISTRICT

The Eureka-Animas Forks district as here defined includes Mastadon, California, and Eureka Gulches and the area about the townsites of Eureka and Animas Forks. The geology and mineral deposits have been described by Ransome (1901b, p. 174–184), and Burbank (*in* Vanderwilt, 1947, p. 433–435). The rocks exposed in this area are part of the Silverton volcanic series with the exception of a few small intrusive bodies of Tertiary rhyolite and latite. Rhodonite, quartz, and base-metal sulfides occur in veins along strong northeast-trending faults. Helvite was reported from the Sunnyside mine near Eureka by Burbank (1933a). Eight mines in the district were examined and sampled.

Helvite was not noted except at the Sunnyside mine and the quantity there apparently is minute. Descriptions of the samples and analytical results are given in table 76.

TABLE 76.—*eryllia in samples from the Eureka-Animas Forks district*

Sample	*Description*	BeO *(percent)*
328–142	Composite grab sample from dump of Sunnyside mine (rhodonite, rhodochrosite, galena, sphalerite, and fluorite)	<0.001
144	Channel sample across 5 ft of rhodonite in vein on main adit level at Sunnyside mine 200 ft in from portal	.0014
145	Channel sample across 2 ft of rhodonite in vein on main adit level at Sunnyside mine, 250 ft in from portal	.0002
830	Grab sample of rhodonite and sulfide ore from dump of Sound Democrat mine near head of Mastadon Gulch. 1 mile west of Animas Forks	.0021
831	Channel sample across 5-ft rhodonite zone in vein at Silver Queen mine, 500 ft west of Sound Democrat mine	<.0001
832	Chip sample across 6-ft rhodonite zone in vein at Golden Prince mine a few hundred feet west of Silver Queen mine	.0002
834	Chip sample across 2-ft rhodonite vein at Neptune mine, near abandoned mill at head of Mastadon Gulch	.0015
838	Grab sample from dump of Mountain Queen mine, in California Gulch 2 miles west of Animas Forks (chalcopyrite, galena, sphalerite, quartz, fluorite, and rhodonite)	<.0001
840	Grab sample of rhodonite and sulfide ore from dump of Vermillion mine, north side of California Gulch 1 mile west of Animas Forks	<.0001
841	Grab sample of sulfide ore from dump of Columbus mine at west edge of Animas Forks	<.0001

MINERAL POINT AND POUGHKEEPSIE GULCH DISTRICTS

The Mineral Point and Poughkeepsie Gulch districts (Ransome, 1901b, p. 185–189; Kelley, 1946; Hazen, 1949) adjoin one another in the northern part of San Juan County at the headwaters of the Animas and Uncompahgre Rivers. The predominant rocks exposed in the area are latite and rhyolitic flows, tuffs, and breccias of the Silverton volcanic series of Tertiary age. In Poughkeepsie Gulch the Silverton series is underlain by the San Juan tuff, also of Tertiary age. Kelley (1946, p. 289) describes the ore deposits as fissure and cavity fillings, breccia-chimney and breccia-dike deposits, and replacement deposits. Most of the productive veins in the area are in the Silverton series. Gold, silver, lead, zinc, and copper are the principal metals produced. Samples from the dumps of 10 mines in the area are described in the following list:

328–815 Grab sample containing rhodonite, quartz, galena, and sphalerite from dump of Bill Young mine, 200 ft south of Miners Creek at Mineral Point.

817 Grab sample of sulfide ore in quartz gangue, with minor quantity of rhodochrosite from dump of Uncompahgre Chief mine, about 1,000 ft southeast of Bill Young mine.

819 Grab sample of quartz-rhodonite gangue containing galena, sphalerite, and pyrite from dump of Red Cloud mine, half a mile southeast of Bill Young mine.

821 Grab sample from dump of Eurades mine, 5 miles from U. S. Highway 550 on road to Mineral Point (pyrite, galena, sphalerite, and minor tetrahedrite in quartz gangue).

822 Grab sample of quartz and sulfides from dump of Old Lout tunnel at end of road up Poughkeepsie Gulch.

824 Grab sample of sulfide ore in rhodonite-rhodochrosite-quartz gangue from dump of Alaska mine, near head of Poughkeepsie Gulch.

826 Grab sample from dump of Picket mine, north of Lake Como at head of Poughkeepsie Gulch (quartz, pyrite, and barite, with minor quantities of galena and sphalerite).

827 Grab sample of quartz and sulfides with some rhodonite and rhodochrosite from dump of Amador mine, 3,000 ft northeast of Alaska mine.

828 Grab sample from dump of Poughkeepsie mine, 1.5 miles from end of road up Poughkeepsie Gulch (galena, sphalerite, tetrahedrite, chalcopyrite, quartz, rhodonite, and rhodochrosite).

829 Grab sample from dump of Alabama mine, 3,000 ft north of Poughkeepsie mine (galena, sphalerite, pyrite, chalcopyrite, barite, and quartz).

Beryllium was detected in only one of the samples (328–815), which contained 0.0016 percent BeO; the limit of detection was 0.0001 percent BeO.

SILVERTON DISTRICT

The Silverton district centers around the town of Silverton in the central part of San Juan County. The geology and mineral deposits of the district have been described by Burbank (1933b), Cross, Howe, and Ransome (1905), and Ransome (1901b). The Tertiary Silverton volcanic series, consisting of andesite, latite, and rhyolite flows and breccias, cover much of the area. In the deep valley south of Silverton, Precambrian schist is exposed below the volcanic rocks. Several quartz monzonite bodies intrude the Tertiary volcanic rocks. Samples collected from the contact zones on Sultan Mountain, and from 4 mills and 3 mines in the Silverton district are described in the following list. Beryllium was not detected in spectrographic analyses of the samples, the limit of detection being 0.0001 percent BeO.

328–151 Grab sample of silicified porphyry containing zunyite from dump of Zuni mine, west side of Anvil Mountain.

154 Grab sample of garnet-epidote tactite in Hermosa formation, northeast side of Sultan Mountain.

835 Mill heads from Lead Carbonate mill at Gladstone, 7 miles north of Silverton.

844 Mill heads from custom mill at Howardsville.

847 4-ft channel sample across vein in upper adit of Adams mine, 1 mile southwest of Gladstone (huebnerite, pyrite, arsenopyrite, calcite, fluorite, and milky quartz).

851 Mill heads from Shenandoah-Dives mill, 2 miles east of Silverton.
854 Mill heads from Highland Mary mill, 4 miles south of Howardsville.
857 Grab sample from dump of Mighty Monarch mine, south side of Kendall Mountain at Silverton (galena, sphalerite, pyrite, huebnerite, and quartz).

SAN MIGUEL COUNTY

OPHIR DISTRICT

A brief visit was made in August 1949 to the Ophir mining district in southeastern San Miguel County to obtain samples of mill products from the Silver Bell Mines, Inc., mill at Ophir Loop. Ore from the Silver Bell mine was being processed to obtain a bulk sulfide concentrate of galena, pyrite, sphalerite, and chalcopyrite. A grab sample (328–868) of mill heads did not contain as much as 0.0001 percent BeO.

SUMMIT COUNTY

BRECKENRIDGE DISTRICT

The Breckenridge district is near the headwaters of the Blue River, about 60 miles west of Denver. Comprehensive reports on the geology of the district were given by Ransome (1911), Lovering (1934), and Lovering and Goddard (1950, p. 102–122). Precambrian gneiss, schist, and granite are exposed in two small areas to the west and north of Breckenridge. Sedimentary rocks including Pennsylvanian to Cretaceous formations cover most of the district. Tertiary monzonite and quartz-monzonite porphyries intrude the sedimentary rocks. Veins along small faults have been mined for lead, zinc, silver, and gold. Small contact-metamorphic deposits have been worked for copper and gold.

A tactite zone in the Morrison formation (Jurassic) is exposed for about 1,000 feet on the north side of French Gulch, 1 mile east of Breckenridge. Lenses and bands of magnetite are interlayered with garnet-epidote tactite. The layers range from less than an inch to several feet in thickness. Two samples of tactite (328–099 and –101) were taken from a cliff exposure at the eastern end of the zone, near a bend in the road about 1,500 feet southwest of the Wellington mill. A third sample (328–109) was taken near the western end of the zone, a few hundred feet west of where it crosses Gibson Gulch. None of the samples contained as much as 0.0001 percent BeO.

MONTEZUMA DISTRICT

The Montezuma district is at the headwaters of the Snake River, about 40 miles west of Denver. The geology and ore deposits were described by Patton (1909), Lovering (1935), and Lovering and Goddard (1950, p. 122–134). Precambrian granites, gneisses, and schists are exposed over most of the Montezuma quadrangle, but sedimentary rocks of Mesozoic age are exposed in the southwestern corner. Tertiary stocks, dikes, and sills intrude the older rocks and occur in a belt that extends from the southwest part to the northeast part of the quadrangle. The chief ore deposits are in mesothermal veins, which have been mined profitably for lead, zinc, and silver. Only the lead-zinc-silver veins at the Silver Wing mine and Burke Tunnel and the contact zones near Tiger were investigated.

The Silver Wing mine, owned by T. E. Martin of Montezuma, is on the east side of Glacier Mountain, about 1 mile south of town. The mine workings are driven southwesterly along a quartz vein that dips 50° NW. Galena, sphalerite, pyrite, barite, and manganosiderite are the principal vein minerals. The country rock is Swandyke hornblende gneiss of Precambrian age. A grab sample (328–728) of vein material did not contain as much as 0.0001 percent BeO.

The Burke Tunnel is 1½ miles south of the Silver Wing mine. The tunnel has been driven northwesterly under Glacier Mountain for the purpose of intercepting known veins at depth. Several quartz veins containing galena, sphalerite, pyrite, and barite have been cut. A sample (328–729) of ore from one of the veins did not show as much as 0.0001 percent BeO.

One mile south of Tiger between Brown and Summit Gulch, the Pierre shale (Cretaceous) has been replaced by garnet, epidote, actinolite, pyrite, and magnetite near the contact of a Tertiary quartz monzonite stock. A grab sample (328–721) of the tactite from the dumps of the Cashier mine and a chip-channel sample (328–722) across a 6-foot-wide tactite zone near the portal of the Cashier mine did not contain as much as 0.0001 percent BeO.

UPPER BLUE RIVER DISTRICT

The Upper Blue River district, about 5 miles south of Breckenridge, is bounded on the east and south by the Park Range, on the west by the Tenmile Range, and on the north by the Breckenridge mining district. The geology of this district has been described briefly by Singewald (*in* Vanderwilt, 1947, p. 343–346 and 1951, p. 1–73). The sedimentary rocks include dolomite, shale, quartzite, and limestone of Cambrian to Mississippian age, which crop out on the east flank of the Tenmile Range. The core of the range consists of Precambrian granite, gneiss, and schist. Tertiary porphyries occur as dikes and sills in the older rocks. The ore bodies generally are localized along faults; they are veins and replacement deposits containing gold, silver, lead, zinc, copper, tungsten, and molybdenum. A contact-metamorphic deposit at the Vanderbilt mine and veins at the Governor mine were sampled.

The Vanderbilt mine is 10 miles south of Breckenridge on State Highway 9. The mine is principally a gold producer, although ore from the dump contains small quantities of galena and sphalerite in a gangue of silicified limestone, diopside, pyrite, specularite, and some quartz. Analysis of a grab sample (328–724) from the dump did not show as much as 0.0001 percent BeO.

The Governor mine is 6 miles south of Breckenridge near State Highway 9. Silver has been produced from a quartz vein in Pennsylvanian and Permian strata. A grab sample (328–727) from a dump, consisting of galena, sphalerite, pyrite, molybdenite, and quartz, did not contain as much as 0.0001 percent BeO.

TELLER COUNTY

CRIPPLE CREEK DISTRICT

Six samples of mill products were obtained from the Golden Cycle mill at Colorado Springs in 1942 for the Mine, Mill, and Smelter Survey. Virtually all of the ore represented by these samples was from mines in the Cripple Creek district, a detailed description of which was given by Loughlin and Koschmann (1935). The sampling data are shown in table 77. No samples from the Cripple Creek district were analyzed for this investigation.

TABLE 77.—*Beryllia in samples from the Golden Cycle mill*

Sample	*Description*	BeO (*percent*)
5–GC–1	Gold concentrates	0.005
2	Mill heads, gold ore	.005
3	Roaster dust, gold refinery	Not found
4	Flue dust, gold refinery	.01
5	Refinery byproduct (easily removed gold has been extracted)	.001
6	Refinery slag (from roaster)	.002

CENTRAL UNITED STATES

By L. A. WARNER and V. R. WILMARTH

Several areas in the central United States were examined during November 1948 (fig. 57). Samples of feldspathoidal igneous rocks were taken at several places in central Arkansas. Spectrographic analyses indicate that beryllium is present in relatively high concentrations in some of the rocks at Magnet Cove, Ark., but the volume of these rocks is probably not large and the beryllium may not be recoverable. Many of the ore deposits in the Tri-State lead-zinc district were sampled, but no beryllium was found in any of them.

FIGURE 57.—Index map showing localities sampled in the Central United States.

ARKANSAS

MAGNET COVE

The igneous complex at Magnet Cove (fig. 58) is a composite intrusive body about 3 miles in diameter. In cross section it is saucer-shaped, with the more resistant rocks forming a rim that surrounds the less resistant central part. The geology has been described by Halton (1929), Landes (1931), Spencer (1946), Washington (1900), and Williams (1891, p. 163–343). Sedimentary rocks of Devonian and Mississippian age surround the complex and form irregular inclusions within it. Landes (1931, p. 322) has divided the igneous rocks into three types: (1) the cove intrusives consisting of ijolite and biotite-ijolite, (2) the ridge intrusives consisting of foyaite, shonkinite, and leucite porphyry, and (3) the dike rocks which include pegmatites, tinguaites, monchiquites, and fine-grained porphyries. Jacupirangite is considered as part of the cove intrusive.

A detailed study was made of the area near Cove Creek bridge (fig. 59). Marble containing coarse calcite, monticellite, magnetite, wollastonite, rutile, sphene, idocrase, and pyrite is exposed in a quarry northwest of the bridge. The limestone has been intruded by a

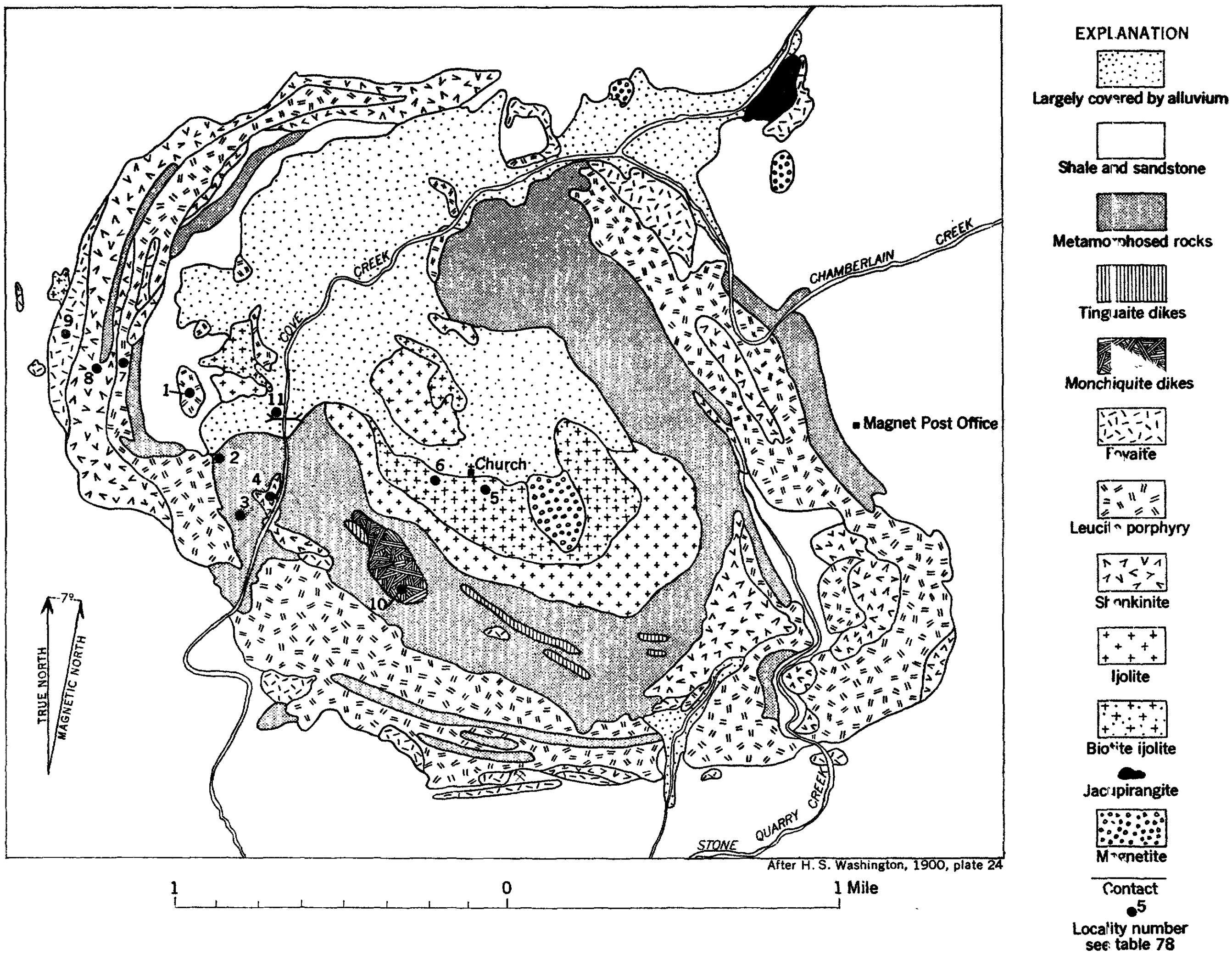


FIGURE 58.—Geologic map of Magnet Cove, Ark., showing localities sampled.

leucite-syenite dike and a nepheline-eudialyte pegmatite. The leucite-syenite dike averages 10 feet in width and extends from Cove Creek northwest to the north side of the quarry where it is covered by dump material. The 14-foot-wide nepheline-eudialyte pegamatite is best exposed in the road cut just west of the bridge. Small crystals of eudialyte were noted in the pegmatite. Tufa Hill, a large deposit of siliceous sinter, is about 200 feet north of the road. A small body of ijolite is exposed on the east side of the hill. Contacts in this area are covered.

Five samples were collected near Cove Creek bridge. Elsewhere in the Magnet Cove area, samples of nearly all igneous rock types were obtained. The samples are described in table 78; sampling localities are shown on figures 58 and 59.

The only samples that contain appreciable quantities of beryllium are 329–293, of altered marble from the road cut west of Cove Creek bridge and 328–313, of altered biotite ijolite from the stream bed in front of the Baptist church, east of Cove Creek bridge. The nature of the beryllium-bearing material in the samples has not been determined. Thus far no beryllium min-

TABLE 78.—*Beryllia in samples from Magnet Cove, Ark.*

Locality No. on fig. 58	Sample[1]	Rock type	BeO (percent)
1	328–305	Leucite porphyry	0.0002
2	307	Leucite tinguaite dike	.0005
3	309	Nepheline syenite porphyry dike	.002
4	318	Shonkinite	.002
5	312	Biotite ijolite	.0003
6	313	Altered biotite ijolite	.007
7	315	Leucite porphyry	.0001
8	317	Shonkinite	.001
9	319	Foyaite	.001
10	320	Monchiquite	.001
	328–293	Silicated marble	.028
	294	Nepheline eudialyte pegmatite	.002
	299	Marmorized limestone	.002
	300	Silicated marble	.001
	303	Siliceous sinter	.003

[1] Localities of samples 328–293 to –303 are shown on figure 59.

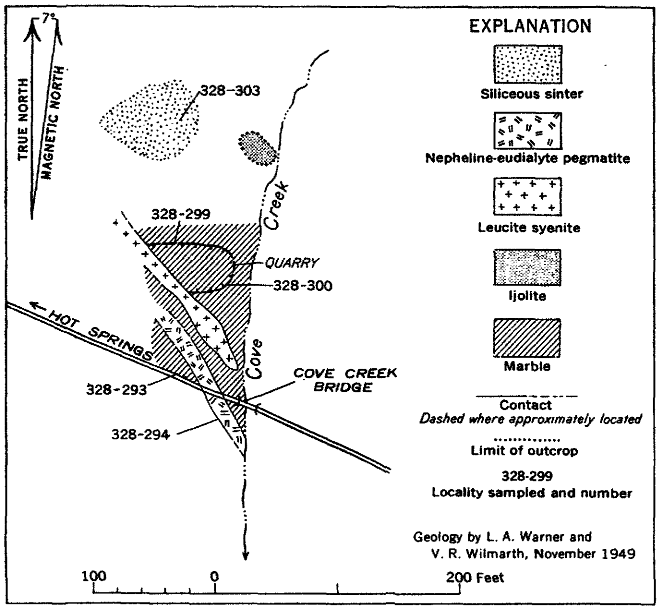


FIGURE 59.—Geologic sketch map of area in vicinity of Cove Creek bridge, Magnet Cove, Ark.

erals have been reported from Magnet Cove, and it seems probable that the beryllium occurs as an accessory constituent in other minerals.

LITTLE ROCK AREA

An intrusive mass composed chiefly of pulaskite, shonkinite, and foyaite is exposed about 3 miles south of Little Rock on U. S. Highway 167. A grab sample (328–323) of pulaskite from the Big Rock quarry did not contain as much as 0.001 percent BeO.

BRYANT AND BAUXITE AREAS

By W. T. HOLSER

In eastern Saline County, near Bryant and Bauxite, several masses of nepheline syenite intrude folded sedimentary rocks of Paleozoic age. The syenite is the source of large bauxite deposits.

Tinguaite dikes cut the nepheline syenite in NE¼ sec. 2, T. 2 S., R. 14 W., southwest of Bryant (Hildebrand, 1949). The dikes are in four zones that are traceable for 2,000 feet in a northeasterly direction. They contain aegirite, nephelite, sodalite, and alkali feldspars; some show orbicular structures.

Three samples (329–842, –843, –844) collected by F. A. Hildebrand of the U. S. Geological Survey were analyzed spectrographically for beryllium. Sample 329–842, from the centers of the orbicles, and sample 329–843, from the matrix of the orbicles, contained 0.002 percent BeO. Sample 329–844, a composite of 12 samples of the dike rock, contained 0.000X percent BeO.

TRI-STATE LEAD-ZINC DISTRICT

In 1942, the U. S. Geological Survey sampled 42 mines and mills in the Tri-State lead-zinc district. The analytical results of this sampling appeared to indicate that beryllium is concentrated in the lead-zinc ores of this district. The BeO content of the samples was as high as 0.3 percent by weight. In 1948 Warner and Wilmarth spent 2 weeks in the Tri-State district sampling mines and mills, in an effort to determine the mode of the beryllium occurrence and its distribution in the lead-zinc ores. Many of the localities previously sampled were revisited and duplicate materials obtained. Spectrographic analyses of 23 representative samples from the district showed no beryllium, the lower limit of detection being 0.001 percent BeO; and several reanalyses proved the accuracy of these results. The samples that were analyzed are listed below.

328–257	Grab sample mill heads, Rialto mill, Treece, Kans.
261	Grab sample of stope fill, Peck and Gregory mine, Commerce, Okla.
264	Dump rock from Bonnet mine, Hockersville, Okla.
267	Dump rock from Roanoke mine, Baxter Springs, Kans.
268	Dump rock from E. L. Bullard mine, Galena, Mo.
281	Ore from Little Ben mine, Waco, Mo.
283	Ore from Richie mine, Waco, Mo.
285	Ore from Crutchfield property, Carl Junction, Mo.
324	Ore from Trilby mine, Granby, Mo.
325	Mill tailings from Federal mill, Granby, Mo.
326	Ore from Dungy mine, Stark City, Mo.
327	Do.
328	Ore from Pioneer mine, Stark City, Mo.
330	Ore from Bluebird mine, Spurgeon, Mo.
334	Ore from Olsen mine, Spring City, Mo.
339	Ore from Mutual mine, Oronogo, Mo.
340	Ore from Wingfield mine, Oronogo, Mo.
343	Ore from Federal-Duenweg mill, Duenweg, Mo.
345	Ore and gangue from Katy C mine, Carterville, Mo.
347	Ore from Buckingham mine, Carterville, Mo.
351	Ore from mine 750 ft south of Capital mill, Stotts City, Mo.
354	Ore from Craig-Owens No. 1 mine, Wentworth, Mo.
355	Mill tailings from Sciota mill, Webb City, Mo.

EASTERN UNITED STATES

By W. T. HOLSER

Information on nonpegmatite beryllium was obtained for six localities in Maine, New Hampshire, New Jersey, and Virginia (fig. 60). These are mainly localities from which beryllium-bearing minerals had been reported previously. Deposits relatively rich in beryllium occur at Iron Mountain, N. H., and along Irish Creek, Va., but the reserves may be small. Further sampling is needed in these areas to appraise the commercial possibilities. Beryllium occurs in willemite and other minerals at Franklin, N. J. The

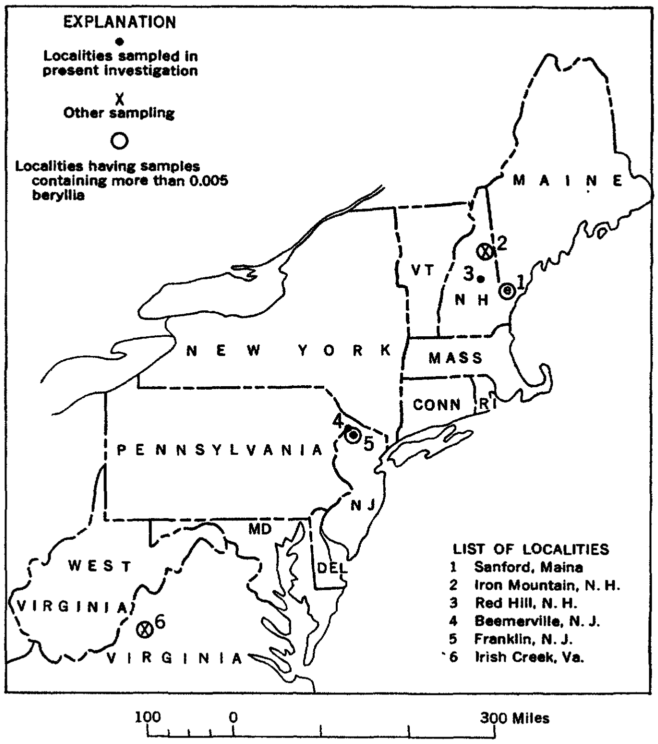


FIGURE 60.—Index map showing nonpegmatite beryllium occurrences investigated in the Eastern United States.

tonnage is large but the grade is low, and much of the beryllium may not be recoverable.

SANFORD, YORK COUNTY, MAINE

Beryllian idocrase occurs at Sanford, Maine, as dark greenish-brown prismatic crystals as much as 2 cm thick and 6 cm long, with pinacoidal terminations. The prisms are deeply striated and the crystals have a parting parallel to the faces, seeming to follow growth zones. The crystals grew at random or in radial clusters in openings that were later filled with quartz and calcite. The idocrase-bearing rock overlies an epidote-rich tactite. The geology of the deposit has not been described. According to the geologic map of Katz (1917, pl. 61), the locality is near the contact of the Rindgemere formation of Pennsylvanian(?) age and the Biddeford granite, which is thought to be related to the White Mountain magma series of Billings (1934).

The locality was not visited during the present investigation but a specimen from the Cornell University mineralogical collection (CUM 393-26) was spectrographed by A. A. Chodos and found to contain 0.009 percent BeO. Earlier spectrographic determinations on idocrase from Sanford by George Steiger (1931, written communication) indicated a trace of BeO in one sample and none in another. Probably the BeO content of the idocrase is irregular but the quantity in the Cornell specimen is considerably above the average for analyzed specimens of this mineral. Although it is doubtful that the idocrase is of commercial value, other beryllium-bearing minerals commonly occur with beryllian idocrase and further investigation of the deposit may thus be warranted.

CARROLL COUNTY, NEW HAMPSHIRE

IRON MOUNTAIN

Helvite-group minerals were reported by Wadsworth (1880) from an iron ore prospect near Bartlett, N. H. The locality is on the south slope of Iron Mountain at an altitude of about 2,000 feet. A road leading to the mountain turns west from State Highway 16 at Jackson. The deposit was not visited during the present study, but samples and geological data were furnished by D. M. Henderson of the University of Illinois. The following description was taken largely from his notes.

The Iron Mountain deposit is in the Conway granite, of Mississippian(?) age, near its contact with gneisses of the Littleton formation of Early Devonian age. The mine workings consist of a 45-foot adit and a small opencut. The ore body is very irregular but its elongation is approximately parallel to a northwest-trending joint set that may have partly controlled the deposition. In the opencut, the body is about 20 feet wide and 50 feet long.

Magnetite and hematite are the chief ore minerals and appear to have formed by replacement of granite. Quartz is abundant in small irregular aggregates and veinlets and in vuggy lenses as much as 3 feet across. Irregular streaks and veinlets containing galena, chalcopyrite, fluorite, and quartz are common in the iron ore.

Danalite occurs in irregular aggregates in the ore, much of it as apparent reaction rims around quartz. Well-formed octahedral crystals occur in a few places. Most of the crystals are 2 or 3 mm across and are zoned, consisting of a yellow core and a red-brown rim. Refractive indices (Glass, Jahns, and Stevens, 1944, p. 183-185) indicate that the yellow material is probably helvite and the red material danalite.

Descriptions and analyses of Henderson's samples are given in table 79. The analyses indicate that the beryllium content of the deposit is probably high and that the granite is relatively rich in niobium. Because of its small size, the deposit is not likely to be of commercial interest unless further prospecting in the region adds to the reserves.

TABLE 79.—*Beryllia and niobium in samples from Iron Mountain, N. H.*

[Quantitative spectrographic analyses by K. J. Murata]

Sample	Description	BeO (percent)	Nb (percent)
329–850c	Composite of 2 samples from inside of adit, and 1 from 30 ft south of the portal, all in fresh biotite granite	0.0017	0.02
852c	Composite of 2 samples from the contacts of the zone of iron mineralization	1.0	.02
853c	Composite of chips taken at intervals of 1 to 2 ft across the zone of iron mineralization	1.6	<.01

RED HILL

Red Hill is an alkalic ring complex 3 miles in diameter, just west of State Highway 25 at the north end of Lake Winnipesaukee. As described by Quinn (1937, 1944) the rocks are all syenites, of coarser grain toward the outside. Principal minerals are microperthite and hastingsite, with some biotite. An inner ring about half a mile wide contains as much as 30 percent nepheline and sodalite; some of the rocks in the center of the complex contain quartz. The rocks of Red Hill intrude the Winnipesaukee quartz diorite of Precambrian(?) to Carboniferous age, but the contacts are nowhere exposed.

Specimens of the Red Hill rocks were collected in May 1950, in the course of other geologic work. Sample 329–812 from a pit known as the "Horne quarry," in the inner ring contained only 0.000X percent Be (spectrographic analysis by A. A. Chodos). The rock is coarse-grained syenite composed of abundant early nepheline, albitized microperthite, and hastingsite, with streaks and veinlets of later sodalite (Quinn, 1937, p. 384–387). Wohlerite ($NaCa_2(Zr,Nb)FSi_2O_8$) is sparingly present (Pirsson and Washington, 1907, p. 270–271). Sample 329–813 was of coarser grained hornblende syenite without nepheline and is probably equivalent to Quinn's "outer coarse syenite" (Quinn, 1937, p. 383–385; chemical analysis on p. 380). Spectrographic analysis did not detect any beryllium in the sample, the limit of sensitivity being 0.000X Be.

SUSSEX COUNTY, NEW JERSEY

BEEMERVILLE AREA

Feldspathoidal rocks are common around the village of Beemerville, south of State Highway 23 and west of Sussex, N. J. The geology of the area was described by Aurousseau and Washington (1922), Milton [12], Wilkerson (1946), and Davidson.[13] Recently the commercial uses of these rocks were appraised by Parker (1948, p. 52–57) and Wilkerson and Comeforo (1946). The main intrusive body extends 2 miles along the eastern face of Kittatinny Mountain, where it apparently was intruded as a thick sill-like mass between the Martinsburg shale of Ordovician age and the Shawangunk conglomerate of Silurian age. Most of this body is a granular syenite composed of nepheline, orthoclase, and aegerite-augite, with minor amounts of biotite, sphene, magnetite, sodalite, garnet, apatite, and fluorite. At least 25 sills and dikes intrude the Martinsburg shale and the Precambrian formations within a few miles of Beemerville. They have been classified as nepheline syenite (tinguaite and bostonite), lamprophyre (minette or camptonite), and diabase.

Samples were obtained from the main mass and several of the smaller bodies on June 13, 1950. Through the courtesy of J. H. C. Martens of the New Jersey Bureau of Mineral Research, samples from the bureau's collections also were made available for analysis. The analyzed samples are described in table 80.

TABLE 80.—*Beryllium in samples from the Beemerville area, New Jersey*

[Spectrographic analyses by A. A. Chodos except No. –828]

Sample	Location [1]	Description	BeO (percent)
329–826	2084.8 N., 845.7 E.; Parker 102; Wilkerson 12.	Specimen of bostonite dike or sill.	0.00X
827	2083.2 N., 841.5 E.; Parker 103; Wilkerson 15.	Specimen of porphyritic nepheline syenite from dike.	.00X
828	2090.3 N., 844.5 E.; Parker 99; Davidson 38.	Sample of nepheline syenite from main mass.[2]	[3].00[illegible]
829	2090.6 N., 844.9 E.; Parker 99; Davidson 46.	Sample of biotite-rich nepheline syenite from main mass.	.00[illegible]X
830	2089 N., 849.7 E.; Parker 100; Wilkerson 1; Milton and Davidson.	Composite of three specimens of nepheline syenite from sill.[4]	.00[illegible]X

[1] Location according to U. S. 1,000-yd grid system, as shown on Branchville quadrangle, 1:31,680, U. S. Army Corps of Engineers, 1943. Localities also as numbered by Parker (1948, pl.1); Wilkerson (1952, fig. 1); Davidson (Davidson, E. S., 1948, The geological relationships and petrography of a nepheline syenite near Beemerville, Sussex County, N. J.: Rutgers Univ. M. Sc. thesis); and Milton and Davidson (1950).

[2] Mode is given by Davidson (idem.), in percent: nepheline 43, potassium-feldspar 37, aegirite-augite 11, biotite 2, sphene 3, magnetite and pyrite 3.

[3] Analyzed by J. K. Murata for BeO, in percent.

[4] Average of 3 modes by Wilkerson, in percent (personal communication from J. H. C. Martens, 1950): nepheline 45, potassium-feldspar 34, aegirite-augite 18, sphene 2, and magnetite 1.

FRANKLIN DISTRICT

The Franklin district, one of the largest producers of zinc ore in the United States, is between Franklin and Ogdensburg on the western edge of the Precambrian New Jersey Highlands. In June 1950, the district was visited and samples were obtained through the courtesy of the New Jersey Zinc Co. and with the cooperation of D. W. Jenkins and L. H. Bauer of the chemical de-

[12] Milton, Charles, 1929, Nepheline syenite and related rocks of the Franklin Furnace quadrangle, New Jersey: Johns Hopkins Univ. Ph. D. thesis.

[13] Davidson, E. S., 1948, The Geological relationships and petrography of a nepheline syenite near Beemerville, Sussex County, N. J.: Rutgers Univ. M. Sc. thesis.

partment, and A. W. Pinger and E. N. Newcomb of the geological department. Analytical geological data on the occurrence of beryllium in the district were also made available by the company.

The geology, mineralogy, and ore deposits of the Franklin district have been described in roughly 300 reports; among the more recent are those by Kerr (1933), Palache (1935), and Pinger (1948). The district is almost entirely within the Franklin limestone of Precambrian age, which was metamorphosed to a white, coarse, calcitic marble and squeezed into sharp northward-plunging folds. At the north end of the district the Precambrian formations are unconformably overlain by limestone and quartzite of Paleozoic age.

The two producing mines of the district are the Franklin mine at Franklin and the Sterling Hill mine at Ogdensburg. At both mines zinc ore occurs in tabular masses that are conformable to synclines in the Franklin limestone. The composition of the ore is approximately 40 percent franklinite, 25 percent gangue carbonates, 23 percent willemite, 11 percent gangue silicates, and 1 percent zincite. The distribution of the ore minerals is remarkably uniform throughout the ore bodies; the distribution of gangue silicates is less uniform. Pyroxene is fairly common at both mines; garnet and rhodonite are common at Franklin and rare at Sterling where tephroite is more widespread.

Granite pegmatite occurs at Franklin but has not been identified at Sterling Hill. Some of the pegmatite apparently is earlier than the ore and some later. The pegmatite is pink to gray and composed of quartz, orthoclase, microcline, albite, and micoperthite, with some hornblende, pyroxene, epidote and sphene. Complex tactite deposits containing rhodonite, hardystonite, manganoan-zincian pyroxenes, garnet, mica, and rare silicates appear to be localized at places where ore is associated with pegmatite.

Palache and Bauer (1930) described barylite and beryllian idocrase from Franklin, and chemists of the New Jersey Zinc Co. have found traces of beryllium in other minerals. In the present investigation, an attempt was made to determine the distribution of beryllium in the ore. Analytical data for the mill products are shown in table 81. A magnet and heavy liquids were used to prepare mineral separates from the ore and mill products. The BeO contents of these samples, together with results of other workers, are given in table 82. The analyses indicate that the ore from Franklin is higher in beryllium content than that of Sterling Hill. Most of the beryllium is in the willemite concentrate and probably is contained in willemite. The average grade of the concentrate appears to be much too low for it to have been as a probable source of beryllium. The other beryllium-bearing minerals at Franklin are present only in small quantities.

TABLE 81.—*Beryllia in mill products from the Franklin district* [1]

	Franklin mine		*Sterling Hill mine*	
Material	*Sample*	*BeO (percent)*	*Sample*	*BeO (percent)*
Crude ore	329–832	0. 003	329–837	0. 001
Franklinite concentrate	833	<. 0004	838	. 001
	------	(. 005)	839	. 002
Willemite-franklinite product	836	. 001	------	-------
	------	(. 0008)	------	-------
Willemite concentrate	834	. 003	840	. 0005
	------	(. 025–0. 03)	------	(. 0075)
Tailings	------	. 0006	841	. 0004
	835	(. 001–0. 0015)	------	(. 0006)

[1] Numbered analyses made by A. A. Chodos of composite samples for the period 1940–44, submitted by the New Jersey Zinc Co. Unnumbered analyses (in parentheses) made by New Jersey Zinc Co. in 1944 (Laboratory Report 160) of composites of similar products from a single month in 1941.

Barylite, a rare beryllium barium silicate, that contains as much as 15.77 percent BeO is known only on the 400-foot level of the Franklin mine (Palache and Bauer, 1930, p. 32). Small white plates of barylite embedded in hedyphane (a calcium-lead-chloro-arsenate) occur in a layered vein. The succession of layers from vein wall inward are: brown calcite and native copper; gray calcite; a thin zone of willemite and serpentine; white calcite; and barylite, hedyphane, and willemite.

There are two types of beryllium-bearing idocrase at the Franklin mine. That containing the most beryllium "occurs in the form of slender brown prisms embedded in a coarsely crystalline mixture of green willemite, brown garnet, leucophoenicite, and barite with subordinate amounts of svabite, native copper, and gageite" (Palache and Bauer, 1930, p. 30). Analyses by F. A. Gonyer of two specimens of brown idocrase from the mine showed 1.56 and 3.95 percent BeO (Table 85). A blue to blue-green idocrase, known as "cyprine," contains from 1 to 2 percent copper and as much as 0.11 percent BeO. As described by Palache (1935, p. 95), it occurs for the most part as fibrous crystals associated with garnet, calcite, willemite, biotite, bustamite, and native copper in granular tactite. A large pocket of this variety of idocrase was found in 1920 on the 850-foot level of the Franklin mine, but on the whole it is rare. Both idocrase and calcite replace coarse calcite (Ries and Bowen, 1922, p. 561). In discussing the idocrase at the Franklin mine, Palache (1935, p. 95) states, "It now appears certain that the beryllium is not genetically associated with the primary willemite ore, but is a postore element introduced into the deposit from intrusive pegmatites." While it is probably true that the beryllium-bearing idocrase is a postore mineral, whose

TABLE 82.—*Beryllia in minerals from the Franklin district*

Species	Location [1]	Sample [2]	BeO (percent)	Analyst and reference	Remarks
Franklinite	F	329–833A	<0. 0004	A. A. Chodos	No visible impurities.
	SH	838A	<. 0004	do	Do.
Willemite	F	834A	. 004	do	One percent garnet and dark inclusions.
	SH	840A	. 005	do	One percent impurities, including cloudy altered products.
Zincite	F	834B	<. 0004	do	One percent impurities, including dark inclusions.
Rhodonite	F	CUM–335–2	. 002	do	One percent impurities.
	F		. 00X	Goldschmidt and Peters, 1932, p. 368.	
Tephroite	F	CUM–379–1	<. 0004	A. A. Chodos	No impurities except cloudy altered products.
Garnet	F	329–815A	<. 0004	do	Two percent anisotropic inclusions.
Pyroxene	F	819B	. 01	do	One percent inclusions and alteration products.
Calcite	F		<. 001	Goldschmidt and Peters, 1932, p. 368.	
Sphalerite	SH	CUM–58–42	<. 0004	A. A. Chodos	No visible impurities.
Svabite	F	329–817A	<. 0004	do	One percent inclusions and alteration products; trace of garnet.
		818A	. 001	do	Three percent inclusions and alteration products.
		819A	<. 0004	do	One percent inclusions and alteration products.
Apatite	F	CUM–549–114	<. 0004	do	Three percent inclusions and alteration products.
Idocrase	F		1. 56	F. A. Gonyer (C. S. Hurlbut, Jr., written communication, 1951).	Brown variety.
			3. 95	do	Do.
			. 04	A. A. Chodos	Blue variety (cyprine); 1 percent garnet.
			. 11	Sandell, 1940a, p. 675	Do.
Barylite	F		15. 77	Bauer (Palache and Bauer, 1930, p. 32).	

[1] F, Franklin mine; SH, Sterling Hill mine.
[2] Separates from samples of corresponding number in table 81.

presence depends on the proximity of pegmatite and ore, the source of the beryllium is not known. No beryl has been noted in the pegmatites at Franklin.

A specimen of pyroxene from the 1,050-foot level of the Franklin mine was found to contain 0.01 percent BeO. The pyroxene, tentatively identified as zincian-manganoan diopside, occurs in a coarse-grained aggregate of willemite, svabite, and leucophoenicite. Minor quantities of beryllium are contained in rhodonite and svabite.

IRISH CREEK DISTRICT, ROCKBRIDGE COUNTY, VA.

The tin-beryllium-bearing quartz veins of the Irish Creek district, Virginia, were described by Koschmann, Glass, and Vhay (1942). The locality was not visited during the present investigation. The country rock of the district is Precambrian and consists of gneiss and granodiorite with small dikes of aplite and basic rock. The known quartz veins are restricted to the granodiorite and are as much as 9 feet wide, though commonly less than a foot wide. Bordering the veins on one or both sides are greisen layers as much as 5 feet thick. Four periods of mineral deposition with intervening periods of fracturing are recognized. Quartz was deposited during the first stage; cassiterite, muscovite, beryl, and wolframite during the second stage; muscovite, siderite, ankerite, fluorite, biotite, phenakite, and chlorite during the third stage; and nontronite, vermiculite, hematite, montmorillonite, clinozosite, and calcite during the fourth stage (Koschmann, Glass, and Vhay, 1942, p. 271).

Pale-green to yellow beryl crystals as much as 2 cm long are most abundant at the edges of the quartz veins, although minor quantities of small beryl crystals are disseminated in the greisen. According to Glass (oral communication, 1950), the green beryl forms a border along the quartz-greisen contact and is a replacement of quartz. A chemical analysis of the green beryl by R. E. Stevens showed 12.33 percent BeO. Phenacite occurs as irregular grains and as pseudomorphs after beryl; it is generally associated with chlorite (Koschmann, Glass, and Vhay, 1942, p. 282).

The reserves of beryl in the Irish Creek district were not determined. However, the beryl is sufficiently coarse grained to make it recoverable if the vein material is milled for tin.

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