THE GEOLOGY AND GEOCHEMISTRY OF BERYLLIUM IN SOUTHERN ARIZONA

by

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ABSTRACT

Nine beryllium deposits were studied in order to determine the geological environment of beryllium mineralization in southern Arizona.

Beryllium occurs in two pegmatite areas, two contact metamorphic deposits, two quartz-tungsten veins, two quartz-feldspar veins, and in one quartz monzonite stock. It is associated in almost all of these deposits with purple fluorite and tungsten.

Beryllium mineralization is associated with granitic and quartz monzonite intrusions of Laramide age, and generally occurs at the intersection of northwest-trending lineaments and the Texas lineament.

ACKNOWLEDGMENTS

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1. INTRODUCTION

Recent technological developments in the fields of atomic energy, missles, space craft and allied fields have created increased interest in beryllium and beryllium alloys. These technological advances have brought about accelerated exploration programs by numerous organizations searching for beryllium.

In order to assist in the general exploration for beryllium, a survey was conducted of all known beryllium deposits in southern Arizona. All of the deposits were mapped on U.S. Geological Survey topographic maps at a scale of 1 inch = 1 mile. Detailed geologic mapping was conducted on a few of the deposits. Particular attention was devoted to igneous rock type, geologic structure, related minerals, and geologic age in order to determine the extent and possible origin of the Arizona beryllium province.

The geologic literature on beryllium is scarce, particularly with respect to mineral localities. Although nine beryllium deposits are described, an additional twelve have come to the writer's attention. However, the question as to validity and/or exact location of these latter occurrences necessitated their exclusion from the thesis. They are, however, listed in the appendix with a few comments on each locality.

The writer made use of all available geologic reports for the areas examined.

2. GEOGRAPHY AND TOPOGRAPHY

The area studied is shown in Figure 1, and includes about 20,000 square miles. The Gila and Salt River base line was arbitrarily chosen as the northern boundary of the area.

The region lies wholly within the Basin and Range province, which is an area characterized by mountain ranges separated by broad valleys or basins. The mountain ranges are relatively short, and more or less parallel, trending generally north-northwest, and consisting of fault blocks with simple or complex internal structure.

3. GEOCHEMISTRY OF BERYLLIUM

The geochemistry of beryllium has been studied by Goldschmidt (1954), Rankama and Sahama (1950), Beus (1956, 1957, 1958), Warner and others (1959), and only general statements need be given here. Detailed geochemical studies on certain types of deposits are discussed under the respective deposits.

Beryllium is a rare element in the upper part of the lithosphere (approximately 5 parts per million), and all current knowledge of geochemistry indicates that in the deeper regions of the earth beryllium will be even less abundant. Beryllium has strong oxyphile affinities, and is thus a typical element in the residual magmas and solutions related to magma evolution, as demonstrated by the following table from Warner and others (1959):

ROCK TYPE	% BeO
Average igneous rock	0.001
Feldspathoidal rocks	0.0025
Granitic rocks	0.002
Syenitic rocks	0.001
Intermediate rocks	0.0007
Mafic and ultramafic rocks	0.0001

Although the feldspathoidal rocks are somewhat richer in beryllium than granitic rocks, the light residual fraction from granitic rock crystallization contains more beryllium than the corresponding fraction from feldspathoidal magma crystallization. This is due to the fact that in feldspathoidal magma differentiation the beryllium will crystallize out during the main stage of crystallization, while in granitic magma crystallization beryllium will not crystallize out until the very last stages of crystallization.

In areas of contact metamorphism, where granitic rocks have intruded limestones, idocrase, garnet, magnetite, fluorite, scheelite, and diopside-hedenbergite are commonly formed. According to Warner and others (1959), fluorine-rich idocrase and fluorite are commonly associated with helvite in beryllium-bearing tactites.

Jahns (1944) has described a unique beryllium-bearing tactite from New Mexico, and states that this "ribbon rock" may be a clue to beryllium-bearing tactites. This "ribbon rock," a rhythmically layered variety of tactite believed to be the result of activity by hydrothermal solutions, occurs in the zone between the massive tactite and the unaltered limestones.

Warner and others (1959) have observed that there is a general affinity between beryllium and tungsten or iron, and a marked lack of affinity between beryllium and copper, lead, and zinc.

4. GENERAL GEOLOGY OF SOUTHERN ARIZONA

Older Precambrian rocks in southern Arizona consist of the Pinal Schist which has been intruded by granite in numerous areas. These rocks are overlain by the younger Precambrian rocks consisting largely of clastic sedimentary beds which thicken toward the west.

Paleozoic rocks are exposed extensively in the southeastern portion of the State, thinning toward the northwest. They consist mainly of limy marine strata.

Mesozoic rocks are predominantly Cretaceous marine beds, although some continental and volcanic rocks, also of Cretaceous age, are present. Triassic and Jurassic continental beds may be present. Cretaceous and pre-Cretaceous intrusives may also occur in the area. Tertiary rocks consist of volcanic and continental deposits.

The dominant structural features of southern Arizona were formed in older Precambrian time. The Mazatzal Revolution (Wilson, 1939) produced east and north-northwest-trending faults, dominantly northeast folding (although north, northwest, and east trends are also present), and north-northwestward thrusting. The revolution culminated with the intrusion of granitic batholiths, and some smaller intrusions of varying composition. Giletti and Damon (1961) determined the ages of several basement rocks in Arizona and concluded that the Mazatzal Revolution occurred approximately 1,200-1,550 million years ago, and that the revolution affected an area of provincial size.

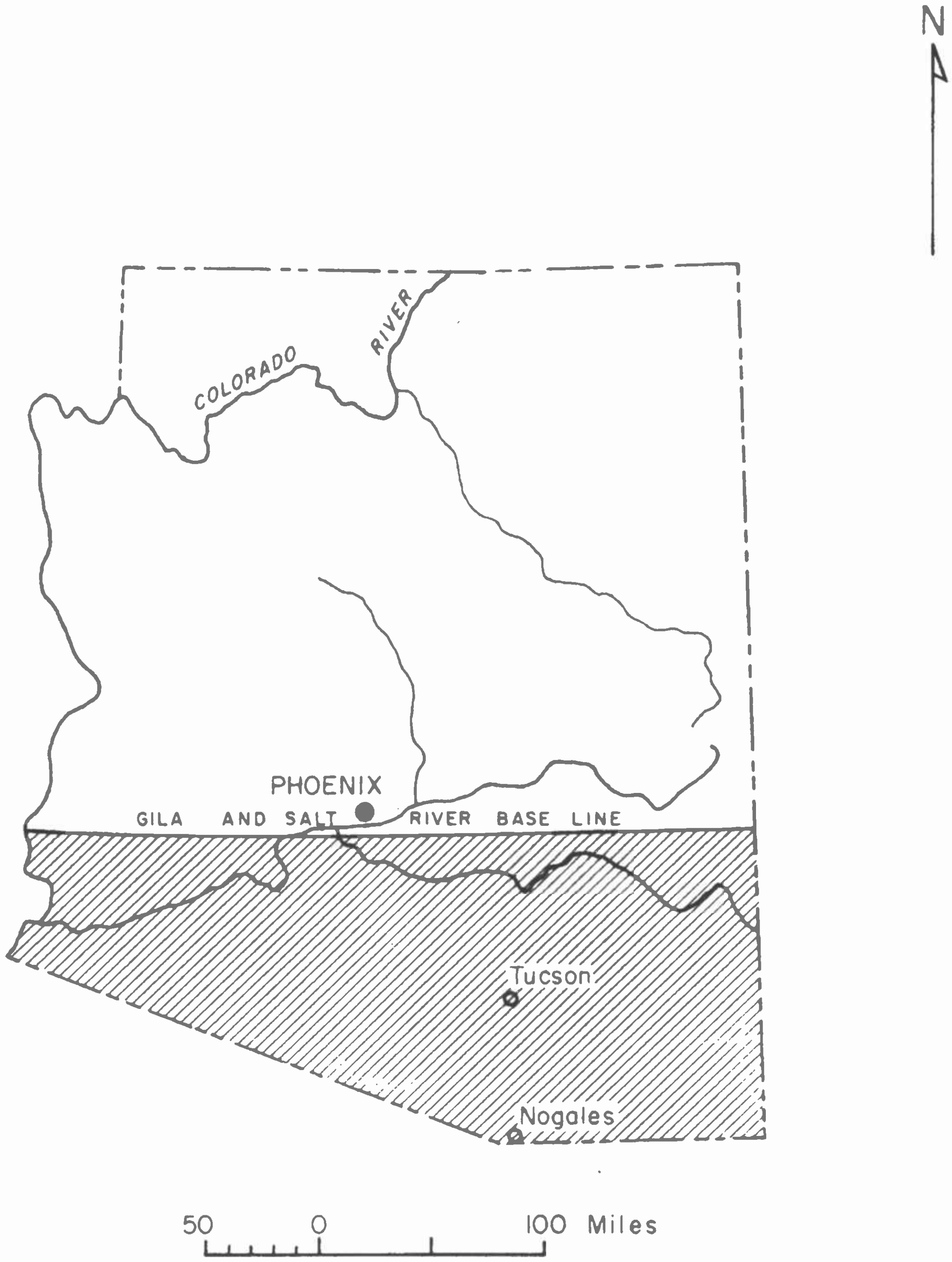
Younger Precambrian structure consists dominantly of diabasic intrusions and north-northeast folding.

During the Paleozoic Era, a segment of the Sonoran geosyncline occupied the southeastern portion of the State, while the southwest portion was a positive area. There has been no igneous activity noted during the Paleozoic Era in southern Arizona except for diabasic intrusions.

Little is known about the Triassic and Jurassic in southern Arizona. There apparently was local mountain building and intrusion, as at Bisbee and possibly Ajo. These disturbances have generally been regarded as Nevadan, although they may be younger in age. During the Cretaceous period extensive volcanism occurred throughout the area.

During the Upper Cretaceous and early Tertiary time the Laramide Revolution occurred forming west-northwest-trending faults and east- and north-trending faults parallel to the older Precambrian trends. Northwestward-trending folds predominated, with minor northeastward to eastward thrusting. The Laramide Revolution was climaxed by the intrusion of granitic to monzonitic stocks and batholiths. Most of the ore deposits of the southwest are associated with this igneous activity.

From middle Tertiary to Recent time, faulting, doming, erosion, sedimentation, and volcanism have occurred intermittently throughout southern Arizona.



LOCATION MAP

Figure 1

5. DESCRIPTION OF DEPOSITS

(5.1) Cochise County

(5.1.1) Dragoon Mountains

The Dragoon Mountains are a northwest-trending range of mountains located in the west-central portion of Cochise County, Arizona, approximately 12 miles east of Tombstone. Numerous geological investigations have been conducted in the Dragoons, the most comprehensive of which is the U. S. Geological Survey Professional Paper by Gilluly and others (1956). The economic geology has been studied by Wilson (1951).

The rocks in the central Dragoons range in age from older Precambrian to Recent. They consist in general of Precambrian schists and granites, Paleozoic limestones, Triassic and Jurassic granites and monzonites, Cretaceous volcanics and limestones, and Tertiary volcanics and intrusives. Plate 1 shows the regional geology of the area.

The Abril and Gordon mines are situated where the Stronghold Granite has intruded the Paleozoic limestones. The Stronghold Granite is a holocrystalline, seriate, plutonic rock. Approximately 60% of the rock is quartz, 25% orthoclase, 10% plagioclase (oligoclase), and 5%

or less biotite. The rock in other areas has intruded the Cretaceous Bisbee Formation and Late Cretaceous-early Tertiary thrust faults, and is therefore assigned a Tertiary age. Intrusion of the granite caused widespread metamorphism of the country rock, extending to about 2 miles from the contact.

Gilluly (1956) studied the granite and noted that it cuts across the tectonic fabric of the area, and was emplaced without noticeable distortion of the structure of the wall rocks.

(5.1.1.1) Abril Mine

The Abril mine is located on the western slope of the Dragoon Mountains at an elevation of about 6,600 feet. The mine was first developed in 1943 and optioned to the Shattuck Denn Mining Company in 1945. They operated the property until 1949. Total production was 19,941 tons of zinc-copper ore, with some lead. The mine is presently closed.

The U.S. Geological Survey sampled the tactite and ore from specimens obtained from the dump and found 0.004 and 0.02 percent BeO, respectively.

The ore deposits occur in a wedge of Escabrosa Limestone that is surrounded by the Stronghold Granite. The limestone has been altered to tactite near the contact and grades into marble and unaltered limestone with increasing distance from the contact.

Mineralization consists of sphalerite, chalcopyrite, and galena, with some molybdenite and silver. The tactite minerals are principally garnet, epidote, fluorite, and helvite. The fluorite is dark purple in color, and occurs in the barren tactite. Two thin sections examined showed only minor helvite. Since helvite is a common beryllium-bearing mineral in tactite, which may contain up to 15.0 percent BeO, the writer feels that the beryllium detected by the U.S. Geological Survey is probably in the form of helvite. The so-called "ribbon rock" described by Jahns (1944) was not observed.

According to Wilson (1951) the ore deposits are irregular replacements in impure beds within the stratigraphically lower 70 feet of the Escabrosa Limestone.

(5.1.1.2) Gordon Mine

The Gordon, or San Juan, mine is located about half a mile south of China Peak, on the western side of the Dragoons. The mine is presently closed, although it has been worked intermittently since at least as early as 1913. Total production from the mine is not accurately known, but is probably about a million pounds of zinc.

The U.S. Geolcgical Survey sampled the tactite from the mine and found 0.0007 percent BeO, although a sample of ore from the ore bin at the mill in Tombstone assayed 0.04 percent BeO.

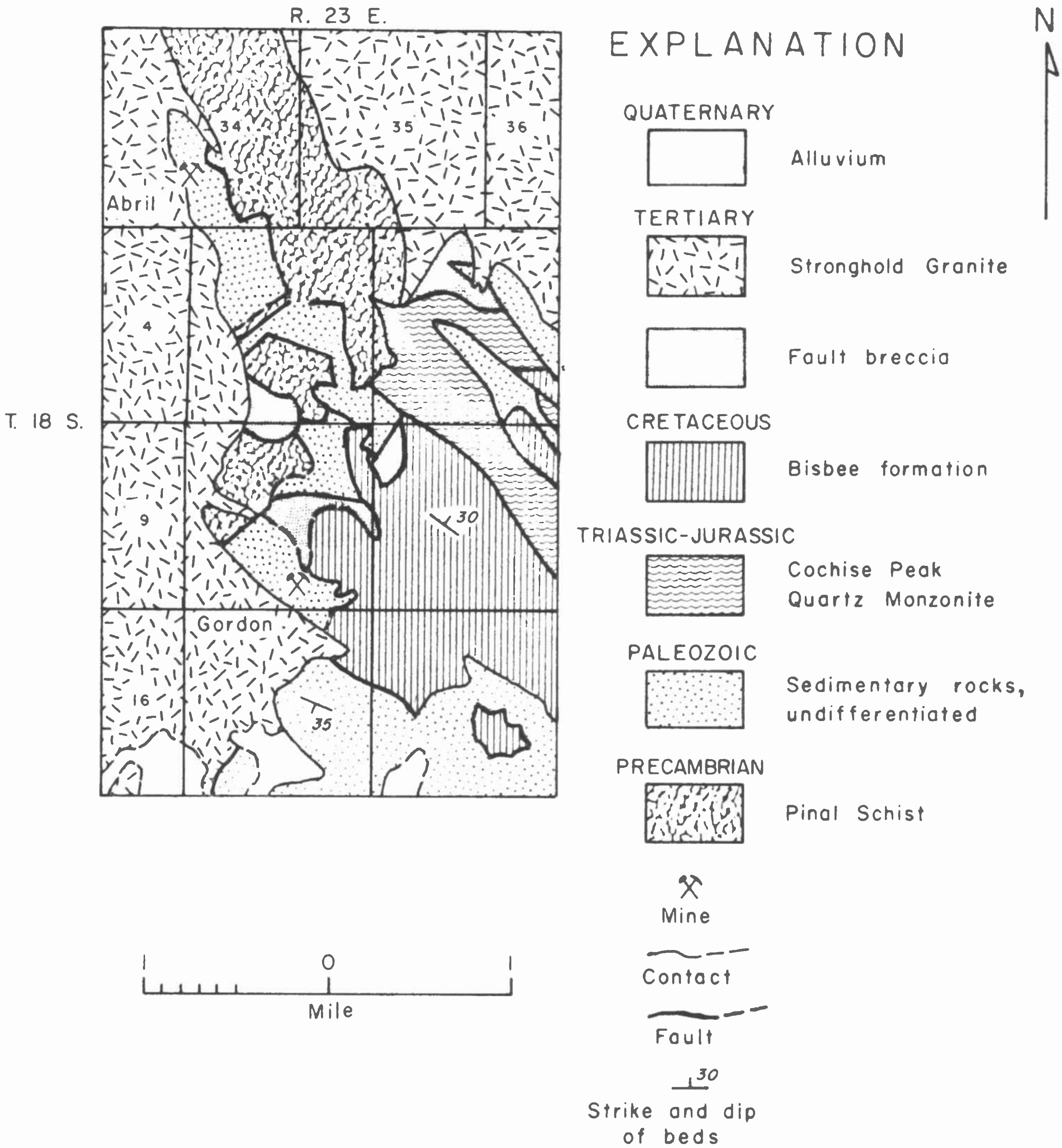
The rocks in the area consist of southerly dipping Cambrian and Devonian strata which are in fault contact with the Escabrosa Limestone. These rocks have been thrust upon Cretaceous(?) shales. The Stronghold Granite to the west has intruded these rocks.

Sphalerite, with some argentiferous galena, occur in the Escabrosa Limestone with hematite and calcite. Tactite minerals include garnet, hedenbergite, and epidote, but no fluorite was found. Thin sections of specimens of ore and barren tactite taken from the mine did not show any beryllium mineral as an essential constituent, and no specimens of "ribbon rock" were observed. The beryllium present in the deposit could occur in a number of the tactite minerals as an accessory element.

(5.1.2) Little Dragoon Mountains

The Little Dragoon Mountains are located in northwestern Cochise County, and are the northern extension of the Dragoon Mountains. Previous geologic work in the area includes a discussion of the Johnson Camp area by Cooper (1950), and a study of the tungsten deposits by Wilson (1941) and Dale and others (1960). The Dragoon quadrangle is the subject of a forthcoming professional paper by Cooper, who gave a progress report of his work in 1959 in the Arizona Geological Society Guidebook II.

The rocks in the Little Dragoons range in age from Precambrian to Recent. The Precambrian rocks consist of the older



GEOLOGIC MAP OF A PORTION OF THE DRAGOON MOUNTAINS, COCHISE COUNTY, ARIZONA

After Gilluly, 1956

Plate I

Precambrian Pinal Schist, with some granitic intrusions, and the younger Precambrian Apache Group. Paleozoic rocks comprise about 6,000 feet of limy sediments, while the Mesozoic is represented by volcanics and some clastic sediments. The Tertiary rocks consist principally of the quartz monzonite of Texas Canyon, with overlying volcanics.

The area has undergone two major orogenies, the Mazatzal and Laramide Revolutions, with the latter producing major thrust and block faulting.

Beryl occurs in two known deposits in the Little Dragoons; one is the Tungsten King mine in the southwest portion of the range, and the other is the Bluebird or Primos tungsten deposit in the southeastern part of the mountains.

(5.1.2.1) Bluebird Mine

The Bluebird (Boericke) deposit is owned by the Primos Chemical Company and has produced several thousand units of tungsten concentrates. The deposit has been extensively prospected by open cuts, but is presently closed.

Galbraith and Brennan (1959) report beryl from this property. Warner and others (1959), however, failed to confirm this occurrence. The writer spent one day examining the numerous open cuts and did not identify any beryl.

The Bluebird deposit lies wholly within the quartz monzonite of Texas Canyon, designated Tertiary in age by Cooper (1959). The quartz monzonite is a holocrystalline, seriate, plutonic rock consisting of about 35% quartz, 30% plagioclase (andesine), 20% orthoclase, 10% muscovite, and 5% biotite.

A series of fractures trending approximately N. 30° E. contain quartz with sporadic occurrences of wolframite. A little pyrite occurs occasionally in the veins which are about a foot in width. A greisen zone, generally about a foot to 2 feet in thickness, occurs between the quartz veins and the quartz monzonite. Moderately dark-purple fluorite occurs as patches in fractures near the quartz-greisen contact, and is also sporadically disseminated through the greisen.

The U. S. Geological Survey conducted spectrographic analyses of specimens from this deposit and reported values ranging from 0.001 to 0.0005 percent BeO.

(5.1.2.2) Tungsten King Mine

The Tungsten King mine was originally located in 1913. The mine has been worked sporadically since then, with a total production of about 25,800 pounds of scheelite concentrate. The mine is presently closed.

The Tungsten King mine is on a north-trending fault contact between Precambrian Pinal Schist on the east and probable Precambrian granite on the west. This fault is the east boundary of the

Tungsten King horst (Cooper, 1959), and can be traced for at least 2 miles.

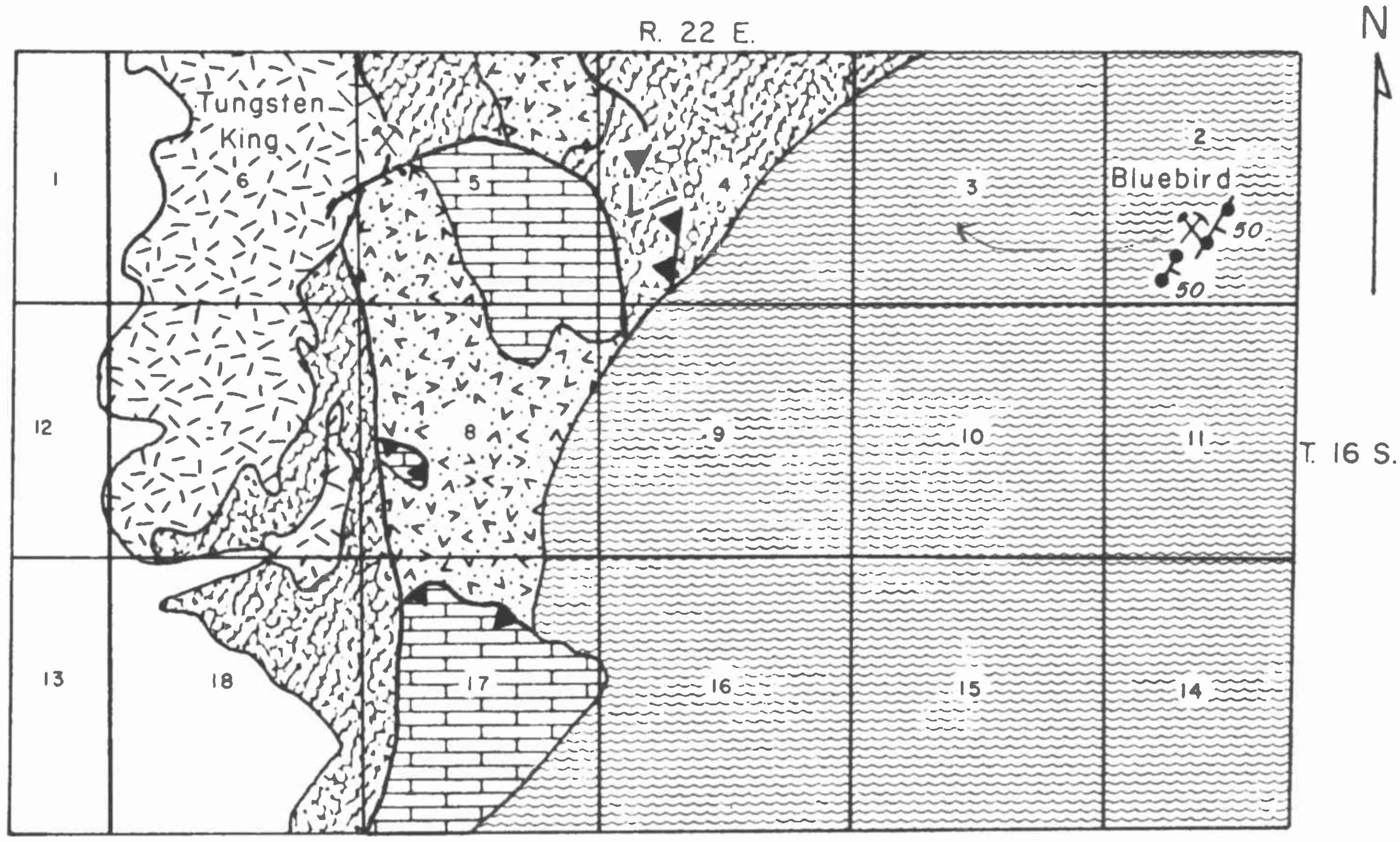
The Tungsten King vein varies in width along the outcrop from 1 to 6 feet. Numerous prospect pits occur along the vein which trends slightly west of north and dips steeply to the east.

The vein consists essentially of quartz. Scheelite, beryl, orthoclase, chlorite, and muscovite occur intermittently. The vein has been sheared and brecciated by post-mineralization faulting.

Approximately 2 feet above the vein there is a smaller, parallel vein which contains discontinuous lenses of quartz. This vein has not been affected by later faulting.

Although the vein was examined closely along its strike, only a few specimens of beryl were observed. The beryl occurred as radiating crystals about 1.5 inches long, and about .25 inch in diameter. The beryl is a light-blue color, and was closely associated with subhedral orthoclase crystals. Warner and others (1959) report beryl occurring in the schist adjacent to the quartz vein. None was observed by the writer.

The Tungsten King horst was probably formed in Laramide time, and the Tungsten King fault is therefore also of probable Laramide age. Therefore, mineralization is considered to be of probable Laramide age, although there are no Laramide intrusives which might be considered to be the source of the mineralization near the deposit.



EXPLANATION

QUATERNARY
Alluvium

TERTIARY
Quartz monzonite

PALEOZOIC
Limestones undifferentiated

PRECAMBRIAN
Apache Group

Granite

Pinal Schist

Mine

Contact

Fault

Thrust fault

50
Vein

1 0 1
Mile

GEOLOGIC MAP OF A PORTION OF THE
LITTLE DRAGOON MOUNTAINS, COCHISE COUNTY, ARIZONA

After Cooper, 1951

Plate 2

(5.1.3) Swisshelm Mountains

The Swisshelm Mountains are a small northwest-trending range located in southeast Cochise County, approximately 20 miles north of Douglas, Arizona. The only previous work in the general area is reported in a thesis by Loring (1947) on the northern portion of the mountains, a paper by Epis and Gilbert (1957) on the stratigraphy, and a reconnaissance map by Cooper (1959).

There are four beryllium occurrences known to date. These have all been exposed by small prospect pits (Pl. 3). The only known production of beryl from this area has come from the southernmost occurrence where some specimens of aquamarine were found.

The principal rocks in the area are shown on Plate 3 and consist of a small granitic stock (herein called the "Elfrida quartz monzonite") which has intruded quartzites and limestones of Pennsylvanian and Permian age and shales of Cretaceous age. Hence the quartz monzonite is Cretaceous or younger in age and is assigned to the Laramide.

The quartz monzonite contains numerous aplite dikes and quartz veins. Some of the aplite dikes are as much as 3 feet in thickness and can be traced along their strike for distances up to 100 feet. The quartz veins vary in thickness from a few inches to about 2 feet and can be traced from a few tens of feet to several hundred feet.

The quartz monzonite is a holocrystalline, seriate, plutonic rock. The rock contains about 45% quartz, 35% orthoclase, 20% plagioclase, and less than 1% biotite and magnetite.

(5.1.3.1) Elfrida Area

All of the beryllium occurrences in the quartz monzonite are associated either with the aplite dikes or occur at intersections of the aplite and quartz veins. The beryl in all but one prospect occurs as small patches on fractures in the aplite. Muscovite and fluorite were found associated with the beryl on the fractures. The fluorite is a pale-lavender to light-purple color. The beryl is light-blue to colorless and rarely shows crystal form. The quantity of beryl is small, the largest patch observed was about 3 inches in diameter and about an eighth of an inch in thickness.

The largest prospect in the area occurs near the center of sec. 23, T. 20 S., R. 27 E. This is at the contact of the Elfrida quartz monzonite and Paleozoic limestones. The limestone has been altered to garnetite for a few feet away from the contact, grading into marble and finally unaltered limestone. A thin section of the garnetite showed garnet and a little quartz and calcite. No other minerals were observed.

Small, transparent, nearly colorless crystals of aquamarine occur scattered on the dump, apparently formed at the contact between the quartz monzonite and garnetite; however, no beryl was found in place.

A large aplite dike occurs near the prospect and strikes toward the prospect, but is covered by dump material at the prospect. A small cut has exposed an area of a very soft, clay-like white material that is believed to be part of the aplite. A thin section could not be made of the material, but it appears to be similar to the clay zone occurring in the pocket pegmatites at San Diego, California (Jahns, 1951). The aquamarine is believed to have come from this clay zone.

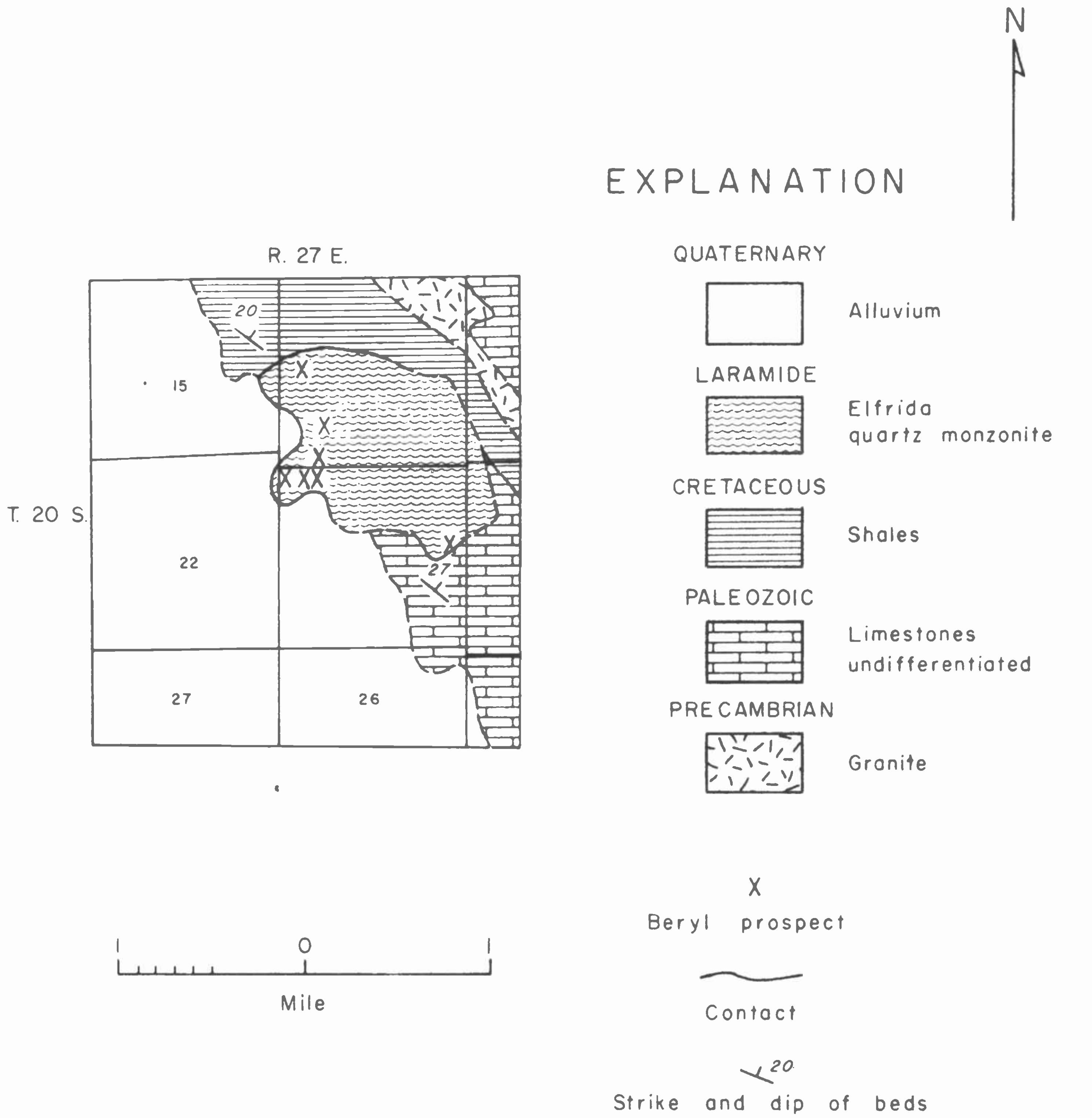
The writer was informed (oral communication, L. A. Stewart, 1961) that a few holes have been drilled in the quartz monzonite and that beryl was found. He has not been able to find any additional information of the drilling.

Bertrandite has been reported from the "Elfrida area" (presumably this deposit) by Norton, et al. (1958). None was observed by the writer.

(5.2) Pima County

(5.2.1) Baboquivari Mountains

The Baboquivari Mountains form a large north-trending range located in south-central Pima County, Arizona. Previous geologic work in the area includes University of Arizona theses by Peter G. Donald (1959) and Jackson L. Clark (1956), and a brief report on the gold and tungsten deposits by Wilson (1934, 1941).



GEOLOGIC MAP OF A PORTION OF THE
SWISSHELM MOUNTAINS, COCHISE COUNTY, ARIZONA

Plate 3

The beryllium deposits occur in two general areas on the east side of the mountains. The northern deposit is in the vicinity of Contreras Canyon and has been studied in detail by Clark (1956). The southern deposit is near Lalo Peak, about 9 miles north of the Mexican border. There has been little, if any, production from either deposit.

(5. 2. 1. 1) Contreras Canyon

The dominant rock type in the Contreras Canyon area is an unnamed porphyritic granite which is correlative with the Otero Granite of Donald (1959), immediately to the south of Contreras Canyon (Pl. 4). The porphyritic granite is a coarse-grained rock composed of quartz, orthoclase, plagioclase, biotite, magnetite, zircon, sphene, and apatite. Large phenocrysts of orthoclase occur randomly distributed throughout the rock.

The age of the granite is as yet unknown. Clark (1956) states that the rock "may be pre-Cretaceous," an opinion based on fragments of granite found in a pebble conglomerate. Donald (1959) considers that the rock may be either post-Cretaceous or pre-Cretaceous in age. C. L. Fair (oral communication, 1961) has evidence west of this area that a rock which appears to be identical to the Otero Granite is of Precambrian age.

Clark (1956) states that analysis of specimens of the granite shows trace amounts of beryllium. An EDTA (Ethylenediaminetetraacetic acid) field test also detected beryllium in the granite. A study of several thin sections of the granite, however, did not show any beryllium-bearing minerals.

The porphyritic granite is the only major rock unit exposed in the area, and it has been intruded by aplite and later pegmatites and basic dikes. Aplite occurs throughout the area as "local segregations" (Clark, 1956), and vertical, north- to northwest-trending dikes. Clark (1956) states: "The aplite is a fine-grained holocrystalline xenomorphic granular igneous rock composed of albite, oligoclase, microcline, quartz, orthoclase and perthite."

Pegmatite dikes are abundant throughout the area. The major minerals are quartz and orthoclase, and the minor minerals are beryl, fluorite, bismuthinite, bismuthite, native bismuth, koeclinite(?), magnetite, hematite, specularite, muscovite, biotite, powellite, and scheelite. These pegmatites will be discussed in detail later.

Basic dikes, which are the youngest rocks in the area, range in composition from basalt to andesite. They generally trend northwest, but may also occur striking east or northeast, dipping steeply or vertically. Clark (1956) concludes from a study of the contact effects that "these dikes were emplaced relatively cool and essentially dry."

The pegmatite veins consistently strike nearly west, with an average dip of about 40° to the south. They can generally be traced for about 100 feet along their strike, and vary in thickness from a fraction of an inch to several feet. The veins diminish in thickness along their strike until only a fracture remains in the granite.

The minerals comprising the pegmatites occur only as veins or dikes. No pegmatites occur in the area which exhibit the characteristics of the classical complex pegmatites of New England, South Dakota, or San Diego, California, and no mineralogical or textural zoning is apparent.

Beryl is found in nearly all of the pegmatites in the Contreras Canyon area as light-blue, euhedral crystals ranging in diameter from a fraction of a millimeter to about 20 millimeters. The beryl crystals occur as elongated prisms, with the length of the crystal about 40 times the diameter. The smaller crystals are clear, although an increase in size is generally accompanied by increasing opacity and cloudiness. The color will generally not vary. Clark (1956) reports that chemical analyses of the beryl consistently indicate a BeO content near 14 percent, and that there have been no other beryllium minerals identified from the area.

The quartz occurring in the pegmatite veins is light gray in color and translucent. It is generally massive, with occasional subhedral crystals occurring in small vugs in the quartz.

The Contreras Canyon area apparently was the center of beryllium mineralization for the Baboquivari area. Beryl is present in the next canyon to the north of Contreras Canyon, but only occurs in a few veins (oral communication, J. L. Clark, 1961).

The Otero Granite or porphyritic granite occurs at least as far south as Brown Canyon, a distance of approximately 5 miles. The pegmatite dikes occur throughout the area, with the same characteristics as the pegmatite dikes of Contreras Canyon; however, beryl declines in abundance toward the south. The writer could not find any beryl below the center of sec. 28. Donald (1959) does not mention finding it in any of the pegmatites, although muscovite and biotite, which are generally absent in Contreras Canyon, occur in these pegmatites to the south.

Sulfide mineralization, which is absent in Contreras Canyon, occurs in the form of pyrite, chalcopyrite, specularite, and molybdenite about a mile to the south of Chilitepines Ranch (about 4.5 miles south of Contreras Canyon). Donald (1959) in his discussion of the Gold Bullion mine (auriferous pyrite, chalcopyrite, molybdenite) states that "mineralization of the Gold Bullion Mine apparently represents a late magmatic or hypothermal replacement phase. Close association of mineralization and pegmatization of sediments suggest that ore fluids may be related to exhalations from the pegmatite itself."

There appears to be a definite genetic relation between the sulfide mineralization in the southern portion of the area, the barren (devoid of beryllium) pegmatites in the central portion, and the beryl-bearing pegmatites in the northern portion. Furthermore, there appears to be an increase in beryl content in the pegmatites from about the center of section 28, where beryl is first observed, to the approximate center of Contreras Canyon a mile to the north. North from Contreras Canyon, the beryllium content rapidly diminishes in the pegmatites.

A definite mineral zoning is observable in the area, beginning with beryllium mineralization in the Contreras Canyon area and grading into base metal sulfide mineralization on the periphery. The mineralizing solutions appear to have contained beryllium, bismuth, fluorine, molybdenum, tungsten, copper, calcium, potassium, aluminum, silica, and water, along with other unknown constituents. It should be pointed out, however, that although the mineralizing solutions contained the above components (as evidenced by the products of mineralization), the solutions probably did not contain all of these components at the same time. Since mineralization takes place over a period of time, it is to be expected that the character of the solutions might have changed during mineralization.

The type and relative amounts of the constituents as indicated by the products of the mineralizing solutions indicates that the fluids were closely related to the pegmatitic sequence of mineralization. The end phases of mineralization, as shown by the base metal sulfides to the south, were probably hydrothermal. The beryllium mineralization might have been either pneumatolytic or hydrothermal.

The age of mineralization in Contreras Canyon is in doubt, since no other rocks are exposed in the area. Donald (1959) has shown that in the southern part of his area mineralization occurs not only in the Otero Granite but also in a sequence of conglomerates to which he assigns an age of Cretaceous-Tertiary. If the above reasoning with regard to mineralization and age of the sediments is valid, then mineralization was at least Cretaceous-Tertiary in age, and therefore Laramide.

As has been noted earlier, the dominant structural elements in the area trend northeast, northwest, and west. The age and importance of the various structural trends may be significant.

In Contreras Canyon Clark (1956) has shown that the northeast trend is the oldest. The aplite dikes which occur along this alignment are generally small. The westerly direction contains beryl-bearing veins, which cut the aplite but not the basic dikes. The basic dikes trend generally northwest, and cut the pegmatites.

Immediately to the south, Donald (1959) has studied the structure in detail. He has shown that the fractures which contain dikes merely separated or opened up. There was little, if any, movement along fractures. Donald (1959) states that "...acid dikes and basic dikes of northeast trend consistently intersect all members of the northwest set."

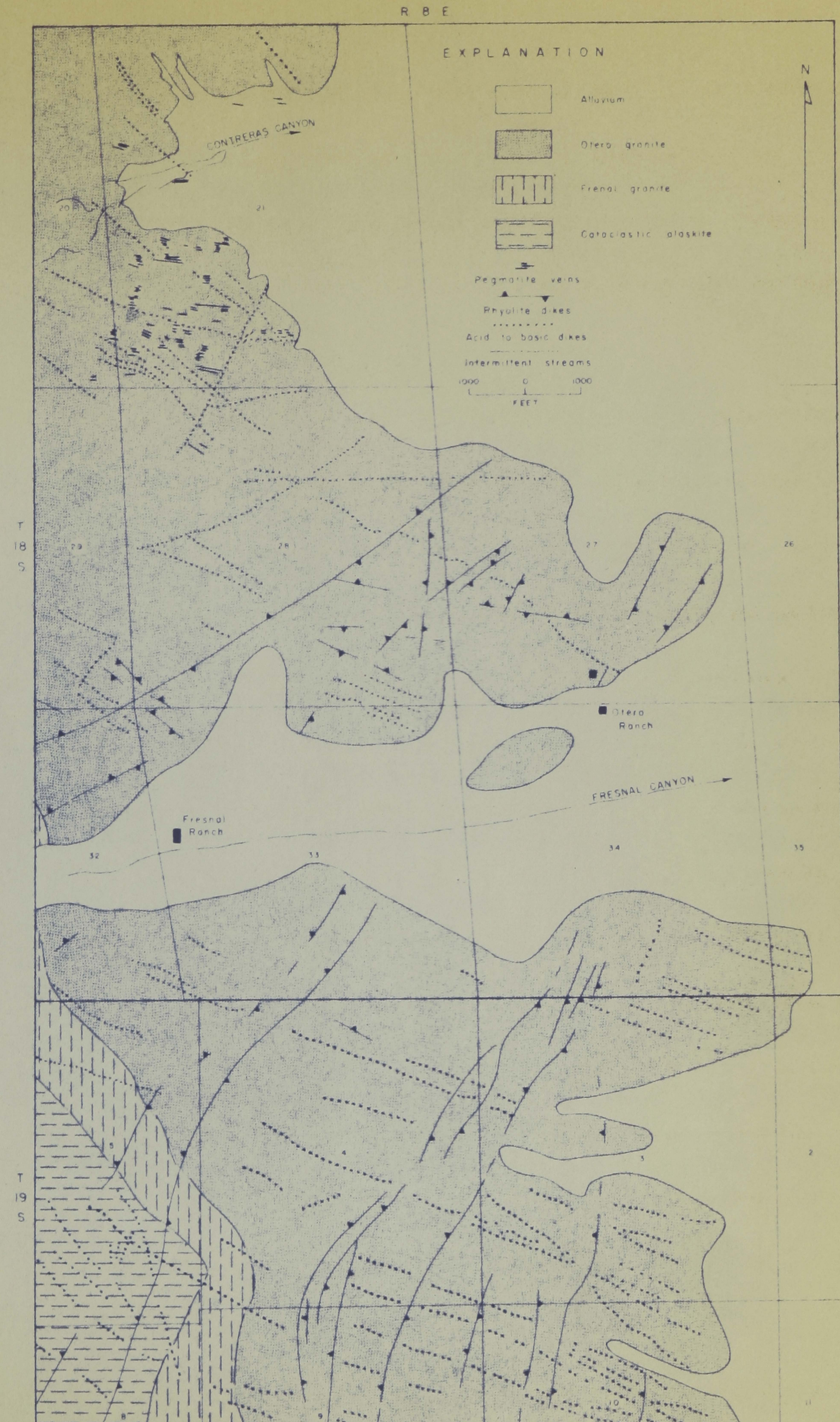
It would appear, then, that the relative ages of the dikes are in a radial pattern. For example, in the northern portion of the area, the youngest joint set is northwest, while in the southern portion it is northeast. Donald (1959) states that "dikes are believed intruded during a late phase of doming," and that the radial pattern of the rhyolite dikes indicates that the center of doming is to the northeast of the bottom of section 27 (Pl. 4).

The center of doming apparently was a short distance to the northeast of section 27. The maximum degree of fracturing (due solely to doming) would occur near this center (Wisser, 1960, figs. 2 and 3). Mineralizing solutions would tend to be concentrated near the center of doming, since the greater degree of fracturing would increase the number and volume of channelways available for the transport of material. There would therefore be a higher intensity of mineralization in this area than near the outer fringes of doming where there would be less fracturing and consequently a decrease in the number of channelways available for mineralization. That the above might have happened is indicated by the zoning in mineralization in the area. High-temperature beryllium was deposited in Contreras Canyon, gradually diminishing in quantity until base metal sulfides were deposited in the southern portion of the area.

The writer suspects that the beryllium emplacement was not directly related to the doming however. The remarkable westerly trend indicates to the writer that a fundamental west-trending structure occurs in the vicinity of Contreras Canyon, and that this structure cuts across the doming. Mineralization is related to this structure, which is near the center of doming. The mineralizing solutions probably migrated away from this intersection and into fissures opened by the doming.

A study of the Baboquivari and Sierrita Mountains beryllium occurrences reveals some interesting features. The persistent westward trend of the beryllium-bearing veins, and lack of other beryllium-bearing trends may be significant. In the Sierrita Mountains to the east, beryllium occurs in dominantly west-trending structures. The writer suspects that this west trend may be more than coincidental. Whether the beryllium mineralization in the Sierritas is related to the beryllium mineralization in the Baboquivaris is not known, and the fact that the two beryllium occurrences are separated by about 20 miles of totally unknown geology certainly rules out any direct association between the two deposits.

However, this consistent westerly trend is remarkable. The writer wonders if perhaps the beryllium mineralization is related to two separate but parallel structures (lineaments). Another possibility, which the writer at present considers unlikely, is that the two deposits are segments of the same structure, offset approximately 9 miles by faulting, possibly along the so-called "boundary faults" of each mountain range.



Geologic map of a portion of the Contreras Canyon area, Baboquivari Mountains, Pima County, Arizona

After Clark (1956) and Donald (1959)

Plate 4

(5.2.1.2) Lalo Peak

Clark (oral communication, 1960) reported that beryllium was spectrographically discovered in this area, although the nature of the occurrence was not determined. The area lies in the E-1/2 sec. 33, T. 20 S., R. 7 E., Gila and Salt River base line and meridian.

The area consists of schists, quartzites, and conglomerates of unknown age. The schists do not lithologically resemble the Pre-cambrian Pinal Schist, so that are tentatively assigned a Laramide age.

The schists have been intruded by a series of west-trending quartz dikes which contain small amounts of orthoclase and epidote. One dike was found that contained a few small crystals of light-blue beryl. The dikes are all small, generally 2 feet or less in width, and can be traced along their strike for about 100 feet.

In the northern portion of this area, the quartz dikes contain abundant schorlite, although no beryl. The beryllium may be in the schorlite, which can contain up to 0.0X percent BeO (Warner and others, 1959).

(5.2.2) Sierrita Mountains

(5.2.2.1) Northern Pediment Area

Beryllium occurs in scattered deposits in the northern pediment of the Sierrita Mountains. The area is shown on Plate 5. Extensive geologic work has been done in the surrounding areas, although only two workers mention the beryllium pegmatites (Waller, 1960; Cooper, 1960).

There are six known beryllium occurrences, but only one, the "Sharon D," is currently being worked. Production to date from the Sharon D is reported by the claimants as a few hundred dollars worth of beryl sold as collector's specimens.

The rocks exposed in the area, excluding the pegmatites, are the Precambrian Sierrita Granite of Lacy (1959), possibly the late Cretaceous-early Tertiary granodiorite of Cooper (1960), and schists and gneisses of possible Laramide age. The entire northern pediment appears to be a granitic complex.

The Sierrita Granite is a coarse-grained granite which underlies most of the area. The rock consists essentially of microcline, oligoclase, and quartz, with minor amounts of biotite. It is phaneritic, holocrystalline, and equigranular. In general, it is badly weathered, and locally hematite stains the rock a red or pink color. It has been established as Precambrian in age by Lacy (1959) on the basis of unconformable relationships with Cambrian strata in adjacent areas.

Cooper (1960) has mapped a biotite granodiorite occurring in the western part of the area. This rock is a medium- to coarse-grained rock consisting of biotite, quartz, plagioclase, and orthoclase. Cooper (1960), in the Twin Buttes area, approximately 6 miles to the south, has shown this rock to be of late Cretaceous-early Tertiary age.

The contact between the two rocks as mapped by Cooper (1960) was not observed. The writer suspects that perhaps the biotite granodiorite does not extend this far north, and that the entire area is underlain by the Sierrita Granite complex.

In the vicinity of Gunsight Mountain, the Sierrita Granite has been intruded by granodiorite, which in turn has been intruded by quartz monzonite and lamprophyre dikes. The granodiorite is very similar to the granodiorite occurring throughout the Twin Buttes area, and is tentatively assigned a Laramide age.

The western half of the small hill immediately north of Gunsight Mountain consists of a series of schists and gneisses that have an almost north-south schistosity which dips steeply to the west. The age of the schists and gneisses is not known. They lack the dominant northeast trend of the older Precambrian Pinal Schist, and they do not appear to resemble the Pinal. There are not enough outcrops, however, to conclusively demonstrate the age of the rocks.

The schists have been intruded by granitic pegmatites and granodiorite concordant with the schistosity. A little aquamarine beryl was found in one of the pegmatites. The pegmatites are all small; no pegmatite was observed that was larger than 3 feet in width.

A vein of fluorite occurs in the schist and is also concordant with the schistosity. The mineralization can be traced for a few hundred yards along its strike, and averages about a foot in width. The fluorite is generally clear or white in color, with small amounts of the green and purple varieties also present.

Numerous simple granitic pegmatites occur throughout the northern pediment area. They are, in general, only a few inches wide and can be traced for a few tens of feet, although there are a few that are up to 5 feet in width and can be traced intermittently for about 1,500 feet. These pegmatites form rather conspicuous small ridges a few inches to a foot high.

The simple granitic pegmatites contain large subhedral crystals of quartz and orthoclase, with minor amounts of muscovite, and they do not exhibit any pronounced zoning. Occasionally, however, they may be zoned, with orthoclase in the outer zone and quartz in the inner zone.

The pegmatites trend east-west with dips ranging from 60° to vertical. A few of the pegmatites have northwest and northeast trends. Near Gunsight Mountain, the lamprophyre dikes have an almost due north strike.

The beryllium-bearing complex pegmatites occur only in the northern portion of the pegmatite area, and near Gunsight Mountain. Only six beryllium pegmatites have been noted to date, but there are probably more in the area. The complex pegmatites trend east-west and dip steeply to the south. Although they appear to be related to the simple granitic pegmatites, there is no exposure which shows a simple granitic pegmatite merging into a complex pegmatite.

The simple pegmatites are uniform in thickness throughout their length, while the complex pegmatites are lenticular in plan, and apparently lenticular in cross section. The beryllium-bearing pegmatites are small, the maximum size noted being approximately 30 feet in length and about 20 feet wide.

The complex pegmatites contain two zones, an inner "core zone" and the outer "border zone." A third, intermediate zone may be present locally. The core or inner zone consists entirely of massive white, translucent quartz, although a few random crystals of beryl have been reported in the core of the Sharon D pegmatite.

The intermediate zone is not well defined, and in some cases may be absent. This zone consists of intergrowths of large crystals of white quartz and orthoclase. A little muscovite may be present.

The outer zone varies from 6 inches to a foot in thickness, and consists of medium-sized biotite in a fine-grained groundmass of orthoclase and quartz, with minor amounts of apatite. The quartz is white to light gray and transparent, and may occur as small crystals or large anhedral masses.

The beryl in this area is a fine to coarsely crystalline, translucent to transparent, light-blue mineral. Some of the crystals approach aquamarine in color. The crystals range in size from microscopic to a foot in length and a couple of inches in diameter. There does not appear to be any consistent relationship between color, transparency, and size. All of the crystals are fractured, with the number of fractures increasing with increasing size.

The beryl is restricted to the outer zone of the pegmatite except for a few large crystals which occasionally occur in the light-gray quartz in the inner core.

The sequence of crystallization in a pegmatite is generally agreed to have started at the outer walls and proceeded inward (Jahns, 1955). From the spatial distribution of the various minerals in these pegmatites, a few conclusions may be drawn. The beryl crystallized out of the mineralizing solutions after the feldspar and biotite, but before the quartz, since the quartz occurs in the core zone, the last part of the pegmatite to form. A little beryllium was still in solution during the end phases of crystallization, since a little beryl has been found in the core zone. Numerous specimens of beryl have portions of biotite enclosed within the beryl crystal, indicating that the beryl formed after the formation of the biotite.

Fluorite has been reported from the Sharon D claim, but none was observed by the writer in any of the pegmatites or adjacent areas.

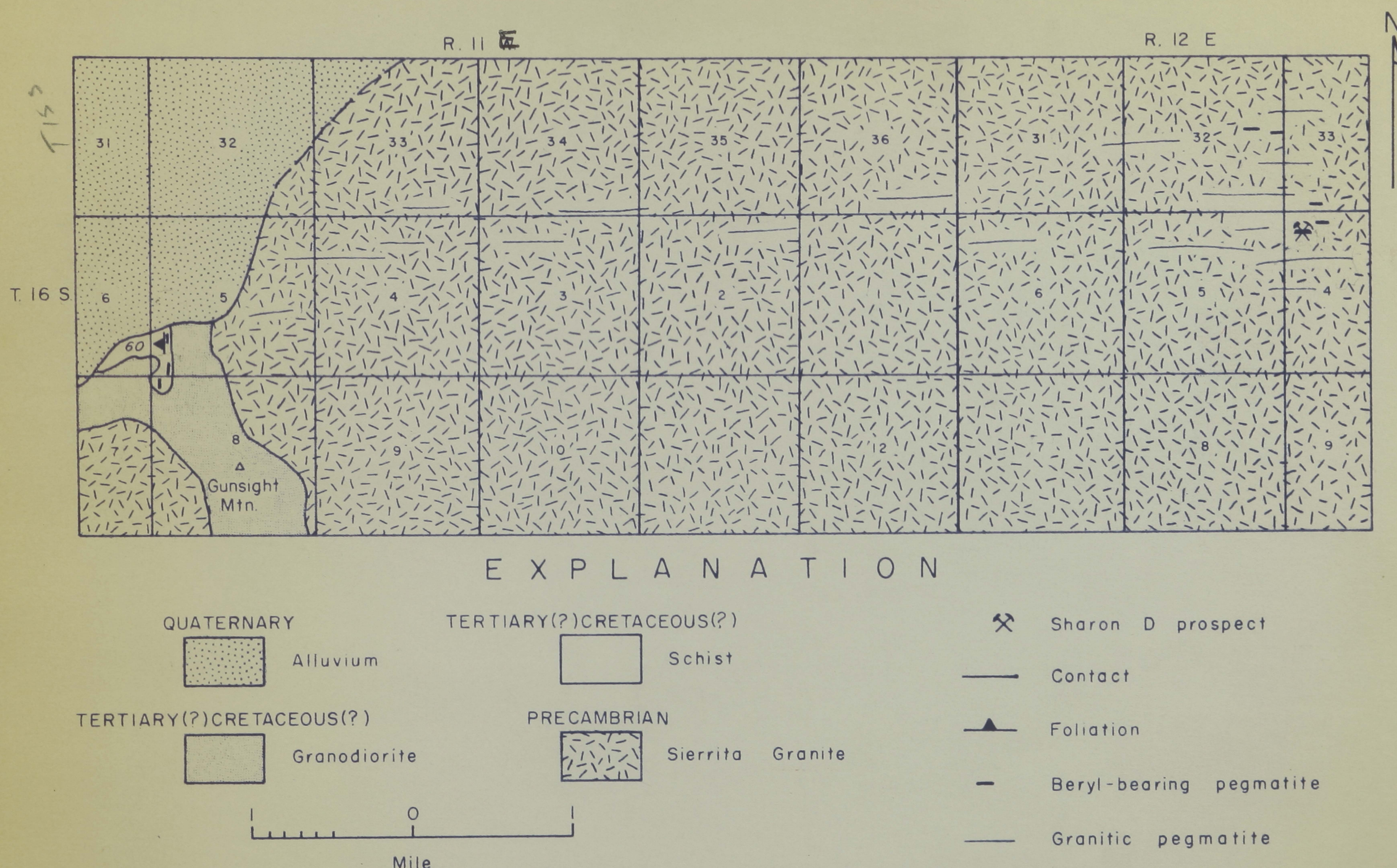
(5.3) Yuma County

(5.3.1) Gila Mountains

(5.3.1.1) La Fortuna Mine Area

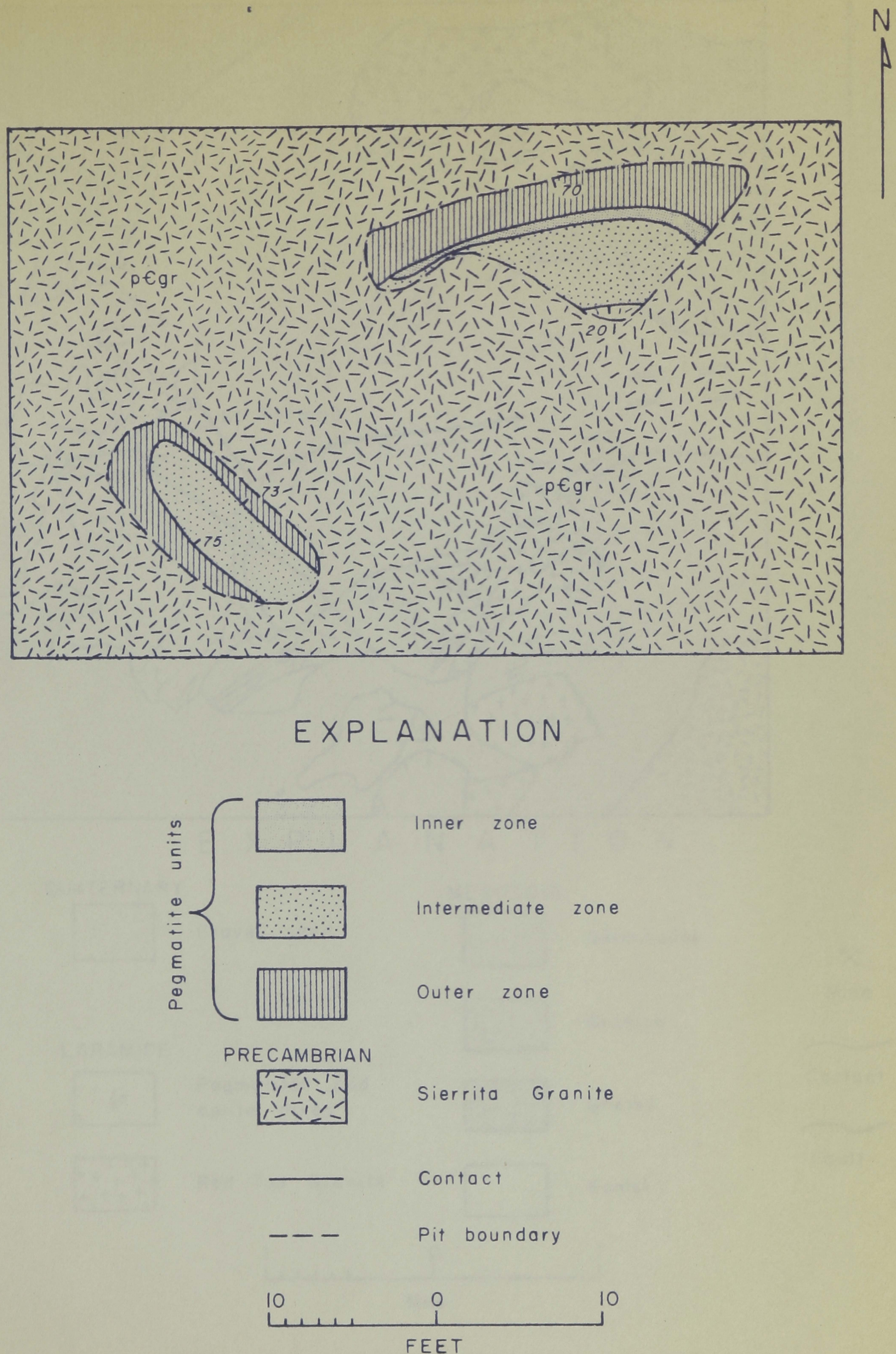
Galbraith and Brennan (1959) report beryl as occurring 1.5 miles east of the La Fortuna mine. Wilson (oral communication, 1961) states that although numerous granitic pegmatites occur in the area, he has not observed beryl. Soule (oral communication, 1961) reports that the U.S. Bureau of Mines investigated the area and did not fine any beryl. The writer did not visit the area because it is presently situated within an Armed Forces Gunnery Range and is not accessible to the general public.

Wilson (1935) describes the geology of the area in a regional report (Pl. 7). Schists, gneisses and amphibolites of Mesozoic age have been intruded by the Red Top Granite which occurs in three different masses, elongated along a north-northeast trend. Numerous simple granitic pegmatites occur in the area and are related to the granite. Beryl, if present, probably occurs in some of these pegmatites.



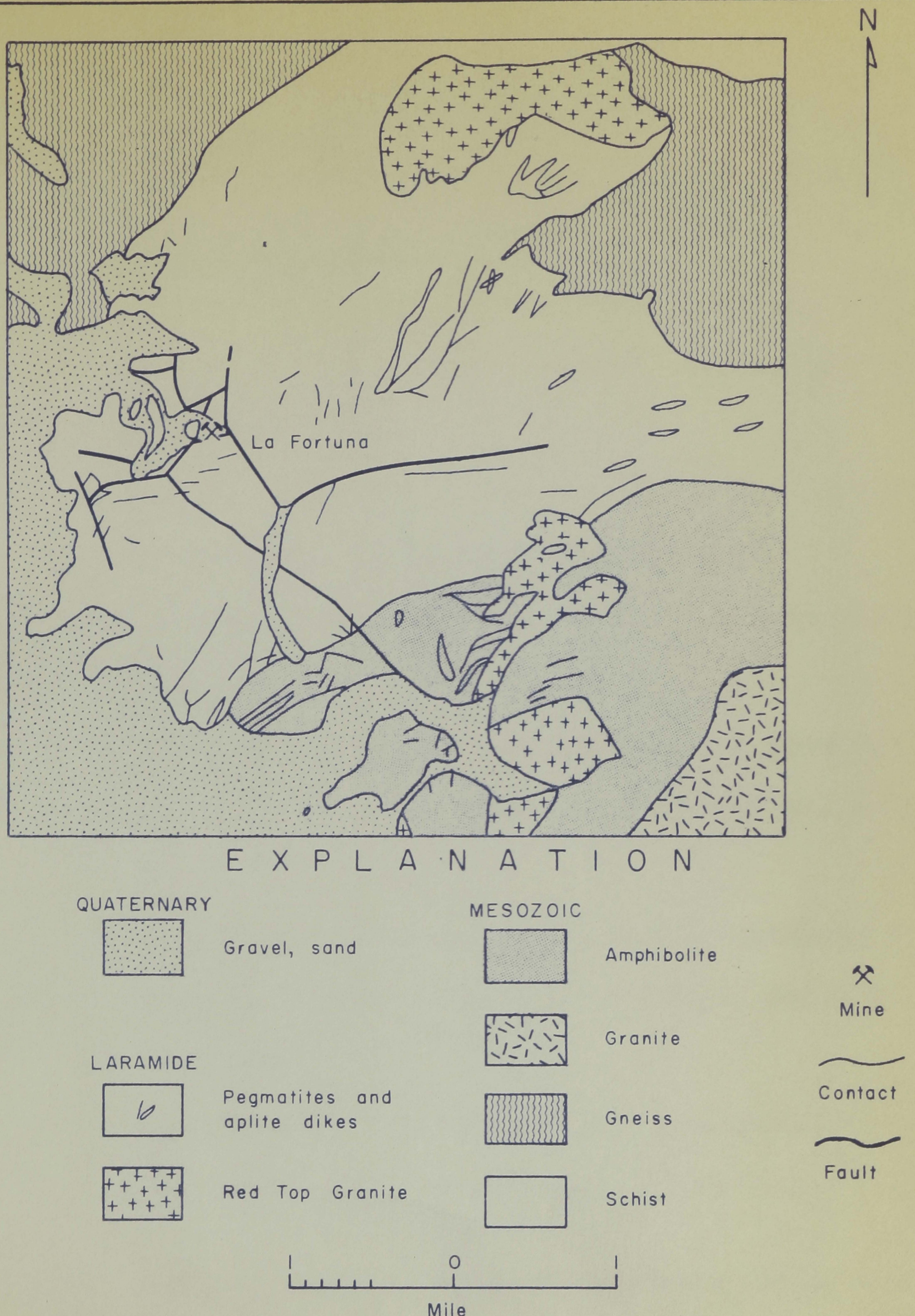
GEOLOGIC MAP OF THE NORTHERN SIERRITA MOUNTAINS PEDIMENT

Plate 5



GEOLOGIC MAP OF THE SHARON D PROSPECT, SIERRITA MOUNTAINS

Plate 6



GEOLOGIC MAP OF A PORTION OF THE
GILA MOUNTAINS, YUMA COUNTY, ARIZONA

After Wilson, 1933

Plate 7

6. SUMMARY OF BERYLLIUM MINERALIZATION IN SOUTHERN ARIZONA

The known beryllium deposits in southern Arizona are grouped below, and conclusions drawn from these deposits and other sources are discussed in the next section.

1. Deposits within Precambrian granites: 1, possibly 2 (Contreras Canyon, possibly Sierrita Mountains).
2. Deposits within Precambrian schists, adjacent to Precambrian granites: 1 (Tungsten King).
3. Deposits within Laramide granitic rocks: 2, possibly 3 (Swisshelm Mountains, Bluebird, possibly Sierrita Mountains.
4. Deposits within Paleozoic sedimentary rocks adjacent to Laramide granitic rocks: 3 (Abril, Gordon, Swisshelm Mountains).
5. Deposits within Mesozoic schists: 1 (La Fortuna).
6. Deposits within Laramide schists: 1 (Lalo Peak).

I. Pegmatite deposits: 2 (La Fortuna, Sierrita Mountains).

II. Pyrometasomatic deposits: 2 (Abril, Gordon).

III. Quartz-tungsten vein deposits: 2 (Tungsten King, Bluebird).

IV. Quartz-feldspar vein deposits: 2, possibly 3 (Contreras Canyon, Sierrita Mountains, possibly Lalo Peak).

V. Deposits of granitic rocks: 1 (Swisshelm Mountains).

7. BERYLLIUM MINERALIZATION RELATED TO ASSCCIATED ELEMENTS

Fluorine and tungsten are the two significant elements that seem to be associated with beryllium in southern Arizona. The tungsten occurs at the Tungsten King mine, Bluebird, and Contreras Canyon areas. It is not directly associated with the beryl, but occurs within the veins, close to the beryl. Although tungsten and beryllium are not similar chemically, the stabilities of their complexes apparently are similar, so that they occur together.

Fluorite has been found in nearly every deposit. The only deposits at which fluorite has not yet been found are Tungsten King and Lalo Peak. Almost all of the fluorite that was found was colored. The colors ranged from colorless through green, lavender, and dark purple. The great majority of the specimens have a light- to dark-purple color.

An interesting feature of the fluorite-beryllium occurrences is that fluorite occurs with beryllium irrespective of its geologic environment. Whether the deposit is a pegmatite (Sierrita Mountains), vein (Contreras Canyon), disseminated (Swisshelm Mountains), or contact metamorphic (Abril) is apparently immaterial. This relationship probably stems from the fact that in hydrothermal deposits beryllium is probably carried as a beryllium-fluorine complex. When the chemical conditions force the breakdown of the beryllium-fluorine complex, beryllium, in the form of beryl, and fluorine, in the form of fluorite, are deposited.

8. BERYLLIUM MINERALIZATION RELATED TO GEOLOGIC AGE

The summary of the geology of southern Arizona in a previous section stated that granitic intrusives were either older Precambrian, Mesozoic, or Tertiary in age.

In southern Arizona, beryllium mineralization is probably either older Precambrian or Laramide, with the strong possibility that all of the deposits are Laramide. In only a few deposits, however, can the age be conclusively demonstrated.

None of the beryllium deposits can be demonstrated to be of older Precambrian age, although three of the deposits, Contreras Canyon, Sierrita Mountains, and Tungsten King, could be older Precambrian in age. Six of the deposits are of Laramide age (Swissheim Mountains, Abril, Gordon, Bluebird, Lalo Peak, and La Fortuna), and possibly the Contreras Canyon, Sierrita Mountains, and Tungsten King deposits are also Laramide.

The Elfrida quartz monzonite has intruded Paleozoic and Cretaceous rocks; hence, the quartz monzonite is Cretaceous or younger in age. The associated beryllium deposits are therefore assigned a Laramide age.

In the Dragoons, the Abril and Gordon mines are genetically related to the Stronghold Granite of Tertiary age. In the Little Dragoons the Bluebird deposit occurs in the Texas Canyon quartz monzonite and is therefore also of Tertiary age.

The age of the Tungsten King deposit is not known; however, if the mineralization is related to the adjacent granite, then the mineralization is Precambrian. The deposit occurs in the Tungsten King horst of Laramide age, according to Cooper (1959), and thus may be Laramide in age.

The Sierrita Mountains deposits are of doubtful age. If the interpretation of the geology by Cooper (1960) is correct, then the beryllium mineralization is of Laramide age. If the entire area consists of Sierrita Granite as shown by Waller (1960), then the age is uncertain. Waller (1960) has shown that the dike pattern in the granite has no relation to other structures of known age, and he suspects that the pegmatites may have formed in tension fractures created in Laramide time by uplift of the Sierrita Mountains.

Whether or not the beryllium mineralization is related to the tension fractures in the granite is debatable (see section on regional structure for further discussion of this problem). However, the lack of known Precambrian mineralization of any kind in this area leads the writer to conclude that the deposits are probably Laramide in age.

The beryllium mineralization in the Baboquivari Mountains presents a problem similar to that of the Sierrita Mountains. C. L.

Fair (oral communication, 1961) has shown that a rock identical to the Otero Granite is of probable Precambrian age. Donald (1959) is unsure of the age of the Otero Granite but feels that the dikes in the area are Tertiary. If he is correct, then the beryllium mineralization is also of Tertiary age. Clark (1956) suspects that the granite porphyry is pre-Cretaceous in age, and that the beryllium mineralization is genetically related to this rock. If he is correct, then the beryllium mineralization may be Precambrian.

In the Lalo Peak area beryllium occurs in schists and quartzites of probable Laramide age; hence, the mineralization is post-schists, and is therefore probably Laramide.

Since the Lalo Peak beryllium is of probable Laramide age, and because of the indefinite age relationships in the Fresnal Canyon-Contreras Canyon area, the writer feels that the Otero Granite or granite porphyry is of Precambrian age, but that the beryllium mineralization is Laramide.

In the La Fortuna area, Wilson (oral communication, 1961) mapped the schists as Mesozoic in age. This is based on metamorphosed Paleozoic(?) limestones occurring with the schists in the northern end of the Gila Mountains. The Red Top Granite with its associated pegmatites intrude the schists, and therefore are of Mesozoic age or later. Since in this portion of Arizona Nevadan disturbances are more common than elsewhere in the State, the exact age is highly speculative.

9. BERYLLIUM MINERALIZATION RELATED TO IGNEOUS ROCKS

Beryllium mineralization in southern Arizona is related to mafic-free quartz monzonite and granite stocks.

The Swisshelm Mountains deposit is related to a mafic-free quartz monzonite stock, as is the Bluebird deposit in the Little Dragoons. The Abril and Gordon deposits are related to the Stronghold Granite, which is actually an alaskite.

In the Contreras Canyon area, Clark (1956) feels that the beryl is genetically related to the porphyritic granite. Donald (1959) does not state any hypothesis on the problem. The writer elsewhere has indicated that he suspects that the beryllium mineralization is not genetically related to the porphyritic granite.

In the Lalo Peak area, no granitic rocks were observed.

If the interpretation of the geology in the northern pediment area of the Sierrita Mountains by Cooper (1960) is correct, then the beryl is probably associated with the biotite granodiorite, since it occurs in both the granodiorite and the wall rocks. However, if the area is composed of the Sierrita Granite complex, then the intrusive source for the beryllium is not known.

The Tungsten King deposit may be related to the adjacent

Precambrian granite, although the writer does not think that there is proof of a genetic relationship. Therefore, the source of the beryllium is unknown.

If the above inferences are correct, then a problem arises with respect to the source of the beryllium. The deposits all seem to be related to strong structural features. Perhaps during the time that these structural features were tectonically active they permitted solutions of probable magmatic origin to migrate upward, and beryllium was one of the constituents of these solutions.

10. BERYLLIUM MINERALIZATION RELATED TO REGIONAL STRUCTURE

The writer realizes that the lack of reported beryllium deposits in certain areas of Arizona does not necessarily indicate a lack of beryllium mineralization in these areas. As more work is done, particularly in the western part of the State, new occurrences will probably be reported.

All of the reported beryllium occurrences in Arizona are shown on Plate 8. A casual inspection of the map would indicate that beryllium is randomly scattered throughout the State. Closer study, however, indicates that there seems to be significant grouping or concentration of deposits in certain areas.

The Black Mountains-Kingman area contains a number of deposits, as does the area around Grand Wash, to the north. Beryllium occurs in the Wickenburg-Bradshaw Mountain areas in central Arizona, while in southern Arizona beryllium occurs in the Sierrita Mountains-Baboquivari Mountains and Little Dragoon-Dragoon-Swisshelm Mountains areas.

Some geologists (Billingsley and Locke, 1941; Wisser, 1957; Mayo, 1958; Erickson, 1960) recognize that the earth's crust contains four fundamental structural trends; north, east, northwest, and northeast. These structural trends are characterized by zones of parallel structures called "lineaments" (Hobbs, 1911). The intersection of lineaments of different trends may sufficiently fracture the earth's crust to permit magma, ore mineralization, and related phenomena to reach the surface. Some geologists have considered the concept that the type or degree of fracturing brought about by these lineament intersections may be partially responsible for the type of magma and mineralization associated with the intersection.

Mayo (1958) has studied the relation of major ore deposits to lineaments in the Southwest, and from a study of his paper and the location of beryllium deposits in Arizona and adjacent States a few conclusions may be drawn.

Obviously not all of the lineament intersections localizes beryllium deposits, nor should it be expected that all intersections would contain beryllium deposits. Each lineament intersection is characterized by its own structural features developed during its period or periods of tectonic activity. Thus, only certain intersections or lineaments may have developed the proper conditions for beryllium mineralization. The writer has attempted in the following discussion to indicate which lineaments and lineament intersections appear to be important. Further work may alter some of the conclusions.

All of the beryllium deposits in southern Arizona occur in the

Texas lineament (Hill, 1902; Ransome, 1919), a broad zone of transverse structures which may be as much as 150 miles wide in Arizona (Mayo, oral communication, 1959). The persistent westward trend of the Contreras Canyon-Sierrita Mountains deposits is probably a reflection of this lineament.

The reported beryllium deposits in southern Arizona do not occur scattered throughout the area, but are grouped near two northwest-trending lineaments, the southwest Arizona belt and the central Arizona belt. This apparent relationship becomes more definite when the entire State is considered. It is observed that most, if not all, of the deposits in the northwest part of the State occur near one of the northwest lineaments.

Another lineament which appears to be of some importance is the north-trending Colorado River belt. Although only one known deposit (La Fortuna) occurs near it in southern Arizona, the lineament becomes more important in the north, especially where it and the two northwest-trending lineaments merge.

A significant grouping of beryllium deposits occurs where the northeast-trending Wyoming lineament crosses the northerly Colorado River belt.

Northeast structures which may be of importance are the Santa Rita and Morenci belts. Although these two belts are important with respect to base metal deposits, their importance in southern Arizona in regard to beryllium deposits is probably minor, although the trend of the veins at the Bluebird deposit may be due to one of these structures.

The problem arises as to <u>why</u> these lineaments and lineament intersections are important. Specifically, why are some lineaments and lineament intersections favorable for beryllium mineralization, while others apparently are not?

The lineaments are considered to be deep structural features formed during the original solidification of the crust. The fact that earthquakes occur as deep as 720 kilometers (Richter, 1958) indicates that faulting and fracturing occur not only in the crust, but well within the mantle.

The degree of fracturing caused by tectonic activity along any lineament is a function of a number of variables. Probably not all lineaments penetrate the earth's crust to the same depth. Some lineaments probably extend to great depths, while others may be relatively shallow.

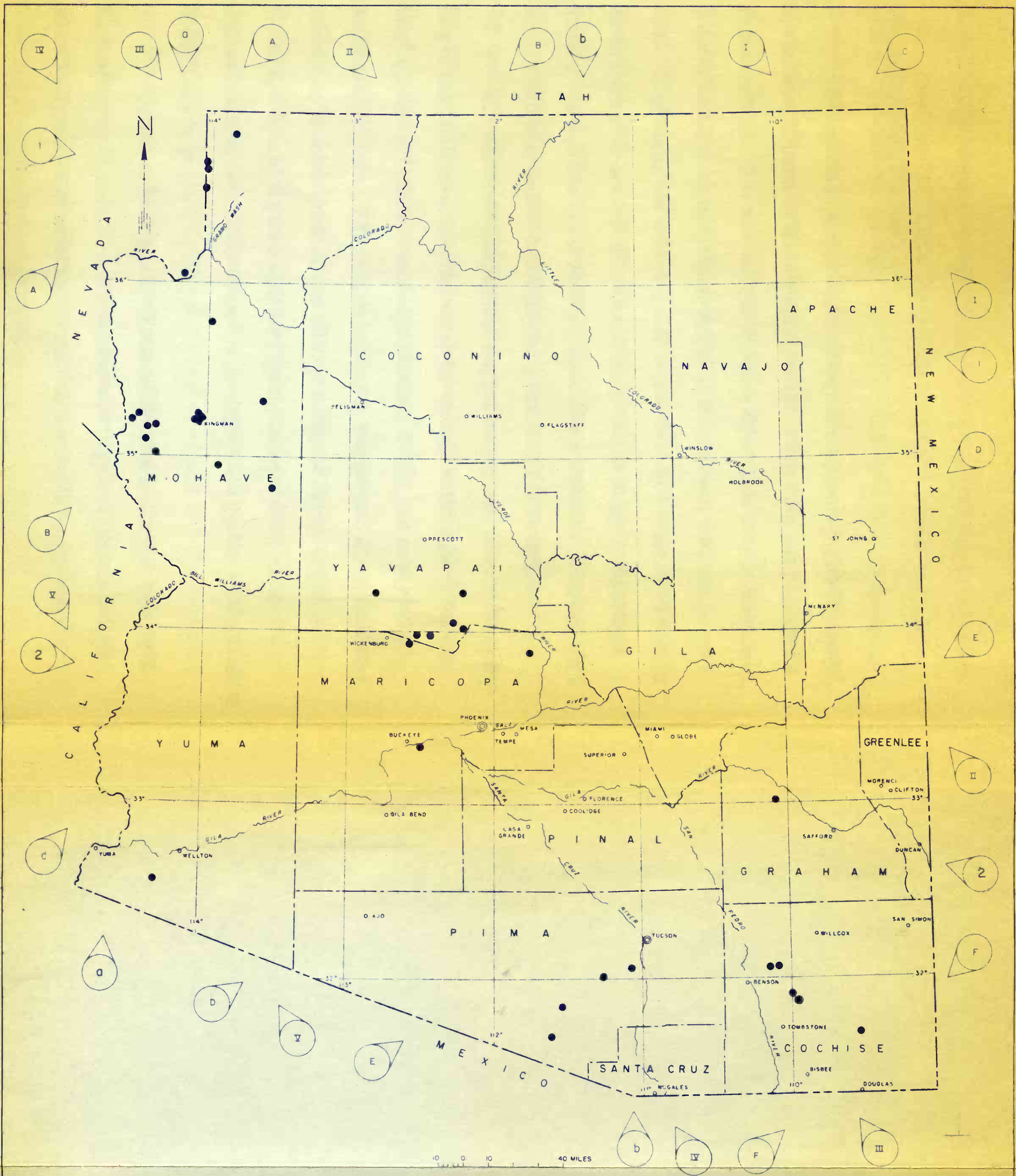
As fracturing occurs, it may permit magmatic fluids (liquids and/or gases) to form (largely due to a release in pressure). These fluids would tend to "mobilize" the rocks in which they occur, forming magma. The temperature, pressure, amount and character of these solutions available for mobilization probably are a product of the depth, degree, and nature of the rocks being fractured.

Tectonic activity along deep lineaments may permit the formation of magmatic fluids and magmas which will differ in physical and chemical characteristics from similar fluids and magma derived from shallower lineaments.

The magmas may then proceed toward the surface along zones of weakness until they reach equilibrium with their environment.

It should not be concluded that the initial mobilization, ascent of the magma, and final solidification of the magma occurs as a single, continuous process. The writer doubts that magmatic activity, which may have its origin deep within the crust or mantle, ceases only when the magma has reached the geological position presently observed. Instead, he suspects that the total ascent of magma may actually be a series of shorter ascents, with remobilization due to repeated tectonic activity along a given lineament or lineament intersection. Curtis, Evernden, and Lipson (1958) determined the ages of some granitic plutons adjacent to each other in the Sierra Nevada batholith in California, and found that the time lapse between the intrusion of the various plutons was on the order of one half to two million years. This may give some idea as to the order of magnitude of time between the emplacement of various plutons.

It should not be concluded that the writer believes that the "kind" (chemical and mineralogical composition) of magma and ore solutions is solely governed by the depth at which mobilization takes place. The type of mineralization and magma is probably a function of the physical and chemical nature of the original solutions, the chemical characteristics of the rock being mobilized, and the conditions under which mobilization takes place. Also, the writer does not believe that the beryllium or the magma is derived through granitization of sedimentary rocks, but that both have their origin deeper within the earth's crust.



EXPLANATION

Northeast Trends

- A Wyoming lineament, western zone
- B Wyoming lineament, eastern zone
- C Front Range zone
- D Jemez zone
- E Morenci zone
- F Santa Rita zone

Northwest Trends

- I New Mexico-Utah zone
- II Southwestern New Mexico zone
- III Central Arizona zone
- IV Southwest Arizona zone
- V Walker zone

North-South Trends

- a Colorado River zone
- b Utah-Arizona zone

East-West Trends

- 1 San Francisco zone
- 2 Texas lineament

● Known Beryllium Occurrences

MAP OF KNOWN BERYLLIUM OCCURRENCES AND THE LINEAMENT FRAMEWORK OF ARIZONA

Lineaments after Mayo (1958)

Plate 8

11. GEOLOGIC HISTORY

Deduction of the geologic history of beryllium mineralization in southern Arizona is largely speculative. Very little can be actually proven as fact. The conclusions drawn in this thesis may in some instances be based on inferences which, in themselves, may not be correct. Therefore, the following discussion should be considered merely as an attempt to present a "unified theory" of the origin and geologic history of beryllium mineralization in southern Arizona. Further work is required to establish with assurance that which is set forth.

The chemical composition and primary geochemical differentiation of the earth have been discussed by various writers (see, for example, Mason, 1958; Rankama and Sahama, 1950), and need not be elaborated on here. The various papers on the subject all indicate that during the primary geochemical differentiation of the earth (probably 3,300-5,500 million years ago) beryllium, because of its lithophile characteristics, was concentrated in the uppermost portion of the earth's lithosphere or crust.

During or before older Precambrian time, the four principal lineament trends were formed, and these have guided igneous activity since that time. The resulting structural intersections probably provided avenues or channelways for heat and solutions to migrate upward, which could assist in the mobilization and intrusion of magma.

In southern Arizona, as elsewhere, beryllium occurs associated with granitic rocks. The literature on the origin of granite is indeed voluminous, and the reader is referred to papers by Bowen (1928), Gilluly (1948), Poldevaart (1955), Tuttle and Bowen (1958, and Buddington (1959) for detailed discussions on this subject.

Some of the granites (Sierrita Mountains, Contreras Canyon) approach batholithic dimensions, while others (Bluebird, Dragoon Mountains, Swisshelm Mountains) are stocks. As was noted elsewhere, the writer doubts that the beryllium in the Sierrita Mountains and Contreras Canyon areas is related to the granites in which they occur. However, the beryllium mineralization in the other deposits has been shown to be related to the intrusive rocks.

The depth and temperature at which these granites formed is unknown, but depths of 10-40 kilometers and temperatures of approximately 640°C (Tuttle and Bowen, 1958) are probably within the correct range of magnitude. These granites, once formed, migrated upward along structural "breaks" until they reached a depth of 7 kilometers or less (Buddington, 1959) from the surface, before they completely solidified. Presumably, had they reached the surface, volcanic activity would have ensued. The beryllium during this interval was transported in the volatile component of the magma.

The beryllium remained in solution until the final stages of crystallization, after the magma was emplaced. At this stage of magmatic activity the geochemical behavior of beryllium was governed by the composition and character of the volatile components of the magma. When the base metal sulfides were present, as at the Abril and Gordon deposits, the beryllium entered the tactite. When base metals and beryllium were concentrated in different portions of the intrusive, as at the Bluebird deposit, the base metals again formed a contact metamorphic deposit (Johnson Camp), only here devoid of beryllium (Warner and others, 1959). What little beryllium was present was concentrated with tungsten and occurred in the Bluebird deposit. In the Swisshelm Mountains deposit, which is devoid of base metals, the beryllium remained within the intrusive and occurs in joints and quartz veins.

The Sierrita Mountains and Contreras Canyon areas provide an anomalous situation. The beryllium cannot be definitely related to any adjacent intrusive, although the Gunsight Mountains deposit may be related to the adjacent Laramide(?) granodiorite. The mineralization is probably related to the lineament structures which provided the conditions for beryllium to be mobilized and deposited.

In southern Arizona known beryllium mineralization has occurred only during Laramide time, although other areas of Arizona may have experienced Precambrian mineralization (White Picacho District, Jahns, 1952, 1955).

PLATE 9

A

Abril mine, Dragoon Mountains. Escabrosa Limestone surrounded by the Stronghold Granite.

B

Elfrida area, Swisshelm Mountains, looking east. The Elfrida quartz monzonite has intruded the Paleozoic and Cretaceous sedimentary rocks which form the main mountain mass.


Tsg
Ce
Tsg

PLATE 10

A

Tungsten King mine, Little Dragoon Mountains. The outcrop of the Tungsten King vein shows as a horizontal line between the arrows. Older Precambrian Pinal Schist occurs above the vein, and probable Precambrian granite occurs below the vein, in the foreground. Pipe in lower right hand corner leads from the building to the portal of the mine, behind the small trees.

B

Tungsten King vein, Little Dragoon Mountains. Looking down the dip of the vein. Note brecciated quartz vein (main vein) and the smaller vein above it. Dark-colored rock is Pinal Schist, light-colored rock is granite.


p€p
p€g


p€g

PLATE 11

A

Contreras Canyon, Baboquivari Mountains. Beryl-bearing quartz-feldspar vein exposed in a small prospect. Surrounding rock is probable Precambrian granite.

B

Contreras Canyon, Baboquivari Mountains. Sawed cut across beryl-bearing quartz-feldspar vein. Dark gray is quartz, blue is beryl, white is orthoclase. Dark-brown spot on right hand side of vein is oxidized sulfides.


0
1
2
3
inches

PLATE 12

Sharon D prospect, Northern Sierrita Mountains. The rock on the right hand side of the contact (where the hammer is located) is the outer wall zone of biotite, quartz, orthoclase, and beryl. The rock on the left of the contact is the intermediate zone, consisting of quartz and orthoclase. At the bottom of the pit are the remnants of the core, which was essentially quartz and beryl.

12. APPENDIX

(12.1) Reported Beryllium Deposits in Southern Arizona

The following reported beryllium occurrences have come to the writer's attention during the course of his work on the problem. None of the localities were visited.

Cochise County

1. Beryl has been reported from the Hillside mine area, Chiricahua Mountains. Theses by Brittain (1954) and Papke (1952) do not mention its occurrence.

Gila County

1. No deposits have been reported to date.

Graham County

1. Beryl has been reported from the western foothills in the Pinaleno Mountains. The beryl may be associated with pegmatites in Precambrian

granite which occur in the general area.

2. The 1961 Metallic Mineral Map of Arizona indicates beryllium near Geronimo. The Arizona Bureau of Mines has no reference on this occurrence.

Greenlee County

1. No deposits have been reported to date.

Maricopa County

1. The 1961 Metallic Mineral Map of Arizona indicates beryllium in the Buckeye Hills. The exact location is unknown, but numerous pegmatites occur in the area and may be the source of the beryllium.

Pima County

1. Galbraith and Brennan (1959) report beryl from the Bella Donna claim in the Sierrita Mountains. This locality was never identified, although it may be one of the prospects in the vicinity of the Neptune fluorite property near Gunsight Mountain.

2. Beryl, similar in occurrence to the beryl deposit in Contreras Canyon, has been reported in the Coyote Mountains. Theses by Kurtz (1955) and Wargo (1954) covering the general area do not mention beryl.
3. Mining claims called the "Beryl Crystal" have been staked in the Quijota mining district in the Quijota Mountains. The exact location is unknown. Gebhardt (1931) in his thesis on the Quijota Mountains does not mention any beryl.
4. The 1961 Metallic Mineral Map of Arizona indicates beryllium near Arivaca. The locality is unknown.
5. Clark (oral communication, 1961) has informed the writer of a possible beryl deposit in the Pozo Verde Mountains. The exact locality is unknown.

Pinal County

1. No deposits have been reported to date.

Santa Cruz County

1. The writer has seen some beryl similar to the

Sierrita Mountains occurrences which reportedly came from the Canelo Hills. Feth (1947) in a dissertation on the northern Canelo Hills does not report any beryl.

2. Beryl has been found in a pegmatite near Ruby.

Yuma County

1. Beryl has been reported from the Trigo Mountains. The occurrence is unknown.

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