# THE LITHIA PEGMATITES

of

PALA and MESA GRANDE

San Diego County

California

b y

Maurice Donnelly

# ILLUSTRATIONS

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TERRANE ABOUT PALA VILLAGE

View looking northward from an airplane flying
at an altitude of about six thousand feet over
a point a few miles east of Lilac.  Pala village
lies at the extreme middle left.

a—Pala Mountain
b—San Luis Rey River valley
c—Temecula Basin
d—Northwestern part of Agua Tibia Mountain

Photo by U.S. Army Air Corps

PLATE IV
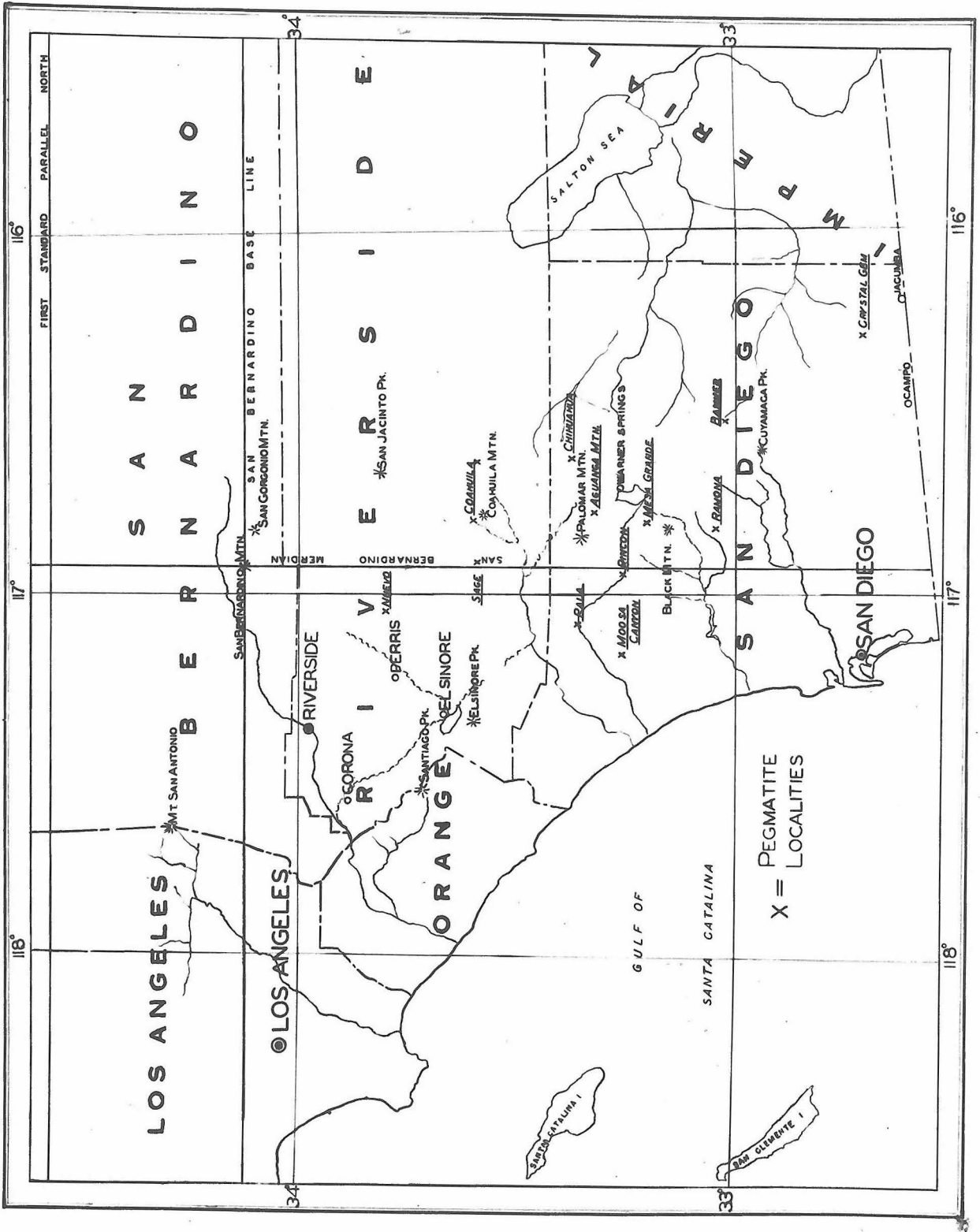
MAP SHOWING LOCATION OF PRINCIPAL PEGMATITE LOCALITIES IN SOUTHERN CALIFORNIA

FIRST STANDARD PARALLEL NORTH

LOS ANGELES

SAN BERNARDINO

RIVERSIDE

ORANGE

SAN DIEGO

◎ LOS ANGELES

● RIVERSIDE

SAN BERNARDINO BASE LINE

SAN BERNARDINO MERIDIAN

※ Mt SAN ANTONIO
⚹ SAN GORGONIO MTN.
San Gorgonio Mtn.
San Bernardino Mtn.
⚹ San Jacinto Pk.
○ CORONA
○ PERRIS
× HEMET
⚹ Santiago Pk.
⚹ Elsinore Pk.
ELSINORE
Sage
× COAHUILA
⚹ Coahuila Mtn.
× PALA
× MOOSA CANYON
× PALOMAR MTN.
× CHIHUAHUA
× AGUANGA MTN.
⚹ Warner Springs
⚹ PONTON
× MESA GRANDE
BLACK MTN.
× RAMONA
Banner
× Cuyamaca Pk.
× CRYSTAL GEM
○ JACUMBA
OCAMPO

SALTON SEA

○ SAN DIEGO

GULF OF
SANTA CATALINA

SANTA CATALINA I.
SAN CLEMENTE I.

X = PEGMATITE
LOCALITIES

118°  117°  116°
34°
33°

# INTRODUCTION

## SITUATION AND ROUTES OF ACCESS

The Mesa Grande and Pala regions, with which this report is chiefly concerned, both lie in the northern part of San Diego County. In an airline Pala is 80 miles southeast of Los Angeles and 45 miles northeast of San Diego. By road these distances are 100 and 55 miles, respectively. Mesa Grande in an airline is 105 miles southeast of Los Angeles and 40 miles northeast of San Diego. Along the most convenient route from Los Angeles to Mesa Grande the distance is 135 miles; from San Diego, 55 miles. Most of the other localities mentioned in this report are in the north-central part of San Diego County; two, Nuevo and Coahuila, are in Riverside County southeast of Riverside. The relative position of these places may be seen in the accompanying map showing the location of the principal pegmatite localities in Southern California.

Pala and Mesa Grande are most conveniently reached from Los Angeles by way of Corona and Elsinore to Temecula. A short distance south of Temecula the route to Mesa Grande turns eastward and proceeds along the eastern side of Agua Tibia Mountain to the vicinity of Henshaw reservoir. Two roads from here to Mesa Grande may be taken. One goes directly over the remarkably steep scarp, that bounds Henshaw reservoir on the south side, to Mesa Grande. The other follows southeastward the trace of the Elsinore fault zone in this vicinity. The turnoff to Mesa Grande from this road is near the Indian church in Santa Ysabel Valley. In order to reach Pala from the Corona-Temecula route, one turns south from the main

highway at Temecula Bridge. From here the road to Pala is unimproved and in the stretches that lie in Pala canyon is frequently narrow and sharply winding. It is little traveled, however, and is usually in good shape.

From San Diego the best route to Pala follows the so-called Inland Route as far north as Bonsall, near where the road to Pala, unimproved but always in fine condition, proceeds up the valley of the San Luis Rey River. To reach Mesa Grande from San Diego an improved highway may be followed to Santa Ysabel, whence the route to Mesa Grande turns northward. No railroads traverse the regions herein discussed.

Of the other localities shown on the sketch map, Moosa Canyon and Banner are difficult of access and relatively unimportant, Aguanga Mountain and Chihuahua are near good roads but the last few miles to them traverse steep, fire-protection roads. Nuevo, Rincon, and Ramona are easily accessible. The Fano mine northeast of Coahuila Mountain is difficult to reach.

## FIELD WORK AND ACKNOWLEDGEMENTS

During the spring of 1931 a week was spent in studying the pegmatites at Mesa Grande. Four weeks field work was done during the summer and fall of 1934 at Pala and one week in August, 1934, was spent in surveying part of the Mesa Grande region. Occasional trips of one or two days duration were made to Pala and Mesa Grande and other San Diego County pegmatite localities at various times during 1932, 1933, 1934, and 1935. The writer spent most of the summer of 1932 and two weeks of the 1933 field season in a study of the Julian district, San Diego County, where the rock formations are much like those at Pala and elsewhere in the Peninsular Range. The results of the Julian investigation have been published as a somewhat

detailed paper in the California Journal of Mines and Geology.[1]

Mr. A. F. Johnson, Indian agent at Pala, extended many courtesies and placed the use of a cabin at the disposal of the writer. Mrs. F.A. Salmons of Pala, widow of the developer of the Pala Chief and Tourmaline Queen mines, kindly permitted access to her properties and allowed the writer to examine her collection of the cut and uncut gem stones which originated from the Pala mines. Mr. Ralph Bushnell, rancher, of Mesa Grande has been especially kind and the writer's thanks are due him for numerous favors. Mr. Kenneth Carver served a volunteer assistant in the field for three weeks in the summer of 1934. To Dr. Rene Engel, until recently instructor in mineralogy in the California Institute and at whose suggestion the problem was undertaken, the writer is deeply obligated for stimulating criticism and penetrating advice. Professor J. P. Buwalda and Dr. Ian Campbell, of the Division of Geology and Paleontology in the California Institute, discussed the questions encountered during the study and the latter critically reviewed the field and laboratory work.

At the inception of the investigation no other worker appeared to be actively interested in a study of the pegmatites of Southern California. Dr. W. T. Schaller of the U.S. Geological Survey had been working on the subject since 1903 and had published numerous papers on the mineralogy and one paper on the genesis of the lithium pegmatites of Southern California. When the program of research of the writer was approved in 1933 no published contributions on the California lithium pegmatites from Dr. Schaller had appeared for about a decade. About the same time that the writer began intensive field work, in the spring of 1934, Dr. Schaller returned to

[1] Donnelly, Maurice. Geology and mineral deposits of the Julian District, California. Calif. Jour. Mines and Geology 30: 332-368 (1934)

the problem and the writer was so fortunate as to spend a few days in the field in Pala with him. Many of the most puzzling questions concerning the mineral association in the Pala pegmatites have already been clarified, although not published upon, by Dr. Schaller and he drew freely upon his wide and intimate knowledge of the problem of the pegmatites in conversations with the writer. While it has been the intention to specifically credit him in this report with ideas advanced, it has not wholly been possible to do so and the writer wishes to take this opportunity to express his appreciation and admiration for the friendly and whole-hearted manner with which Dr. Schaller communicated information and ideas.

## ECONOMIC SUMMARY

### History

The early history of the lithia pegmatite mines of San Diego County is obscure. The brief account appearing here has been gleaned from the writings of Kunz, Schaller, Orcutt, and others. It has not seemed worth while to make detailed references to the historical aspects of their writings.

The earliest recorded discovery of gem tourmaline in California was in 1872, when a Mr. Gillette found or reported the finding of several beautiful achroite (colorless) tourmaline crystals on Thomas Mountain, near Anza in Riverside County. W. P. Blake, writing in the 2nd Annual Report of the State Mineralogist in 1882, records the discovery in southern California of rubellite and lepidolite. The locality was given as the Bernardino range. From the description of the material - the rubellite is a "beautiful rose pink, contrasting well with the matrix of white lepidolite" - the locality from whence it came is undoubtedly Pala.

The pegmatite dike now known as the Stewart dike, from the mine which has been developed in its southern part, is visible from the main road in the San Luis Rey River valley, a communication route that has been in constant use by white men since the time of the Spanish missions. The remarkable color of the purple lepidolite and pink tourmaline occurring in it made the dike known to the Indians, who showed specimens from it to white men. The red color in the tourmaline suggested to a prospector named Magee the possible presence of cinnabar and he accordingly staked out a claim. Failing to extract mercury from the rock, Magee abandoned the claim and it was subsequently relocated as a marble quarry. As might be expected this venture failed too. Some time in the late 80's a German chanced to see a specimen of lepidolite in New York which came from Pala and informed his American acquaintances of its value. Bunsen had, in 1861, discovered the element rubidium in lepidolite from Saxony and probably for this reason the German recognized lepidolite. Eighteen tons of lepidolite and rubellite were produced from the Stewart mine at Pala in 1892; most of this was used as specimen material. Substantial commercial production of lepidolite seems to have commenced in 1900 and in the next few years several hundred tons of lepidolite and a considerable amount of amblygonite was produced from the Stewart mine.

The pink tourmaline found at the Stewart mine is usually highly altered and the specimens produced in the early days were almost never utilized as gems. In the epoch of vigorous prospecting which followed the discovery of the value of lepidolite, search was made, not for gem tourmaline, but for lepidolite and while in search for this the greatly productive gem tourmaline mines of Mesa Grande were discovered by white men. Previously they had been known to the Indians, as several multi-

colored tourmaline crystals of rare beauty had been picked up by Indian children while at play in an Indian encampment near the site of what is now Angel's farm. The dikes from which the tourmaline came was not found until 1898 when prospectors seeking lepidolite discovered the series of closely spaced dikes called herein the Himalaya lode. The Himalaya mine is on the northern end of this lode and the San Diego mine on the southern end. The Esmeralda mine at Mesa Grande was discovered a short time after the Himalaya was found.

The Himalaya mine at Mesa Grande was operated to about 1914 by the Himalaya Mining Company. Up until that time a ready market existed in China for tourmaline of third or fourth grade. The Chinese were deeply fond of red tourmaline and apparently were just as eager to possess flawed as unflawed material, their reasoning being that clear jewels could be made artificially but flawed gems could not be so duplicated. The revolution in China closed this market and the domestic demand was over-supplied. In the same year the Tourmaline King mine at Pala was purchased at a reported price of $10,000 and a formidable program of development was pursued. The amount of gems produced by this work was insignificant and no further work, except assessment work and very little of that, was done on any of the gem mines in San Diego County, until 1928, when the General Electric leased a part of the Himalaya lode and sunk a shaft 268 feet deep in a search for the rare caesium feldspar, pollucite. Pollucite has been reported from Mesa Grande, although the report is not confirmed. After a year's work no pollucite was found[1] and technologic changes caused the demand for pollucite to disappear.

[1] General Electric Co., written communication to the writer.

In the past few years practically no work has been done on the gem mines of San Diego County. The only lithia mine in the county, the Stewart, has been inactive since 1920. The Indian Service has recently, 1934, declared all mining claims on Indian land void. The effect of this ruling on gem mining is not now predictable. It will not, of course, affect patented claims or mines on patented land. Three of the most important mines at Pala, the Stewart lithia mine which also contains some green gem tourmaline, the Pala Chief and the Tourmaline Queen mines are unpatented. Whether any or all of these mines are on Indian land can not now be definitely stated.

About a decade after the first shipment of lepidolite and rubellite was made from the Stewart mine, M. M. Sickler and his son Frederick M., were doing assessment work on a claim held as a lepidolite location on Hiriart Hill, about a mile and a half east of the village of Pala. The elder Sickler was a pioneer resident of the country and had operated for many years a grain mill powered by water from the San Luis Rey River. They had uncovered a mass of chalky substance containing very large quartz crystals, some weighing nearly a hundred pounds. While removing the quartz crystals they found embedded in some odd-appearing clay, beautiful clear crystals, most of which were lilac color, some were straw color, and some colorless. After a fruitless attempt to identify the mineral, specimens of it were sent in December, 1902, to Tiffany & Co., of New York, where they were pronounced spodumene by Dr. Geo. F. Kunz. Dr. Kunz had previously found small, altered pieces of lilac spodumene at Branchville, Conn. The name kunzite was given to the clear and colored varieties (except green) of spodumene by Charles Baskerville in honor of Dr. Kunz.

The next year, 1903, the Pala Chief mine was discovered by two Basque prospectors, Bernardo Hiriart and Pedro Teiletch. It was worked for many years by Mr. Frank A. Salmons and yielded most of the kunzite produced in the United States, as well as abundant and beautiful gem tourmaline. The Tourmaline Queen mine, the Tourmaline King and the Ed Fletcher, Jr., mines were discovered about this time.

The Mountain Lily mine on Aguanga Mountain and the Mack and Victor mines near Rincon were discovered in 1903. The other gem mines in San Diego County were found either about this time or a little earlier.

## Production

### Lithium minerals

The only locality that has yielded lithium minerals on a commercial scale is Pala, where the Stewart mine worked a rather large deposit of lepidolite and a much smaller concentration of amblygonite. The figures reproduced here represent the only estimates of the production from the Stewart mine that the writer could find in the literature.

| | Tons | Estimated price a ton | Total Annual Value |
|---|---|---|---|
| 1900 | 300 | $25 | $7,500 |
| 1901 | 1500 | $25 | 37,500 |
| 1902 | 900 | 20 | 18,000 |
| 1905 | 21 | 11 | 252 |
| 1918 | 3000 | 18 | 54,000 |
| | | Grand total | $174,852 |

Just before the discovery, about 1907, of large amblygonite deposits in South Dakota the price of lithium carbonate, the chief commercial form of lithium, was $2.00 to $2.50 a pound. Shortly after this

discovery the price fell to 50¢ a pound. The deposit of lepidolite at the Stewart mine was too low grade to be worked in competition with the South Dakota mines, whose reserves of amblygonite and spodumene were, and still are, large. Practically no lepidolite was produced from the Stewart mine during the period 1905-1917. The rather small body of high grade amblygonite ore occurring at the Stewart mine apparently was worked out in the early life of the mine. The next production of lepidolite from the Stewart mine came in the closing months of the World War and during the boom that immediately followed it. In order to achieve this production the mine was gutted and the workings today are in very dangerous shape. Were it not for the very light overburden the workings would be entirely caved. All the higher grade lepidolite ore that could be conveniently reached was mined out; that remaining is admixed with much quartz, feldspar, and tourmaline.

An interesting sidelight on the technology of lithium arises from the disposition of lithium ore during the first years of the century. Most of the lepidolite mined in 1900-1905 was shipped to Germany for treatment; most of the spodumene was treated in this country. Although the writer has no means of verifying this hypothesis, it is believed the Germans had a process for the extraction of rubidium and perhaps caesium from the Pala lepidolite and that this byproduct helped compensate for the lower grade in lithium of the lepidolite ore.

Lithium, the lightest known solid element (S.G., 0.53), also occupies the highest position in the electromotive force series of any of the relatively common metals. It is in virtue of this property that it has been found useful in storage batteries, whose manufacture has ab-

sorbed much of the production. A considerable amount of lithia salts and lepidolite is also used in the manufacture of glass. The older literature states that much of the production of lithium was used in medicinal tablets and waters, but this is doubtful. A small amount has been used medicinally and is still being prescribed in Europe, particularly for the treatment of gout. This affliction is not widespread in America and the use of lithium in medicine in various forms has virtually ended in the United States.

## Gem Tourmaline and Beryl

The Himalaya lode at Mesa Grande has been the greatest producer of gem tourmaline in the world. Of the two mines located on it the northerly one, the Himalaya, has been much more productive than the next mine south, the San Diego. Exact production figures are not available, as expectably, gem miners are not prone to divulge information. The production from both mines was estimated to be worth $15,000 in 1901 and $40,000 to $50,000 in 1904. Probably a fair estimate of the value of the yield up to 1904 would be $100,000. From the first year's work on the Himalaya mine it is related there was produced 6 tons of tourmaline of which 400 pounds was flawless gem material and much of the rest good cabinet material. The Himalaya Mining Co. worked this mine for ten years, 1904-1914, during most of which time they used coolie labor. The total production of gem tourmaline was extremely large, although no estimate can be made. Green, blue, deep red, rose, colorless, and yellow tourmaline of solid colors and in a variety of multi-colors has been produced from the Himalaya lode. Red tourmaline (rubellite) in various shades predominated. Aquamarine

beryl has been produced to some extent from the Himalaya lode and a considerable amount of rose beryl, or morganite, has been extracted. Because of the rather poor appearance that most of the beryl makes in the rough much of it was thrown on the dump and has been collected in recent years by screening the dump material.

During the sorting of the gem tourmaline obtained in early mining operations at the Himalaya mine a large amount of third grade specimens were stored in a cache under the sorting house. This cache was uncovered in the past few years by amateur collectors who became thus the possessors of a large stock of beautiful crystals. The writer visited the Himalaya mine in 1932 and again in 1934. In the short period intervening between the two trips a great deal of feldspar and tourmaline material had been carried away by amateur collectors. The surface matter of all the dumps has been screened many times and one dump, named nodule dump, has been entirely screened and many handsome specimens of beryl taken from it.

The depth at which gem tourmaline has been found at the Himalaya mine is also unique; gem specimens having been found at a depth of 200 feet or deeper. Gem tourmaline mining in other districts in the world seldom attains a depth in excess of a hundred feet.

At the Esmeralda mine, at Mesa Grande, the only economic mineral found was gem tourmaline. It occurred as pink, bright red, azure blue, aquamarine blue and a peculiar blue green which when cut produced a stone with one set of facets sapphire blue and another emerald green. This last named gem has not been found elsewhere. Part of the dike at the Esmeralda mine bottomed at a relatively shallow depth and mining operations, never extensive, have been suspended for a long time.

The principal producers of gem tourmaline at Pala are the Pala Chief, Tourmaline Queen, and Tourmaline King and Ed. Fletcher, Jr., mines. The Ed. Fletcher Jr. and Tourmaline King mines worked the same dike and they are described collectively hereafter as the Tourmaline King mine.

The Pala Chief mine, in addition to being the most important producer of kunzite, also yielded a large quantity of beautiful gem tourmaline crystals. Some of these were a foot in length and three inches in thickness. Rubellite predominated over the other colored varieties, although much dark blue material was produced. While not such a prolific producer as the Himalaya mine, the Pala Chief mine was an important producer and is notable for the large crystals of unfractured tourmaline found there. A very rough estimate of the value of gem tourmaline from this mine, for the rough material as produced, would be about $15,000. Tourmaline cut stones currently sell for $10 to $25 a carat. The multi-colored stones are especially beautiful.

The Tourmaline Queen mine, owned and operated for many years by the late Mr. Frank A. Salmons, was worked principally for gem tourmaline. The value of the product at the mine may be placed at $10,000, a very generalized estimate. The Tourmaline King mine produced gem tourmaline which probably had a value between $10,000 and $15,000.

Like all the gem tourmaline producing districts in southern California, tourmaline of various colors, chiefly red, green, blue, yellow, colorless, and combinations of these, were produced at Pala; of these, however, red has been the dominant colored variety and probably has yielded by far most of the financial returns.

The pink beryl, named morganite in honor of the late J.P. Morgan

whose great gem collection was donated to the American Museum of Natural History in New York City, has been found in moderate quantity at Pala, Mesa Grande, Rincon, and other lithia pegmatite localities in southern California. Many of the specimens have been found by collectors who have had them cut for sale. The price of the cut stones is $10 to $35 a carat, although very fine stones may bring a higher price. The value of the total production of pink beryl at the mines in Mesa Grande, Pala, and Rincon is estimated to be between $2,000 and $5,000. This does not include the material surreptitiously found by wandering collectors.

So far as the writer knows, the only locality in San Diego County that has produced green beryl, or aquamarine in notable quantities is Rincon, where a number of fine stones were uncovered by working shallow pits. These stones were worth in the rough several thousand dollars.

### Kunzite

Following the discovery of kunzite, the lilac spodumene, in large amounts at the Pala Chief mine in 1903 a fashionable and sizeable demand was created, based on its attractive color and its unique position of being at that time the only exclusive American gem stone. Stones of a sufficient transparency and color to be cut for gems sold for $50 an ounce, which is the current price today. The following figures are little more than guesses. The kunzite produced from the Pala Chief mine may have had a money value at the mine of $15,000 to $25,000. The kunzite produced from Hiriart Hill, largely by the Sickler family, probably sold for a total of less than $5,000. No other mine or district has produced kunzite in commercial quantities.

The test of time has revealed kunzite to be somewhat soft as a gem stone. The abrasion of silica particles in the air result in a loss of finely cut edges and a dimming of the facets. Some of the deeper colored lilac stones have faded visibly upon exposure to light. Most soft gem stones are cut en cabochon, i.e. with a round face presented to the surface of maximum abrasion, but kunzite is said to lose brilliance when cut in this manner.

## Topaz, Garnet, and other gem stones

Topaz from Ramona and the Mountain Lily mine on Aguanga Mountain, garnet from various districts, especially from Ramona, spinel from Rincon, and clear quartz from nearly all of the gem mining districts, have been cut from time to time as gem stones. The value of all this material at the mine is of the order of $20,000.

## Rose Quartz

Several deposits of rose quartz occur in San Diego County, although not in direct association with the lithia pegmatites. One of these, the Rose Quartz mine, at Mesa Grande, has been worked and a few tens of tons of quartz has been shipped to Los Angeles. Other deposits of silica in San Diego County have been worked but their exact geologic nature is not known to the writer.

## Minor Economic Minerals

A number of other minerals occur in the lithia pegmatites of San Diego County which up to the present time, at least, are not found there in sufficient quantity or proper grade to be worked commercially. Small concentrations of cassiterite have been found in Chihuahua Valley and at the Himalaya mine. The same districts have yielded very small amounts of columbite, and stibiotantalite has been found at the Himalaya mine. Biotite and muscovite, extensively mined in some pegmatites in other parts of the United States and the world, do not occur in the San Diego County pegmatites in a sufficient size or quantity to be utilized. Massive beryl, the present chief source of beryllium, recently in demand in metallurgy, has up to the present time not been found even in moderate quantities in San Diego County. The bismuth and phosphate minerals in the Pala pegmatites do not occur in sufficient quantities or purity to be considered even a potential economic source of their constituents. Feldspar for ceramic purposes is mined from some of the pegmatites of southern San Diego County, but the lithia pegmatites are, in general, too small or too low grade to be potential sources of feldspar for the ceramic industry. The same thing is true of the kaolin minerals which occur in the lithia pegmatites.

One source of revenue which gem mine owners in San Diego County have almost completely overlooked is that which might be derived from the sale of specimens to visitors who come to inspect the deposits. They have also failed to realize that the deposits are famous among mineralogists the world over and that a considerable income might be derived from a fee charged visitors, especially if a few pockets were opened up to

show the mode of occurrence of the gem minerals. As it is now, the deposits do not yield an income large enough to warrant the services of a watchman and such material as is exposed is rapidly being carried off to decorate fish ponds or gather dust on forgotten shelves.

## Future of Mining

A discussion of the future of mining in the lithia pegmatites of Southern California resolves itself into a consideration of four economic products; gem tourmaline, gem beryl, lithium, and kunzite. Of the four mines at Pala which have produced gem tourmaline, two, the Pala Chief mine and the Tourmaline King mine, do not present likely prospects for the future. The Tourmaline King mine was rather thoroughly prospected in an efficient manner about 20 years ago and little of worth was found. The Pala Chief mine has been practically worked out. The Pala Chief dike is definitely cut off by erosion on three sides and most of the favorable ground has been well prospected. The Stewart mine has in recent years produced a small quantity of very fine tourmaline. It is considered a likely place to seek tourmaline in the future. A rather brief examination of the Tourmaline Queen mine leads the writer to believe that further prospecting here might reveal additional tourmaline. The mines on Hiriart Hill have never yielded very much gem material even during the epoch of vigorous prospecting and they are not thought to be favorable places in which to do further work. This belief, admittedly, is founded mostly on past production, as the Sicklers would not allow the writer to inspect their properties, which cover most of Hiriart Hill. The Esmeralda mine, at Mesa Grande, does not appear to

contain much favorable ground in which to do further prospecting. The Himalaya lode, at Mesa Grande, is not worked out but mining here in the future will be expensive and the pockets where found at depth will not be so highly altered as they were near the surface and the dike material will be harder to break and extract. The Himalaya lode offers the best opportunity for gem tourmaline and pink beryl production in the future.

The prospects for lithia production in San Diego County in the future are not bright. This arises not only from the countrywide situation as to lithia reserves, but also from the condition and reserves in the only mine in California, the Stewart, which has produced lithia minerals on a commercial scale. The chief lithia mineral in the Stewart deposits is lepidolite, which contains the least percentage of lithium of any of the economic lithia minerals. The subjoined table shows the comparison between these minerals.

| | Percent of $Li_2O$ | Market price in 1919 |
|---|---|---|
| Lepidolite | 4 | $14 - $20 a ton |
| Spodumene | 7.5 | $20 - $25 a ton |
| Amblygonite | 9.8 | $50 - $60 a ton |

The reserves of amblygonite and spodumene in the Black Hills of South Dakota are believed to be sufficient to supply the domestic demand for lithium, even though there is a substantial increase in demand because of technologic developments.

The presence of rubidium (about 0.65%) and caesium (variable, but about 0.20%) in the Pala lepidolite makes this material a potential source of these rare elements. Whether they also occur in significant amounts in the South Dakota amblygonite and spodumene is not known to the writer.

As indicated in the discussion on the future of gem tourmaline mining, the Pala Chief mine, which has been the chief and only important producer of kunzite, is almost worked out. There is on hand in the possession of mineral dealers in San Diego County, Los Angeles, and New York, a substantial amount of cut and uncut gem kunzite. Mrs. Frank A. Salmons, of Pala, widow of the late F.A. Salmons, owns a large stock of clear or slightly flawed gem kunzite.

Madagascar has yielded a large quantity of beautiful kunzite and the potential reserves on this island may be large. Nevertheless, unless new deposits are opened up in hitherto unproductive regions or in the old, well known localities, this saleable supply of kunzite may be expected to dwindle and the demand may drive the price to a much higher level than now exists.

PLATE  V

THE GABBRO HILLS NORTH OF PALA

a—Tourmaline Queen Mountain
b—Pala Chief Mountain
c—Hirart Hill
        These three hills are all gabbroic masses,
cut by lithia pegmatite dikes which dip south-
westerly.  The names are those locally applied.
d—Cliffs in Pala conglomerate.
        The part of the cliffs marked by the letter
is over a hundred feet in height.

## TOPOGRAPHY

### BROAD TOPOGRAPHIC FEATURES

The mountainous region of San Diego County, in which are situated most of the lithia pegmatites of southern California, is a part of the Peninsular Range of southern and Lower California. The term Peninsular in this application has not been popularly used so that it seems advisable to briefly define it.

The Santa Ana River and San Gorgonio Pass form an irregular east-west line, in about the latitude of Los Angeles, which separates a complex geologic province on the north from a rather simple group of mountains and valleys on the south to which the name Peninsular Range has been applied. The term is an apt one. It was introduced by W. P. Blake[1] who recognized that were it not for the deltaic flood of debris laid down by the Colorado River at the head of the Gulf of California, the waters of the Gulf would spread over the valley of the Colorado Desert as far north as the site of the present day town of Indio, nearly reaching the latitude of San Jacinto Peak, the loftiest eminence (10,805 feet) in the Peninsular Range as developed in southern California.

The eastern margin of the range is in most places formed by steep, east-facing scarps produced by faulting. The east sides of the San Jacinto-Santa Rosa block and the Laguna Mountain block are particularly steep and well-defined. The western margin is obscure. The lithologic boundary between the Cretaceous and Tertiary sedimentary formations bordering the

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[1] Blake, W. P.  Pacific Railroad Surveys, vol. V, p. 138, (1856)

Pacific Ocean and the igneous-metamorphic rocks of the interior, may be considered the western margin.

The Peninsular Range embraces such well known topographic entities as the San Jacinto and Santa Rosa Mountains; the Perris Peneplain; the Santa Ana and Elsinore Mountains: Volcan, Agua Tibia, Laguna, Cuyamaca, and Hot Springs Mountains.

From its northern terminus as defined above the range extends southeastward for three hundred miles, of which the northern one-third is in Orange, Riverside, and San Diego counties, California, and the southern two-thirds is in Lower California. In San Diego County the range attains, by step-like ascents from the coastal belt, elevations exceeding 5000 feet, and, in the middle part of the county, reaches a width of ab-out 50 miles.

The physiography of the Peninsular Range is little known in detail, but even in casual observations the influence of faulting is obvious. Four parallel major faults which trend southeast are prominently develop-ed in its northern part. From east to west these are the Santa Rosa fault, bounding the eastern side, and the San Jacinto fault, bounding the western side of the San Jacinto-Santa Rosa Mountains block; the Agua Caliente fault, so named from its development about Warner's Hot Springs; and the Elsinore fault zone, on which crustal movements have produced a graben in the vicinity of the town of Elsinore. Part of this graben is occupied by Lake Elsinore. Paralleling these major faults are subsidiary crustal failures. Several cross faults have also been postulated.

Much of the Peninsular Range, and all of the terrane described in this report, is drained to the Pacific Ocean. The area specifically

PLATE VI

AGUA TIBIA MOUNTAIN AND THE PALOMAR SURFACE

Airplane view looking northeast over Agua Tibia
Mountain. The Palomar surface which lies on
the top of this mountain is one of the many sur-
faces of low relief found in the Peninsular Range.
The Elsinore fault zone, as developed in this
vicinity, lies near the base of Agua Tibia Moun-
tain. Its position is marked, approximately, by
the road which cuts across the photo from lower
middle left to middle right.

a—Southwest flank of Agua Tibia Mountain
b—The Palomar surface
c—Denuded slopes in granodiorite

treated herein is drained by two master streams, the San Luis Rey River and the San Dieguito River. The lower reaches of these rivers bears southwestward in conformity to the consequent slope initiated by uplift, their upper reaches and headwater branches are largely fault controlled and trend in directions roughly paralleling the main northwest strike of the Peninsular Range.

The oversimplified picture of the northern one-third of the Peninsular Range is that of a peneplain, during the production of which erosion has cut so deeply that the metamorphosed sedimentary cover has been largely removed and plutonic rocks are exposed over most of the country. Tilting and uplift along major faults have modified this peneplain. Although some of this faulting is recent and in places is actually going on at the present time, the initial breaks probably came a long time ago and the blocks outlined thereby have had individual histories for a long period.

## THE TOPOGRAPHY OF THE PALA DISTRICT

About halfway between the canyon of the Santa Ana River and the Mexican border the western margin of the Peninsular Range is broadly warped downward and a hemicircular re-entrant of lowlying county projects inward to the base of Agua Tibia Mountain. Near the eastern extremity of this re-entrant and along the banks of the San Luis Rey River lies the Indian village of Pala. The San Luis Rey River in this vicinity makes a wide swing from the northwest to the southwest and a broad unsymmetrical valley, about a mile wide near Pala, has been formed near the bend.

The rocky hills which surround Pala rise to an elevation of

PLATE VII

SOUTHERN PART OF MESA GRANDE

View from the southeastern slope of Gem
Mountain. The rolling nature of Mesa
Grande is well depicted in this view.
The three peaks on the skyline are, from
left to right, North, Middle, and Cuya-
maca Peaks. These eminences of gabbroic
rock dominate the landscape in this part
of the Peninsular Range.

1000-1500 feet above the floor of the San Luis Rey River valley, which at this point ranges from 400-600 feet above sea level. The slopes of the hills are steep and meet the relatively flat river valley with a moderately sharp break in profile. The hills immediately about Pala are rounded, are of very irregular shape, and have no uniform trend. To the northeast the long spurs of Agua Tibia Mountain rise to the oldland surface which forms the upland portion of this block.

The drainage is all to the San Luis Rey River. There are few springs in the district. Most of the inhabitants obtain their water supply from wells sunk in the gravels of the stream bed. No figures on the rainfall are available; it is estimated to be under 20 inches annually.

## THE TOPOGRAPHY OF THE MESA GRANDE DISTRICT

A few miles south of Henshaw Reservoir rises a steep scarp. Surmounting this scarp is an upland region which, because of its extent and because it is cut off from most of the surrounding country by steep declivities, has been named Mesa Grande. The surface of the broad and undulating mesa is about 4000 feet above sea level. Rising 700 feet to a 1000 feet above its surface are a few rounded hills.

Most of the drainage is to the Santa Ysabel River, which is called the San Dieguito River in its lower course. A few short streams, dry most of the year, have cut back precipitous channels in the northeast scarp and drain to Henshaw Reservoir and the San Luis Rey River. The rainfall is considerable in comparison to nearby districts; an average yearly precipitation of 35 inches has been recorded. Springs are numerous and supply the inhabitants with most of their potable water supply. There are many cienegas, or marshy lands, in the region.

PLATE VIII



ANGEL FIELD, MESA GRANDE

View looking north. The steep-walled, deep
trench of the stream which drains this small
valley is a very youthful feature, probably not
more than a century old. Most of the upland
valleys are, like the one shown here, being dis-
sected by gully erosion, in some cases at an
alarming rate.

# GENERAL GEOLOGY

## SUMMARY

The general geology of that part of the Peninsular Range con-
stituting the mountainous region of San Diego County, is essentially the
geology of an igneous-metamorphic complex in which igneous rocks predomin-
ate. No well-sorted or well-consolidated unmetamorphosed sediments are
found and only a relatively small body of poorly-sorted, little-rounded
Quaternary conglomerate occurs. Over wide areas denuded bedrock forms
the surface and elsewhere the soil covering, except in valleys and benches,
is generally thin.

The oldest rocks recognized are the Pala quartzite and Indian
gneiss, metamorphic rocks which contain a large proportion of initially
sedimentary material. Their exact age is unknown; they may possibly be
Triassic. These rocks have been invaded on a batholithic scale by medium-
grained plutonites. The order of such invasion is (1) gabbro, (2) quartz-
diorite and diorite, (3) granodiorite. Gabbro, generally in small masses,
is a widespread rock. Quartz diorite and granodiorite are also widely
distributed, frequently in bodies of considerable size. Probably the
dominant rock regionally is quartz diorite.

Long continued erosion has cut deeply into the rocks of the area.
The stage of erosion reached is the endobatholithic stage of Emmons,[1]
in which the invaded (metasedimentary) bodies lie as islands or roof
pendants surrounded by the invading rocks. The end products of this
erosion are surfaces of low relief such as the Palomar surface, which

[1] Emmons, W. H. Ore deposits of the western states.
   p. 346, A.I.M.E. N.Y. (1933)

forms the upland of Agua Tibia Mountain.

Uplift by broad arching and by block faulting have caused youthful valleys to be produced in parts of the region. Some of these valleys were filled to a considerable depth with coarse, angular debris, and in places this is now being removed by westward-flowing streams.

PLATE IX



A. EAST SIDE OF TOURMALINE QUEEN MOUNTAIN, PALA

Panorama of the east side of Tourmaline Queen
Mountain from a point on the western slope of
Pala Chief Mountain.  The contact between San
Marcos gabbro (left) and Pala quartzite (right)
is marked by the line.  The pronounced difference
in surficial expression of these two rock types
is well shown.
a—Stewart mine
b—Gem mine      Both of these are on the Stewart dike
c—Tourmaline Queen mine



B. LITTLE PALA CHIEF MOUNTAIN,
                        PALA

View looking northwest from the
Sickler homestead.  The mountain
is composed of Luis quartz
diorite cut by numerous westerly-
dipping pegmatite dikes.

# ROCK FORMATIONS

## Pala Quartzite

Small beds of quartzite are scattered widely throughout the
region, largely as inclusions in plutonic and gneissic rocks. In virtue
of their superior resistance to assimilation they frequently have sur-
vived as recognizable units when all other sedimentary material has been
changed. Generally most of the quartzite beds are too small to permit
of their being differentiated in mapping. At Pala, however, a large body
of quartzite, herein called the Pala quartzite, has been separately mapped.
It outcrops as a curved, continuous band a short distance north of the
village of Pala. The southern boundary of this body of quartzite is
San Marcos gabbro. The intrusive contact between these two rock forma-
tions is sharp and in most places well defined. To the north the quart-
zite grades into Carver granodiorite. The contact relations here are
intrusive, but the contact is so gradational that no line can be drawn
delineating it, and on the geologic map of the Pala district included in
this report the quartzite is shown as merging into granodiorite. The
thickness of that part of the Pala quartzite formation clearly recognizable
as quartzite ranges from a hundred feet to several hundred feet. Carver
Hill, the steep rocky knob near the head of the canyon between Tourmaline
Queen Mountain and Pala Chief Mountain, is composed mainly of Pala quart-
zite (See Plate IX A). Excellent exposures of Pala quartzite are found
in the vicinity of the Tourmaline Queen mine and the Tourmaline King mine.

In its most typical form the Pala quartzite is a fine-grained,
sandy, thinly-laminated rock made up largely of quartz. Biotite is a
frequent constituent, usually in small amounts, occasionally in large am-

PLATE X

ZONED PLAGIOCLASE IN MIGMATITE

Photomicrograph showing zoned plagioclase
in a thin section from a rock from the
Pala quartzite and Carver granodiorite
contact zone. The fine-grained groundmass
is largely quartz.

Crossed nicols x22

ounts so that the rock becomes an impure quartzite or schist. On freshly
broken surfaces the lamination is not well seen; weathered surfaces show
it plainly. Other forms of the Pala quartzite which are obviously quart-
zite in the hand specimen are revealed by the microscope to contain
important quantities of microcline and albite or oligoclase. A specimen
of dense, tough quartzite from near the contact with San Marcos gabbro
was found to contain numerous rounded grains of pyrrhotite and a few
ragged grains of green hornblende. Pyrrhotite is a common accessory min-
eral in the gabbro and it may be reasonably inferred that pyrrhotite
present in Pala quartzite came from the gabbro.

In going from the contact between gabbro and quartzite toward the
Carver granodiorite, the quartzite becomes coarser grained, biotite com-
monly increases in amount, and the rock assumes a more gneissic appear-
ance. The microscope reveals large, irregular grains of quartz, and some-
what smaller grains of oligoclase and microcline intercalated in rude
layers between fine-grained quartz. The proportion between the coarse-
grained quartz and oligoclase and microcline suggests that some of this
quartz represents recrystallized sedimentary quartz. Biotite is developed
parallel to the bedding.

The zone between undoubted quartzite and undoubted granodiorite
is a hybrid rock, partly metasedimentary and partly igneous. Such rocks
are called migmatites, or mixed rocks. The best notion of the appearance
of much of the Pala quartzite is furnished by the fact that earlier in-
vestigators in the district considered it to be an igneous rock.

The Pala quartzite shows a number of interesting structural features. The western contact between the quartzite and gabbro dips under the gabbro; the northeastern contact between these same rocks dips under the quartzite; on the northwest the contact is nearly vertical. This relation suggests that the gabbro has been intruded into quartzite as a sill-like body. The occurrence, near the Tourmaline Queen mine, of a large mass of gabbro interfingered in quartzite strengthens and supports this interpretation. It might be pointed out that, broadly viewed, the quartzite mass being discussed occurs as a screen between two kinds of plutonic rocks, namely, gabbro and granodiorite. Professor Esper S. Larsen[1] has stated that many of the metamorphic bodies of the region occupy such a position. Professor Larsen calls these bodies "screens." The writer has observed similar spatial relations in rock bodies in the Julian district. The schistosity of the Pala quartzite coincides with the bedding. This is not an unusual feature but is prevalent in most of the metasedimentary rocks of the Peninsular Range.

The rocks now represented by the Pala quartzite were initially fine-grained sandstones, in places quite pure. They were regionally metamorphosed and that part of them forming the quartzite mass herein described was intruded by (1) a sill-like body of gabbro and (2) a batholithic body of granodiorite. The gabbro had little contact action on the quartzite other than a slight baking effect, accompanied by the introduction into the quartzite of a small amount of basic minerals and pyrrhotite. The granodiorite "granitized" the contact zone between it and the quart-

[1]
Written communication to the writer.

zite.

The age of the Pala quartzite is uncertain. No fossils have been found or are likely to be found in it. Most of the metasedimentary rocks in the region have been correlated with the Santa Ana slates of upper Triassic age. The Sierra Nevadan disturbance, which was accompanied by enormous batholithic intrusion, took place some time in the upper Jurassic. The San Marcos gabbro and other plutonic rocks in the Pala and Mesa Grande districts were presumably emplaced during the Sierra Nevadan disturbance. The only definite statement which can be made at the present time concerning the age of the Pala quartzite is that it is pre-Sierra Nevadan, hence pre-upper Jurassic. The probabilities are that the Pala quartzite is of Triassic age.

As indicated elsewhere in this section, there are numerous bodies of quartzite included in the plutonic rocks of the region. These are probably referable to the Pala quartzite. There are several such quartzite masses in the gabbro of Tourmaline Queen Mountain and Pala Chief Mountain.

## Indian Gneiss

Many of the plutonic rocks of southern California are more or less gneissic. In fact, a truly massive acid plutonite is comparatively rare. In the Pala and Mesa Grande region the quartz diorite, particularly, possesses a foliation visible plainly on a large outcrop. Nevertheless, it is usually possible to distinguish in the field between gneissic quartz diorite or gneissic granodiorite and paragneiss. There are doubtful cases, especially as between gneiss and quartz diorite.

PLATE XI



A. BLOCKY INDIAN GNEISS,
                    MESA GRANDE

Indian gneiss exposed at the
northern end of Angel field.
The trend of the block is
parallel to the attitude of
the foliation, which strikes
northwest and dips steeply to
the southwest. View is north.
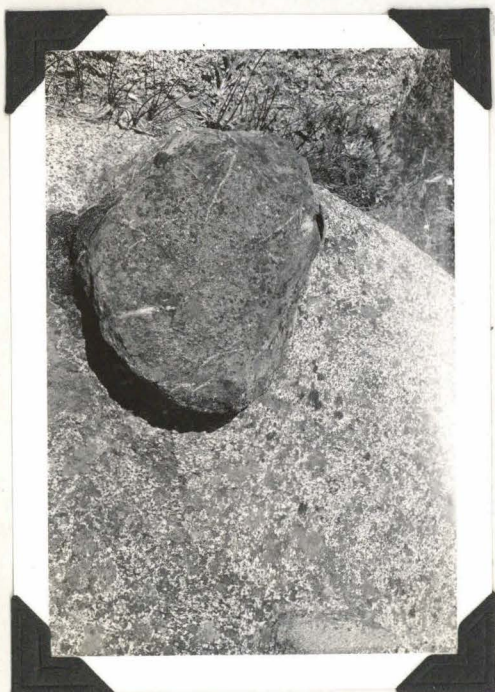


B. GABBRO XENOLITH IN QUARTZ DIORITE,
                    MESA GRANDE

Inclusion of San Marcos gabbro
in Angel quartz diorite. The
contact of the quartz diorite
with the gabbro is a few feet
to the right (south) of this
outcrop. The gabbro xenolith
is about a foot across.

In the Pala district no rocks have been recognized which are undoubtedly paragneisses or lit-par-lit gneisses. In the Mesa Grande district, however, there is a thick section of paragneiss which has been injected in places lit-par-lit. This formation is called Indian gneiss. Areally it is probably the most important rock outcropping on the mesa. Excellent exposures of it are found near the Indian church; on the southeastern end of Gem Mountain on Bushnell's ranch; and on the road to the Rose Quartz mine. The formation as mapped includes much rock that detailed investigation would probably reveal to be quartz diorite or diorite orthogneiss.

The most widespread facies of the Indian gneiss is a grey to dark grey rock consisting of white feldspar, quartz, biotite, and hornblende. Layers of well-banded metasedimentary material having this composition alternate with layers having poor, irregular, or interrupted banding. The layers of highly metasedimentary material frequently contain more of the mafic minerals than the contiguous rock. A thin section cut from a rock from one of these metasedimentary layers contains quartz, acid plagioclase, biotite, and hornblende. The foliation in the thin section is well marked by the biotite and hornblende. Other rocks from the Indian gneiss of this same general nature are disclosed microscopically to contain orthoclase in varying amounts, in one instance greater than the plagioclase. In some of the thin sections examined the plagioclase is andesine. Wherever orthoclase is an important constituent biotite is the dominating femag.

Several other types of metamorphic rocks included in the Indian gneiss have been selected for description:

The country rock of the Rose Quartz mine is a grey-green, coarsely banded gneiss. Layers of varying thickness composed largely of black hornblende alternate with greenish or grayish layers of quartz and plagioclase. The microscope reveals layers of green hornblende, diopside, quartz and plagioclase alternating with layers of plagioclase and quartz. The plagioclase has a composition about midway between that of andesine and labradorite.

The country rock of the Shenandoah mine, which is in sec. 23, T. 11 S., R. 2 E., outside the boundaries of the geologic map of the Mesa Grande district included in this report, is a rather dense, well-banded rock. Hornblende, which makes up a large proportion of the rock, is the only constituent megascopically determinable. The microscope discloses brown and green hornblende and quartz in thin, well-marked continuous layers, adjoining discontinuous, lens-like layers of quartz. Acid plagioclase is a scanty constituent.

A specimen of quartzite which is representative of many small bodies of such rock included in the Indian gneiss, is a dense, blue, fine-grained, thin-bedded quartzite. Under the microscope are seen parallel layers of quartz with a few stringers of hornblende, alternating with layers of quartz, labradorite, and hornblende. Quartz makes up the largest part of the rock. In some layers hornblende is visible megascopically.

Aplite and quartz veins are common in the Indian gneiss, usually as very small concordant stringers. Frequently the aplite, and the quartz even more so, is found forming the structures known as ptygmatic folds.

PLATE XII
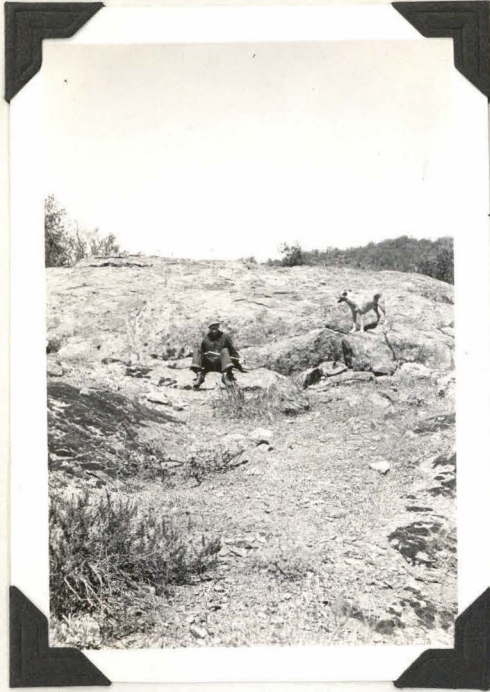


A. INDIAN GNEISS, MESA GRANDE

Indian gneiss exposed on a
rolling hill west of the Indian
schoolhouse. Such bare out-
crops, on which are strewn ex-
foliated plates and angular
scraps of the gneiss, are char-
acteristic of hilly sections un-
derlain by this type of rock.
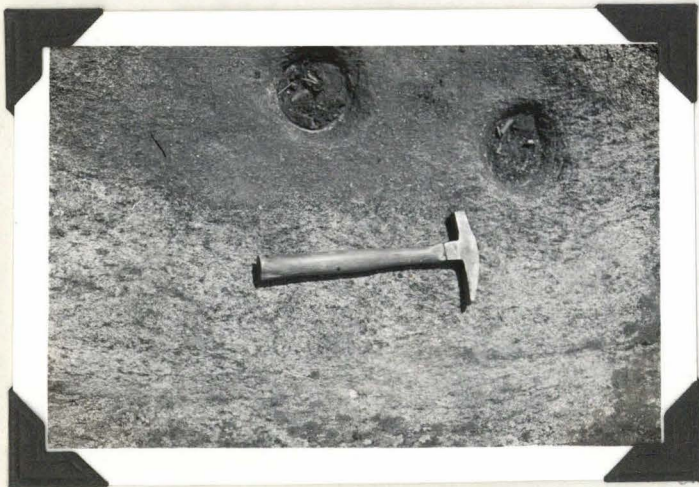


B. INDIAN GNEISS, MESA GRANDE

Close up view of Indian gneiss,
not however, at the same
locality as the one depicted
above. The round depressions
are Indian mortar holes, in
which the Indians at one time
ground meal for food.

Foliation in the Indian gneiss, which seems to be roughly conformable to the stratification, strikes northwest and dips steeply northeast or southwest. The prevailing strike is N. 50° W. This direction is roughly parallel to the main structural grain of the Peninsular Range.

The Indian gneiss represents the product of regional metamorphism of a series of sedimentary rocks whose initial nature is not now decipherable with any degree of precision. The series certainly contained beds of fine clastic sediments. No limestones have been found in it. The metasedimentary portion of the Indian gneiss has been injected, largely litpar-lit by igneous juices which deposited material having the composition of quartz diorite or granodiorite. Bodies of gabbro, quartz diorite, and granodiorite of considerable size have been intruded into the Indian gneiss. Small bodies of quartz diorite, of the order of a few feet across, are commonly included within the main body of Indian gneiss. The contact effects of subjacent bodies of gabbro, granodiorite, and quartz diorite on Indian gneiss appear to be insignificant.

PLATE XIII

A.  PHOTOMICROGRAPH OF OLIVINE GABBRO

a.  Olivine
b.  Augite largely altered to green hornblende
c.  Green hornblende
    The feldspar is bytownite

                                    Crossed nicols X22

B.  PHOTOMICROGRAPH OF HORNBLENDE GABBRO

The lower left quadrant is almost all hornblende.
The light area in the right portion of the figure
is labradorite.  Remaining areas are either green
hornblende or labradorite

                                    Crossed nicols X22
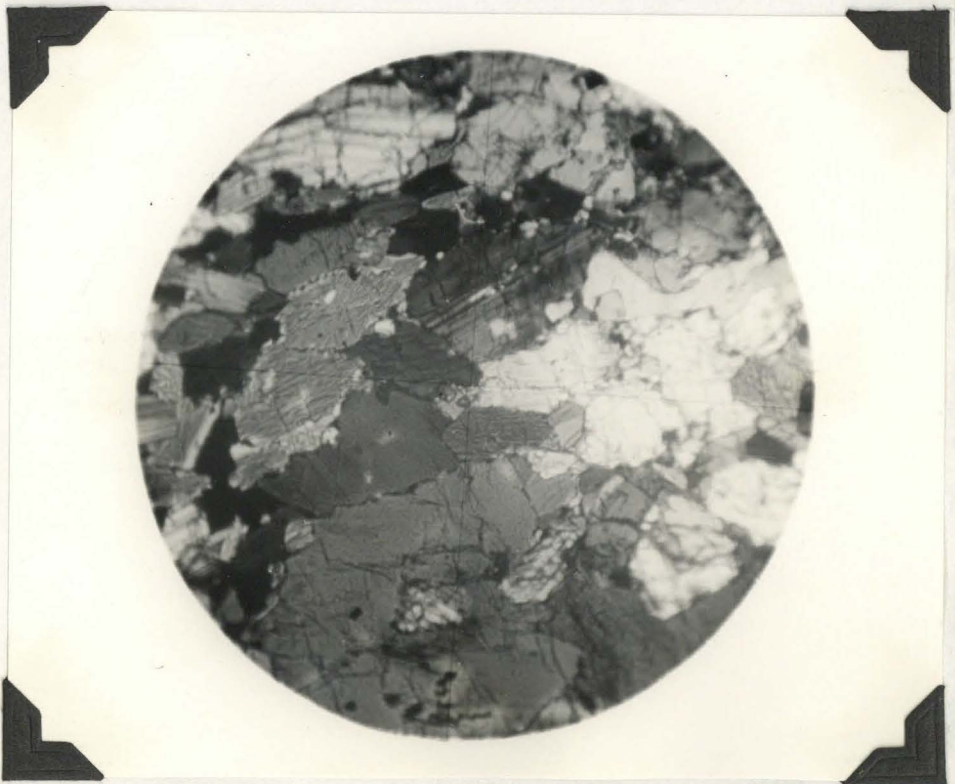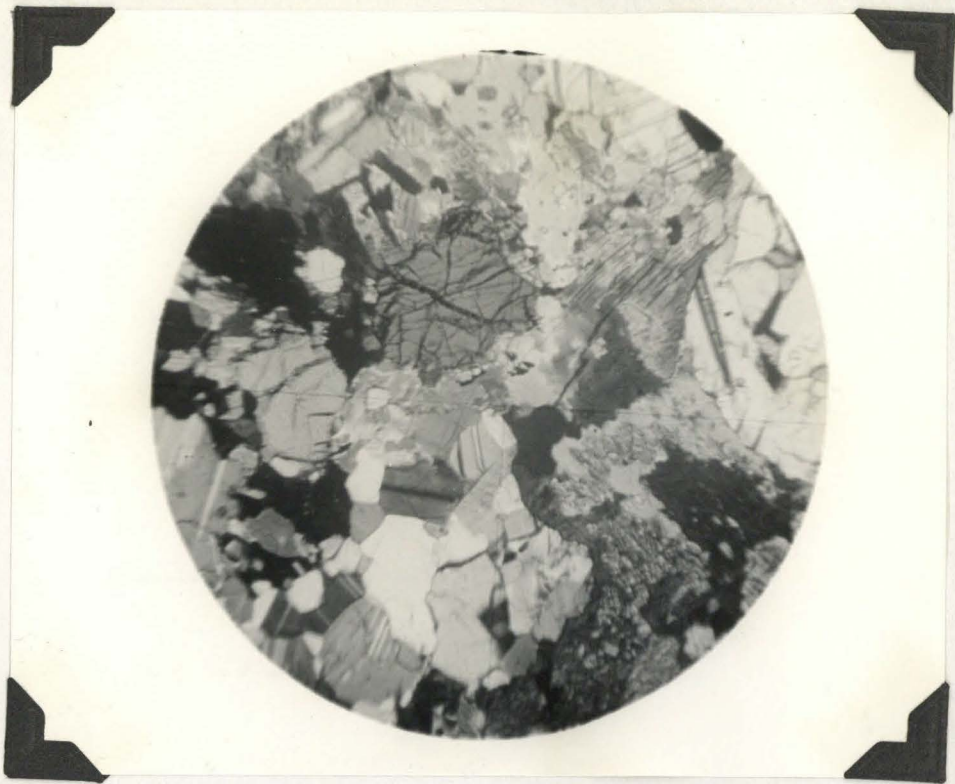
## San Marcos Gabbro

Gabbro is a widespread rock in the mountainous region of San Diego County. As a rule it forms small masses whose horizontal outlines, while rounded, are frequently elongated in a northwest-southeast direction. The gabbro outcropping in the Mesa Grande and Pala regions has been mapped as San Marcos gabbro. This formation was first named in the literature in a paper by Miller[1], one of Prof. Esper S. Larsen's students. Miller[2] has apparently studied in detail the San Marcos gabbro that outcrops in the San Luis Rey quadrangle.

Within the area mapped by the writer at Mesa Grande, San Marcos gabbro forms one large mass and several smaller ones. The large mass makes up most of Gem Mountain and Hill 4001. At Pala, gabbro forms most of Tourmaline Queen Mountain, Pala Chief Mountain, Hiriart Hill, and Pala Mountain. Several other masses of gabbro occur near Pala, either within or just outside the limits of the geologic map prepared for this report.

The petrography of the San Marcos gabbro is complex. The texture varies, even within small bodies and over short distances, from fine-grained to coarse-grained. Because of the nature of the gabbro and the character of gabbroic outcrops it has not been feasible to map the intra-formational facies.

The most typical facies of San Marcos gabbro, if it can be said to show a typical facies, is a dark grey massive rock in which the femags

[1]Miller, Franklin S.
    Anorthite from California.  Am. Mineralogist 20: 139-146  (1935)

[2]Miller, Franklin S.
    Petrology of the San Marcos Gabbro, San Luis Rey quadrangle, Calif.
    Unpublished doctorate thesis, Harvard University, May 1934.

PLATE XIV

ZONED AND UNZONED PLAGIOCLASE

Photomicrograph of part of a thin
section of quartz gabbro, showing
zoned and unzoned plagioclase
Crossed nicols x22

appear megascopically to make up about two-thirds of the rock, the remainder being largely plagioclase. A specimen having this megascopic appearance is found to contain in order of abundance green hornblende (uralitic), bytownite, olivine, augite, and hypersthene. Augite occurs as islands enclosed poikilitically by uralitic hornblende.

A fine-grained facies, common as the wall rock of part of the Stewart dike, is a greenish, massive rock, which microscopically is seen to consist mainly of labradorite (ca 80%) and green hornblende (ca 15%). Magnetite is an abundant accessory mineral.

Two specimens of a medium grained gabbro collected on Hiriart Hill, Pala, within a few feet of each other were examined microscopically. The first is a gray colored rock which megascopically is seen to be rich in feldspar. The microscope discloses hypersthene, biotite, green hornblende, and labradorite. The second specimen is highly mafic, megascopically about four-fifths of the rock appears to be made up of hornblende. The microscope proves this to be the case. Hornblende, green in color and ragged in outline, is revealed to make up the largest part of the section. The remainder is mostly labradorite.

The country of the Himalaya lode is largely a medium-grained, greyish to greenish rock. Megascopically the rock resembles a diorite or quartz diorite. The microscope shows the rock to be mostly acid plagioclase, green hornblende, and biotite. Quartz is present in varietal proportions. Normally a rock of this composition would not be called a gabbro. It is so called here because it occurs in and cannot be conveniently separated from a formation which is undoubtedly gabbroic.

To summarize the petrography of the San Marcos gabbro:  The formation is made up of fine-grained to coarse-grained gabbroic rocks, a greyish to greenish, massive, medium-grained rock seems to predominate.  Plagioclase, augite, hypersthene, olivine, and locally biotite, are the main primary constituents.  Augite and hypersthene are more or less altered to uralite.  The extent of uralitization is highly variable and spotty.  Some of the plagioclase is zoned.  A rough estimate of the amount of zoning is that about one grain in six is zoned.  The composition of plagioclase varies from acid labradorite in rocks that contain quartz, to basic bytownite or anorthite in rocks containing olivine.

The only internal structure in the San Marcos gabbro that the writer has observed which seems to be worth comment is the banding found in parts of the formation.  The areas exhibiting this structure are small in extent and of infrequent occurrence.  The strike of the banding is northwest and the dip is steep or vertical.  As noted under the discussion on the Pala quartzite, the gabbroic mass which makes up most of Tourmaline Queen Mountain, Pala Chief Mountain, and Hiriart Hill is a sill-like body which has been intruded into the metamorphic cover.  Subjacent bodies of quartz diorite and of granodiorite have intruded the San Marcos gabbro, but have produced little contact metamorphic effect upon it.

The plutonic rocks of the mountainous region of S an Diego County were all apparently intruded during the same epoch of igneous invasion.  This epoch is thought to be referable to the upper Jurassic.  Gabbro was the first plutonite intruded during the epoch.  The age relations between gabbro and the metamorphic rocks is, of course, clear.  Gabbro is intrusive into Pala quartzite and into Indian gneiss and is younger than these meta-

PLATE XV

BANDED HORNBLENDE GABBRO

Photomicrograph of banded gabbro. The
section here represented is composed
mostly of green hornblende and labra-
dorite. The banding, not well shown
in thin section, is nearly parallel to
the right hand edge of the sheet
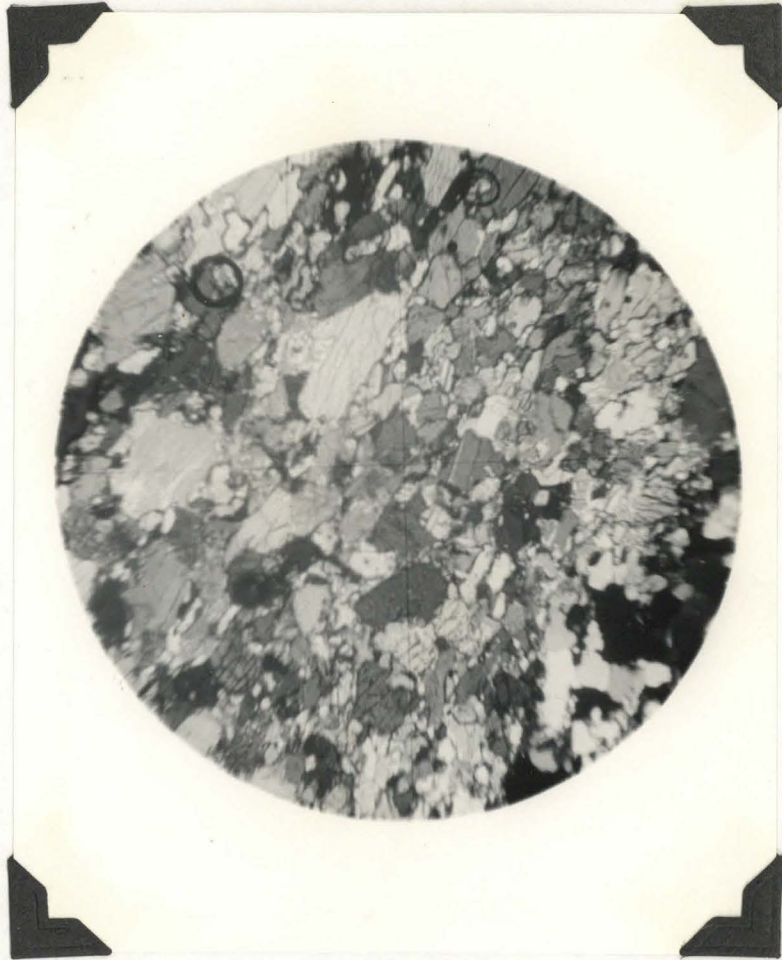
morphic formations. The age relations between the various plutonites now seems clear. Inclusions of gabbro are very common in quartz diorite near the contact between gabbro and quartz diorite. This indicates that gabbro is older than quartz diorite. Quartz diorite appears to be older than granodiorite. Other gabbroic rocks occurring in the mountains of San Diego County are petrologically similar to these of the San Marcos gabbro. Both the writer and F. S. Hudson (184) believed that the Cuyamaca basic intrusive composing the Cuyamaca massif, south of Julian in San Diego County, is younger than the associated quartz diorite and granodiorite. The evidence in this case seemed to be convincing, but in the light of local study by the writer in Pala and Mesa Grande and of regional studies by Prof. Esper S. Larsen and his students in the San Luis Rey quadrangle and adjoining quadrangles, the problem of the age relations of the Cuyamaca basic intrusive needs re-examination. The conclusion reached by the writer and by Prof. Larsen is that gabbro is the youngest of the plutonic rocks of the San Luis Rey and Ramona quadrangles.

Angel Quartz Diorite
and
Luis Quartz Diorite


In the foregoing discussion quartz diorite has been treated, in the main, as a rock type without attempting to discriminate formational or compositional varieties. Prof. Larsen and his students have been able to distinguish and separately map several varieties of quartz diorite in the San Luis Rey quadrangle. Formational names have been given to these varieties of quartz diorite, but the writer does not have at hand sufficiently detailed information to permit his correlating the quartz diorite mapped by him at Pala and at Mesa Grande with the formations set up by Prof. Larsen et al. The quartz diorite in the Mesa Grande district has been designated Angel quartz diorite. The quartz diorite of the Pala district has been designated Luis quartz diorite. These names are to be regarded as tentatively applied. Further work in the region will probably show that various rock bodies included in the Angel quartz diorite and Luis quartz diorite may be referred to one of the formations set up by Prof. Larsen, whose nomenclature should prevail.

Although regionally quartz diorite is perhaps the most important rock, it is relatively subordinate in the Mesa Grande and Pala districts. At Pala, Luis quartz diorite makes up Little Pala Chief Mountain; the small knoll a mile east of Pala village; and the low hills just west of Pala village. At Mesa Grande, Angel quartz diorite underlies a considerable area east of the Angel homestead.

Angel quartz diorite is well exposed near the Angel homestead, from whence the name is taken. The rock here is a medium-grained massive grey

PLATE XVI



A. ANGEL QUARTZ DIORITE,
                    MESA GRANDE

Weathered Angel quartz diorite
exposed in road cut a few hun-
dred yards west of the Mesa
Grande store.



B. ROSE QUARTZ, ROSE QUARTZ MINE,
                         MESA GRANDE

The mass of rose quartz pictured
here is part of a large tabular
body of pegmatite

aggregate which contains in order of abundance plagioclase (basic andesine), quartz, biotite, and green hornblende. Biotite, in addition to being scattered in small grains throughout the rock, also occurs as small flattened clusters about a centimeter in diameter.

Luis quartz diorite from the small knoll a mile east of Pala village is in the hand specimen a fairly massive medium-grained rock consisting of plagioclase (andesine), quartz, green hornblende and biotite. In the field a rude foliation is visible. The strike of the foliation is east-west; the dip is steeply northward. A specimen of Luis quartz diorite from Little Pala Chief Mountain is finer grained than that just described. Megascopically it is a dark grey, medium fine-grained rock, in which the foliation is perceptible even in the hand specimen. The microscope reveals plagioclase (oligoclase), quartz, biotite, and green hornblende. Biotite and hornblende are intergrown in a peculiar texture.

Where Luis and Angel quartz diorite are in contact with gabbro, they frequently contain numerous inclusions of gabbro. Broadly viewed the foliation in quartz diorite, where it is present, is northwest, parallel to the main grain of the Peninsular Range. Locally, however, it may trend in a direction parallel to nearby contacts with other rock bodies.

Both Angel and Luis quartz diorite are younger than San Marcos gabbro. With the granodiorite to be discussed in the next heading, the quartz diorite and gabbro constitute a closely related series of intrusions.

PLATE XVII

A. PILOT BUTTE GRANODIORITE

Monolithic weathering typical
of this rock formation. Photo-
graph of an outcrop near the
eastern end of Pilot Butte,
Mesa Grande.



B. PILOT BUTTE GRANODIORITE

Close up view of the exposure seen
in the above photo. A rude foliation,
not visible in the hand specimen, is
perceptible on the broader scale
included in this photo.

Pilot Butte Granodiorite
and
Carver Granodiorite

The same remarks that have been made concerning the nomenclature
of quartz diorite apply to granodiorite. Several mappable units of
granodiorite have been recognized as a result of regional studies by
Prof. Larsen. The writer is not able to correlate the granodiorite found
in the Mesa Grande and Pala districts with the formations distinguished
by Prof. Larsen, so for cartographic purposes he has devised a separate
terminology. Granodiorite outcropping in Mesa Grande is here designated
Pilot Butte granodiorite; that outcropping in the Pala district is
designated Carver granodiorite. The distribution of these two formations
is brought out on the maps.

Carver granodiorite as exposed in Pala Canyon three miles north
of Pala is a greyish-white medium grained rock composed largely of
plagioclase, potash feldspar, and quartz. Biotite is present but makes
up only a small part of the rocks. Carver granodiorite from near the
head of the small canyon between Tourmaline Queen Mountain and Pala Chief
Mountain is composed, in the order of abundance, of quartz, orthoclase,
plagioclase(oligoclase), microcline, and biotite. This specimen is from
near the contact between Carver granodiorite and Pala quartzite, which
accounts for the unusual proportion of quartz.

A specimen of Pilot Butte granodiorite from near the eastern end
of Pilot Butte, Mesa Grande, is a sugary, white, medium to fine grained
rock. Scanty biotite forms very thin somewhat wavy layers. These layers
are the principal mark of the foliation.

PLATE XVIII

A.   MICROCLINE IN CARVER GRANODIORITE

Photomicrograph of microcline showing
grating structure.  The light and dark
untwinned areas are mainly quartz
                    **Crossed nicols x22**


B.   MICROCLINE IN CARVER GRANODIORITE

Photomicrograph of a specimen of Carver
granodiorite showing:
a.   Twinned microcline
b.   Anhedral quartz
c.   Myrmekite
                    **Crossed nicols x22**
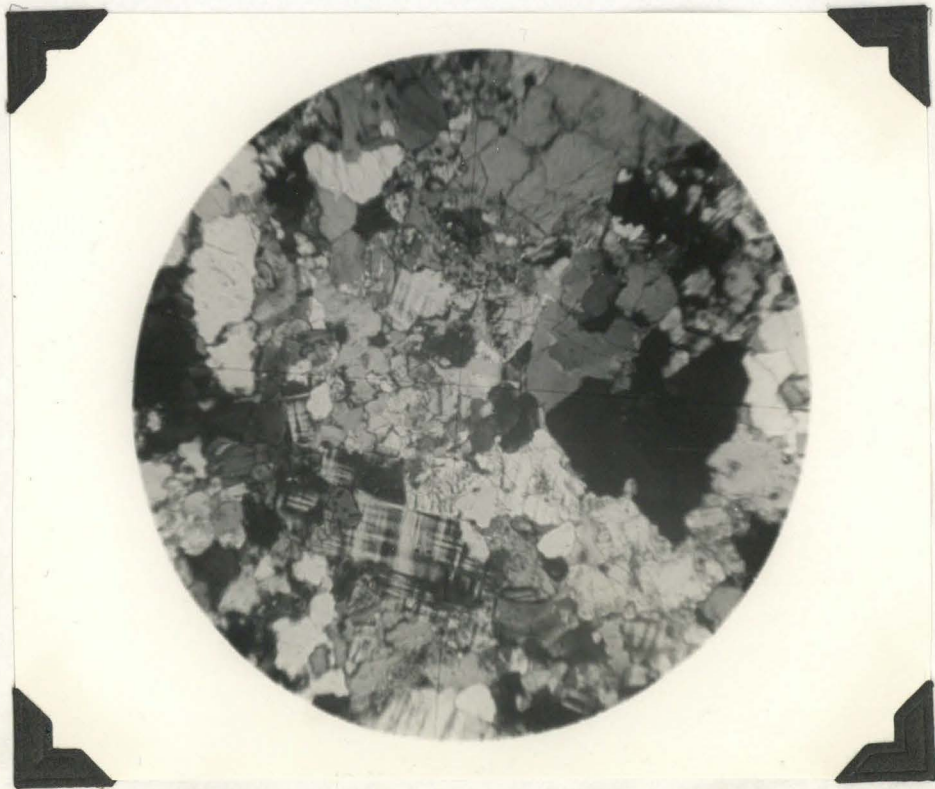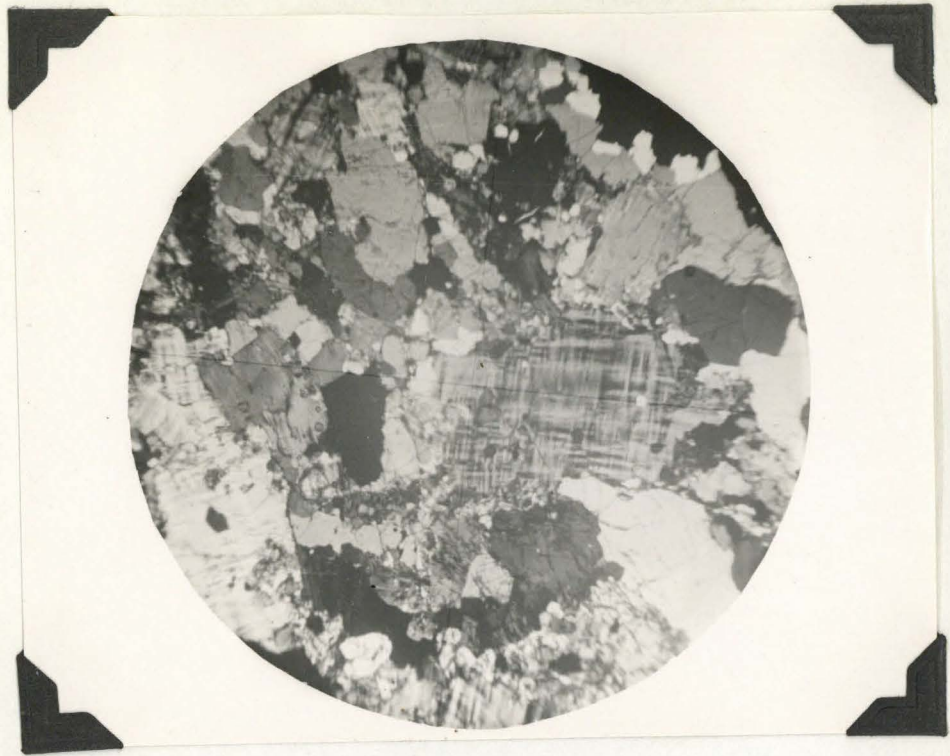
Most of the granodiorite of Pala and Mesa Grande is well foliated. The attitude of this foliation is in the main parallel in strike to the dominating northwest regional trend. At Pala, however, much of the granodiorite lying north of the Pala quartzite has a foliation which trends parallel to that of the quartzite. In the writer's opinion much of the granodiorite of the region is a granitized sediment. It appears that the dominant process of gabbro emplacement was stoping; quartz diorite emplacement was largely by stoping, assimilation, and injection; granodiorite emplacement was mainly by granitization.

The granodiorites constitute the end members of a consanguineous series of plutonic intrusions. The sedimentary record in the Santa Ana Mountains, where Cretaceous sediments lie on eroded batholithic surfaces, indicates that these intrusions, which presumably began in upper Jurassic, were probably completed before the beginning of the Cretaceous.

Quaternary Gravels
and
Alluvium


The only alluvial body in the region which merits description
in this report is that known as the Pala conglomerate. Ellis and Lee
(179) mapped under that name the alluvium occupying the floor of San
Luis Rey River valley from the vicinity of Pala to Rincon. As exposed
near Pala this formation is composed of coarse, poorly-sorted, angular
fragments that have suffered very little transportation. The maximum
exposed thickness is slightly over a hundred feet. The rock fragments
are largely quartz diorite and granodiorite.

The San Luis Rey River has cut a deep trench in the Pala con-
glomerate. Side streams draining into the San Luis Rey River have also
entrenched their courses. This downcutting of alluvium has significance,
in that it may indicate comparatively recent uplift.

# STRUCTURE

## Summary

If faulting and a few minor structures are excepted, the principal structural features of the Pala and Mesa Grande districts involve batholithic emplacement. The terrane examined by the writer is not sufficiently large to permit of many well-substantiated conclusions on this problem. The rock bodies, on the whole, are not large. Any concept of batholithic intrusion involving a single mass whose bounding walls diverge in depth must be cast aside. Rather, in the writer's opinion, the plutonic rocks were intruded in small masses, whose bounding walls probably converge downward. This implies that the magmatic chamber had great breadth and length, but was relatively thin.

Ptygmatic folds are rather common in the paragneisses of the region. As developed at Mesa Grande and Pala, these peculiar structures are usually small and consist mainly of quartz, or of aplite. Study of an occurrence of ptygmatic folding on Pala Chief Mountain, Pala, leads to the conclusion that the quartz which forms the folds is later than most of the deformation. The openings which controlled quartz deposition were set up in a layered rock by compression which caused, at first, some of the layers to slip past one another. Later the layers were thrown in

rather sharp folds, which in some cases broke. Into the voids created by this deformation quartz has been deposited. Probably some post-quartz deformation has taken place.

The Elsinore fault is a major tectonic feature which extends from Santa Ana Canyon, at the northern boundary of the Peninsular Range, into Lower California. This fault is strongly developed near Mesa Grande and Pala. East of Pala, it forms the southwestern base of Agua Tibia Mountain, a fault block that has been uplifted on marginal faults. Apparently faulting on the margins of Agua Tibia Mountain between Magee's ranch (sec. 12, T 9 S, R2 W) and La Jolla Amago has been quiescent for a long time as there is no expression of it in the physiography other than the steepness of the slopes. From La Jolla Amago southeastward through Henshaw damsite and along the scarp that bounds Mesa Grande on the northeast, the physiography is indicative of more recent faulting, although even here there is no one diagnostic feature which can be used to prove very recent movement. Earthquake shocks have been recorded whose epicenters fall along this segment of the fault.

The straightness and continuity of Pamo Valley and Temescal Valley, which lie to the west and southwest of Mesa Grande are strongly indicative of faulting. On the fault map of California prepared (1922) by the Seismological Society of America, a dead fault, well located, is shown as traversing Pamo and Temescal Valleys.

The structure of pegmatite dikes is described under a later heading.

# GEOLOGIC HISTORY

## SUMMARY

1. Deposition of fine grained clastic sediments. Time of deposition uncertain; probably Triassic.

2. Broad folding, accompanied by intrusion on a batholithic scale of gabbro, quartz diorite, and granodiorite.

3. Fractures developed in gabbro, less so in quartz diorite and granodiorite, parallel to the northwest grain of the country.

4. Injection into these fractures, chiefly in gabbro, of pegmatitic matter, probably derived by differentiation in the magmatic reservoir which furnished the plutonic rocks.

5. Differentiation in situ in flat-lying channels of an aqueous magma, yielding pegmatites having (1) a coarse grained graphic granite and quartz (massive) and feldspar (massive) upper phase, and (2) a fine grained quartz-albite-garnet rock lower phase.

6. Fracturing of the flat-lying pegmatites. The rift (direction of greatest ease of fracture) developed parallel to plane of dikes. Introduction into the pegmatites of ~~wave-like~~ hydrothermal solutions which replaced earlier formed pegmatite minerals with a complex group of later minerals.

7. Long-continued erosion, which removed a rock cover many thousands of feet thick. Surfaces of low relief were developed as an end product of this erosion.

8. Uplift (1) by broad arching and (2) by block faulting, along faults trending northwest.

9. Deposition of the Pala conglomerate, and its subsequent partial removal by entrenching streams, a process now going on.

# THE PEGMATITES

## SUMMARY OF PRESENT STATUS OF PEGMATITE PROBLEM

The natural history of pegmatites has fundamental application to the fields of mineralogy, ore deposition, petrology, and to certain branches of chemistry. For this reason the problem of the pegmatites has received much attention from various workers in these fields.

James Furman Kemp[76] in 1924 summarized the ideas previously held and gave a lucid statement of the then-prevailing view of the origin of pegmatites. This view postulates an aqueous-magmatic origin for pegmatites. Hydrothermal replacement is not recognized as an important factor. Variations in composition are believed to result from a variation in composition of the pegmatitic magma initially intruded.

Larsen,[1] working with Wright, on the use of quartz as a geologic thermometer, had found that the quartz of graphic granite is high quartz (above 575°), whereas the quartz in pegmatites occurring in masses associated with, but not in graphic granite, is low quartz (formed below 575°). Apparently this important fact was the experimental basis for the far-reaching generalization later reached, but apparently never published, by Larsen on the origin of pegmatites. In 1925 one of Larsen's students, K. K. Landes,[77] and one of his colleagues, W. T. Schaller,[168] published papers on the pegmatite problem. At about the same time F. L. Hess[72] also published a paper on the same subject. The thesis advanced in these papers is substantially this--many pegmatites, and practically all of the

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[1] Wright, F. E. and Larsen, E. S. Quartz as a geologic thermometer. Amer. Jour. Sci. 27: 421-47 (1909)

more interesting pegmatites, represent (1) the consolidation of a magma
rich in volatiles, which after consolidation underwent (2) a series of
replacement changes by introduced hydrothermal solutions which dissolved
earlier formed minerals and deposited later ones.  Stated in a different
way, this means that many pegmatites were formed by two different pro-
cesses, the first mainly igneous, and the second much like that prevailing
in the formation of metalliferous veins.

Among the pegmatites which have had an important hydrothermal
history are those which contain in appreciable quantities any of the
following:  lithium, beryllium, phosphorus, rare-earth metals, graphite,
cassiterite or sulphide ore minerals.  Vein quartz, if it can be so dis-
tinguished, indicates hydrothermal activity where it occurs in a pegmatite
or can be traced directly into a pegmatite body.  Albite occurring in in-
dividual crystals (i.e. excluding the albite in perthite) indicates hydro-
thermal replacement.

Landes[80] summarized in 1933 the literature bearing on pegmatite
genesis and has given his views on this question and on the question of the
classification of pegmatites. His scheme of classification is simple and
logical.  It is based partly on genetical and partly on compositional con-
siderations.  Pegmatites which show no sign of having had a post-consolida-
tion hydrothermal history are called simple pegmatites.  Numerically, the
vast bulk of pegmatites are simple in character.  Pegmatites are further
subdivided into (a) acid, (b) intermediate and (c) basic classes.  Acid
pegmatites include those in which the initially deposited material has the
composition of one of the following:  alaskite, normal granite, alkaline
granite, granodiorite, quartz monzonite, and quartz diorite.  Intermediate

pegmatites include those in which the initially consolidated material
has the composition of one of the following:  syenite, alkaline syenite,
monzonite, and diorite.  Basic pegmatites embrace those whose initial com-
position is one of the following:  gabbro diabase, anorthosite, and
pyroxenite.  It should be here noted that most pegmatites fall into the
acid class, and mainly in the upper brackets of that class.  Pegmatites
which have had a post-consolidation hydrothermal history are called com-
plex.  The name of the phase, or phases, present is joined with the composi-
tional name as above outlined.  For example, a normal granite pegmatite
possessing a phosphate phase would be called a phosphate granite pegmatite.
Actually, granite pegmatites are so prevalent that in practice the word
granite is dropped and a granite composition is understood if not other-
wise qualified.

Landes [81a] has recently compiled the existing knowledge on the
age and distribution of pegmatites.  He reports that pegmatites have been
formed during periods of intrusive activity from the pre-Cambrian to the
present.  The lithium pegmatites of the Rocky Mountains (including those
of the Black Hills) and the rare earth pegmatites of Llano County, Texas,
are pre-Cambrian in age.  Many of the complex  pegmatites (containing
lithium, boron, phosphate and other phases) of the New England Appalach-
ian belt are Paleozoic in age.  The pegmatites of San Diego County are
thought by Rene Engel[1] to be of Mesozoic age, probably Jurassic.  Pegma-
tites are widely and abundantly distributed through the shield areas of
the world and are common in regions where erosion has penetrated deeply
into metamorphic and plutonic rocks.

[1] Written communication to K. K. Landes and reported by him in the
paper (81a) in the bibliography.

# GENERAL SETTING OF THE LITHIA PEGMATITES OF PALA AND MESA GRANDE

## Composition

The lithia pegmatites of Pala and Mesa Grande are complex granite or alaskite pegmatites which contain an abundance of such minerals as micas(green and white muscovite and white and purple lepidolite), brown or red garnets(mainly spessartite, the manganese garnet), tourmaline (black and colored), euhedral quartz(clear and smoky), and euhedral and massive potash feldspar(microcline and orthoclase). They frequently contain small quantities of beryl(green and pink). Some of the lithia pegmatites at Pala exhibit clear spodumene(colorless, straw colored, and lilac colored), Bismuth and phosphate phases are also developed in several of the dikes at Pala.

Most of the lithia pegmatites which form tabular bodies that dip at gentle angles show a two-fold or three-fold character. The upper portion is composed mainly of graphic granite. The feldspar in the graphic granite is microcline perthite or microcline microperthite. Associated with the graphic granite are clumps of quartz and black tourmaline. The lower portion of the dikes is mainly banded garnet albite aplite. This aggregate is usually called line rock by the miners. Between the graphic granite in the upper part and the aplite in the lower part is a zone called the pay streak. The pay streak is not always strongly developed. In the pay streak is found most of the complex, hydrothermally-deposited minerals listed in the preceding paragraph. They occur here as irregular masses or as euhedral minerals lining open or clay-filled pockets. Not infrequently the complex minerals are found as clumps in the graphic granite or line rock. These clumps often exhibit a rude zoning.

## Occurrence

The lithia pegmatite dikes of Pala and Mesa Grande are comparative- ly few in number. At Pala they are restricted to the three gabbroic hills situated about a mile north and east of the village of Pala. From west to east these hills are called Tourmaline Queen Mountain, Pala Chief Mountain, and Hiriart Hill.

On Tourmaline Queen Mountain there are four large dikes whose at- titudes are roughly parallel. They strike northwesterly and dip gently westward. From the top of the hill to the bottom these are: Tourmaline King dike, which has been worked by the Tourmaline King mine and the Ed Fletcher, Jr., mine; the Tourmaline Queen dike, worked by the Tourmaline Queen mine; the Stewart dike, the southern end of which has been worked by the Stewart mine; and the Douglas dike. In addition to the four main dikes there are several smaller ones which have much the same characteris- tics as the larger ones. The Stewart and Douglas dikes are entirely in gabbro. The Tourmaline Queen and Tourmaline King dikes are largely in gabbro, their northern extremities project in Pala quartzite.

Pala Chief Mountain contains one large lithia-bearing dike, the Pala Chief dike, so named from the mine which has been developed in it. The dike strikes northwest and dips gently westward. The gabbro country rock is less resistant than the pegmatite, so that the dike outcrops as a "blanket" dike which covers a considerable part of the western side of Pala Chief Mountain. A short distance to the southwest of the Pala Chief dike is/still larger barren dike, which, having a similar attitude, also outcrops as a dip slope. Several smaller complex dikes and several large barren dikes are found on Pala Chief Mountain. All of the lithia pegma-

tites of Pala Chief Mountain are in a gabbroic country rock.

Hiriart Hill contains numerous lithia pegmatite dikes. They all strike northerly or northwesterly and dip westerly. Most of Hiriart Hill is owned by the Sicklers, who refused to grant the writer permission to examine their properties. Hence, most of the writer's knowledge of the geology of HiriartHill has been gained from long range observations. The dip of the dikes on the Hill is from fifteen degrees to about sixty degrees west. It appears certain that most of the rare minerals and gemworthy minerals have come from the dikes having a gentle dip. The steeper dikes appear to be entirely barren. The pegmatite dike in which the Sickler tunnel has been driven occurs on the southwest side of the Hill and dips ca 15° west. The Sickler tunnel yielded an unusual suite of phosphate minerals. Hiriart Hill also possesses historic interest in that it was here that the Sicklers are alleged to have made the original find of the transparent lilac-colored variety of spodumene to which the name kunzite was given. The pegmatites occurring on Hiriart Hill are also noteworthy because the banded garnet aplite is often exceedingly well-developed in them. The country rock of all the pegmatites of Hiriart Hill is gabbro.

The lithia pegmatites at Pala range in thickness from a few feet to a maximum of about a hundred feet(the thickest part of the Stewart dike). The average thickness is about twelve feet.

There are only two important occurrences of lithia pegmatite
at Mesa Grande. One is the Himalaya lode on Gem Mountain; the other is
the irregular pegmatite body that has been worked by the Esmeralda mine.

The Himalaya lode outcrops on the northeast side of Gem Mountain.
It has been exposed by erosion or by mining operations over a length of
2000 feet. The lode consists of four parallel pegmatite dikes which
strike N 15° W and dip, near the surface, ca 25° SW. The dikes are, in
comparison to those at Pala, rather thin, ranging in thickness from a
foot to three feet. The dikes are separate by layers of the gabbro
country rock. These layers average about fifty feet thick. Most of the
wall rock of the Himalaya lode is quartz gabbro, described in the chapter
on Rock Formations.

The irregular mass of lithia pegmatite worked by the Esmeralda
mine consists in the main of an unsymmetrical anticlinal-shaped body of
pegmatite, with unoriented offshoots. The axis of the anticline strikes
northeast, the northern limb dips 30° NW; the southern limb is steeper,
the dip is about 45° SW. The lithia-rich portion, indicated by a con-
centration of lepidolite, occurs near the crest of the anticline. Of
course, anticline is used here merely as a structural term. It should
be emphasized that the dike was not initially formed as a horizontal body
and afterwards folded into a structure having anticlinal tendencies. The
country rock of the Esmeralda mine is a coarse grained gabbro, exhibiting
numerous poikilitic phenocrysts of hornblende.

The contact of pegmatite dikes with the wall rock is almost always sharp. The wall rock, which in the majority of cases is a variety of gabbro, is altered for a few feet on each side of the dike. The thickness of the altered zone is the same above and below the dikes. The altered product is commonly a chalky, incoherent substance containing numerous biotite flakes. The nature of the altered rock is the same irrespective of the original character of the gabbro. The minerals and the structures of the pegmatite dikes seem to be, in the main, independent of the type of gabbro in which they are enclosed. Stated in a different way, the gabbro seems to have had little chemical effect on the pegmatite except for a possible reaction which may have produced biotite in the graphic granite.

## Structure

The structure of most of the lithia pegmatites under discussion is shown in graphic form in the accompanying diagram. These relations prevail (1) in practically all the lithia pegmatites on Tourmaline Queen Mountain, (2) in the Pala Chief dike, (3) in many of the pegmatites of Hiriart Hill, and (4) in the Himalaya lode. It should be noted that in many of these examples the banded garnet aplite is not strongly developed, although it is almost always present. In the thinner pegmatite dikes of the Himalaya lode, replacement has frequently attained a stage in which the earlier graphic granite has been completely replaced by complex minerals.

Considerable variation in structure and composition is found along the strike of a single pegmatite dike. To illustrate this the Stewart dike will be described:

The northern end of the Stewart dike is about 12 feet thick. The upper six feet is chiefly quartz and feldspar(both microcline and albite). Graphic granite, although present, is not well developed. White muscovite in small amounts is widespread. Microcline is present in fine grained and coarse grained forms. The coarse grained crystals are of the order of a few inches and are euhedral. Brown garnet is scattered throughout. The lower six feet is much like the upper six feet, except that albite exists in smaller proportion and broken crystals of black tourmaline are abundant. The average size of these tourmaline crystals is 1/8"x3". Some of them are stretched and the openings so produced have been healed with quartz and feldspar. Many of the coarse grained masses of microcline are fringed with quartz, albite, and black tourmaline.

Some three hundred feet south of the locality above described, the Stewart dike is exposed over a vertical distance of eighteen feet. The footwall is hidden. The upper eight is mostly fine grained graphic granite, with clumps of quartz, microcline and black tourmaline. In these clumps quartz and microcline are frequently intergrown in graphic texture. White muscovite occurs in clusters with quartz and microcline. Near the center the dike has been fractured and gouge has been produced. The fractures are parallel to the walls. There has not been deposited in the middle any of the minerals ordinarily found in the pay streak, so that this section of the dike, like the previous one, does not exhibit a pay streak. The lower ten feet of the dike is composed almost entirely of fine grained, rudely banded rock, containing quartz, microcline, albite, black tourmaline, and garnet. (The microcline and albite were microscopically detected). The jointing in the dike at this point is characteristic of that in many of the dikes. The rift is parallel to the walls. There are two sets of joint, about equally strong, normal to the walls. One strikes parallel with the strike of the dike, the other at right angles to that strike. About a thousand feet south of its northern end, the Stewart dike consists of two segments, separated by a few feet of gabbro. The upper segment is ten feet thick and is made up largely of graphic granite. The lower segment, although not entirely exposed, is about twenty feet thick. The whole lower part contains abundant albite. Much of the lower dike is graphic granite, but there is a large amount of black tourmaline, quartz, albite and microcline in irregular masses in the graphic granite. Many of the crystals of tourmaline are stretched and split. Quartz is often found in the central part of black tourmaline crystal. Some of the compact

microcline is greyish. On the other hand, most of the microcline found
in graphic granite is chalky white, frequently slightly iron stained. Al-
though the banded garnet rock is well developed at this point, crystals of
spessartite about a half inch across are common in the bottom rock. Musco-
vite is found throughout the dike in radiating clusters; these are more
abundant in the bottom portion.

About a thousand feet north of the main east workings of the Stewart
mine there is exposed in the Stewart dike the first assemblage of lithia
minerals. The dike here, while not fully exposed, is estimated to have a
thickness of about twenty-five feet. The upper part is mainly graphic
granite. The lower part is a fine grained rock composed of quartz and
feldspar. This fine grained rock is cut (see Plate XXVI A) by veinlets
of quartz, grey microcline, white muscovite, albite, black tourmaline and
scanty pink tourmaline and lepidolite. In the middle of the dike are large
masses (several feet in diameter) of black tourmaline, grey microcline,
albite(var. cleavelandite), and quartz in a host rock consisting largely
of grey microcline. Irregular aggregates of pink tourmaline, cleavelandite,
and lepidolite also transect grey microcline. Pink tourmaline has been
completely altered to a pinkish substance.

At the Stewart mine the dike is about a hundred feet thick. The
top part is graphic granite. The pay streak here is very thick, of the
order of fifty feet. It contains, or did contain, monominerallic masses
of quartz and amblygonite. There were also large masses rich in lepidolite,
most of which have been removed during mining. These larger bodies of
later minerals were, on the whole, lens shaped, with their long and inter-
mediate axes lying in the plane of the dike. In addition to these large

bodies in the pay streak, there occur grey microcline masses cut and re-placed by veins of albite, garnet, and lithia tourmaline; masses of ru-bellite, lepidolite, and quartz; and of rubellite, lepidolite, quartz, and albite.

On the diagram showing an idealized cross section of lithia peg-
matites occurring on Tourmaline Queen Mountain, it will be observed
that the dip increases with depth and that the number of pockets decrease
with a steepening of the dip. This structure is well illustrated in the
Tourmaline King dike, in which the upper part dips southwest at about
$20^{\circ}$-$25^{\circ}$, whereas the lower part dips about $40^{\circ}$ in the same direction.
The upper part has yielded, by far, the largest part of the total gem
tourmaline production from this dike. It seems to be generally true in
the dikes at Pala and Mesa Grande that the steep portions are poor or
barren in pockets. This point is emphasized here because in the thesis
advanced in this report the factor of steepening in depth, with the accom-
panying impoverishment in complex minerals, is of critical importance.

Where minerals whose habit is elongate, such as quartz, biotite,
and tourmaline, are found in the dikes, they show a tendency to be oriented
normal to the walls of the dike. This, in the writer's opinion, is also
significant as showing a structural control inherent in the attitude of
the dikes.

A few of the dikes have been effected by post-mineral faulting.
The offsets are small, resulting in displacements of a few inches or feet.

PLATE XXVII

**MINERALS OF SOUTHERN CALIFORNIA**

Legend:
A – IDENTIFIED BY M.D.
B – RELIABLY REPORTED
G – OTHERWISE REPORTED

S – SCHALLER
W – WILKE
K – KUNZ
G – GREIGER
R – ROGERS
E – EAKLE
V – VAN AMRINGE

Column headings: LOCALITY · MINE · COUNTRY ROCK · SHAPE AND ATTITUDE OF PEGMATITE BODY

Localities (left to right): JACUMBA (Crystal Gem) · NUEVO · MOOSA CANYON · RAMONA · CHIHUAHUA (Granodiorite) · AGUANGA MTN (Mtn. Lily, Gabbro; Columbia) · COAHUILA (Fano; District) · RINCON (Victor, Gabbro; Mack; District) · MESA GRANDE (Esmeralda, Gabbro; Himalaya & San Diego, Quartz Gabbro; District) · PALA (Hiriart Hill; Tourmaline King; Tourmaline Queen; Stewart Dike; Douglas Dike; Pala Chief; District, Gabbro)

| Category | Mineral | Symbol | Formula |
|---|---|---|---|
| FELDSPARS | MICROCLINE (GRAPHIC GRANITE) | T | $K_2O.Al_2O_3.6SiO_2$ |
| | MICROCLINE, MASSIVE, METASOMATIC? | | |
| | MICROCLINE (EUHEDRAL) | | $K_2O.Al_2O_3.6SiO_2$ |
| | ORTHOCLASE | M | $K_2O.Al_2O_3.6SiO_2$ |
| | ALBITE | T | $Na_2O.Al_2O_3.6SiO_2$ |
| | ALBITE, VAR. CLEAVELANDITE | | |
| | POLLUCITE | I | $H_2O.Cs_2O.2Al_2O_3.9SiO_2$ |
| SILICA | QUARTZ (GRAPHIC GRANITE) | R | $SiO_2$ |
| | QUARTZ (MASSIVE) | | $SiO_2$ |
| | QUARTZ (EUHEDRAL) | | $SiO_2$ |
| | OPAL, VAR. HYALITE | A | $SiO_2.nH_2O$ |
| MICAS | MUSCOVITE | M | $(H,K)AlSiO_4$ |
| | BIOTITE | M | $H_2K(MgFe)_3Al(SiO_4)_3$ |
| | LEPIDOLITE (FINE GRAINED) | | $(OHF)_2KLiAl_2Si_3O_{10}$ |
| | LEPIDOLITE (COARSE GRAINED) | | $(OHF)_2KLiAl_2Si_3O_{10}$ |
| | COOKEITE | M | $(OH)_8LiAl_3Si_2O_6$ |
| | MUSCOVITE, VAR. DAMOURITE, SECONDARY PRODUCT | | |
| GARNET | SPESSARTITE | I | $3MnO.Al_2O_3.3SiO_2$ |
| | ESSONITE | | $3CaO.Al_2O_3.3SiO_2$ |
| | GARNET, IN LINE ROCK | | |
| | SPINEL | I | $MgO.Al_2O_3$ |
| | EPIDOTE | M | $H_2O.4CaO3(AlFe)_2O_36SiO_2$ |
| SPODUMENE | SPODUMENE, COMMON | M | $Li_2O.Al_2O_3.4SiO_2$ |
| | KUNZITE (LILAC, TRANSPARENT) | M | |
| | YELLOW (TRANSPARENT) | | |
| | HIDDENITE (GREEN, TRANSPARENT) | | |
| | AMBLYGONITE | Tr | $LiAl(F,OH)PO_4$ |
| | COLUMBITE | O | $(Fe,Mn)Nb_2O_6$ |
| | TANTALITE | O | $(Fe,Mn)Ta_2O_6$ |
| | STIBIOTANTALITE | O | $(SbO)(Ta,Nb)_2O_6$ |
| | MANGANOTANTALITE | O | $Mn(TaNb)_2O_6$ |
| | CASSITERITE | T | $SnO_2$ |
| ZEOLITES | HEULANDITE | M | $(CaNa_2)O.Al_2O_3.6SiO_2.5H_2O$ |
| | STILBITE | M | $(Na_2Ca)Al_2Si_6O_{16}.6H_2O$ |
| | LAUMONTITE | M | $(CaNa_2)Al_2Si_4O_{12}.4H_2O$ |
| | HEMATITE | H | $Fe_2O_3$ |
| | PYRITE | I | $FeS_2$ |
| | SIDERITE | H | $FeCO_3$ |
| | MOLYBDENITE | H | $MoS_2$ |
| BISMUTH MINERALS | NATIVE BISMUTH | R | $Bi$ |
| | BISMUTHINITE | O | $Bi_2S_3$ |
| | BISMITE | O | $Bi(OH)_3$ |
| | BISMUTITE | Am | $Bi_2O_3.CO_2.H_2O$ |
| | BISMUTOSPHAERITE | | $Bi_2(CO_3)_3.2Bi_2O_3$ |
| | PUCHERITE | O | $BiVO_4$ |
| PHOSPHATES | TRIPHYLITE | O | $LiFePO_4+Mn$ |
| | LITHIOPHILITE | O | $LiMnPO_4+Fe$ |
| | PURPURITE | O? | $2(Fe,Mn)PO_4.H_2O$ |
| | HUREAULITE | M | $H_2Mn_5(PO_4)_4.4H_2O$ |
| | PALAITE | M? | $5MnO.2P_2O_5.4H_2O$ |
| | STEWARTITE | Tr | $3MnO.P_2O_5.4H_2O$ |
| | SALMONSITE | O | $Fe_2O_3.9MnO.4P_2O_5.14H_2O$ |
| | STRENGITE | O | $FePO_4.2H_2O$ |
| | SICKLERITE | O? | $Fe_2O_3.6MnO.4P_2O_5.3(LiHO)$ |
| | TRIPLITE | R=Fe,Mn,Ca,Mg. M (MASSIVE) | $(RF)RPO_4$ |
| | MANGANITE | O | $Mn_2O_3.H_2O$ |
| | PSILOMELANE | COLLOIDAL | $MnO_2$ + impurities |
| | BAVENITE | M | $9SiO_2.Al_2O_3.BeO.4CaO.H_2O$ |
| KAOLIN | MONTIMORILLONITE, MASSIVE | | $(MgCa)O.Al_2O_3.5SiO_2.nH_2O$ |
| | HALLOYSITE, MASSIVE | | $Al_2O_3.2SiO_2+H_2O$ |

| | | SiO₂ | Al₂O₃ | Fe₂O₃ | FeO | MgO | CaO | Na₂O | K₂O | H₂O+ | H₂O- | TiO₂ | P₂O₅ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Tourmaline, black | 35.96 | 33.28 | | 11.04 | 3.48 | 0.42 | 2.16 | None | 3.31 | | 0.36 | |
| 2 | " black | 35.21 | 36.07 | | 11.11 | 0.19 | 0.25 | 1.92 | None | 3.51 | | 0.23 | |
| 3 | " black | | | | | | | Detect. | None | | | | |
| 4 | " pale green | 36.72 | 41.27 | | 1.13 | None | 0.67 | 2.23 | None | 3.33 | | 0.06 | |
| 5 | " deep green | | | | | | | Str. | Tr. | | | | |
| 6 | " emeralite | | | | | | | Str. | None | | | | |
| 7 | " achroite | | | | | | | Mod. | None | | | | |
| 8 | " rubellite | | | | | | | Mod. | None | | | | |
| 9 | " pink | 37.57 | 42.18 | | 0.19 | None | 1.20 | 2.05 | None | 3.39 | | Tr. | |
| 10 | " pink* | 36.98 | 43.69 | | | Tr. | 0.25 | 2.02 | 2.29 | 4.67 | 1.16 | | |
| 11 | " pink** | 37.05 | 44.25 | | | 0.10 | 0.22 | 1.06 | 1.95 | 10.81 | 0.83 | | |
| 12 | Spodumene (kunzite) | 64.42 | 27.32 | None | | None | None | 0.39 | 0.03 | | | | |
| 13 | Beryl, pink | | | | | | | Tr. | None | | | | |
| 14 | Amblygonite | | 33.70 | 0.12 | | | 0.31 | 0.14 | | 5.95 | | | 48.83 |
| 15 | " | | | | | | None | Weak | None | | | | |
| 16 | Microcline, grey | | | | | | | Str. | | | | | |
| 17 | " white | | | | | | | Str. | | | | | |
| 18 | Orthoclase, clear | | | | | | | Str. | Str. | Extr. | | | |
| 19 | " perthitic | | | | | | | Str. | Str. | Extr. | | | |
| 20 | " clear | | | | | | | Weak | Str. | Extr. | | | |
| 21 | Cleavelandite | | | | | | | | None | | | | |
| 22 | Halloysite | 43.62 | 35.55 | 0.21 | | 0.19 | 1.02 | 0.19 | 0.03 | 12.25 | 6.63 | None | |
| 23 | Muscovite, pink | 45.63 | 37.42 | Tr. | | None | None | 1.43 | 9.95 | 4.43 | | Tr. | |
| 24 | Green mica | | | | | | | None | Weak | Extr. | | | |
| 25 | Lepidolite, red prp. | 51.12 | 22.20 | 0.80 | | | | 2.28 | 10.00 | 2.05 | | | 0.04 |
| 26 | " blue purple | 50.95 | 23.97 | 0.82 | | | | 2.39 | 10.69 | 1.91 | | | 0.04 |
| 27 | " purple | 50.34 | 28.71 | 0.11 | Tr. | None | Tr. | 1.59 | 10.37 | 3.15 | | | |
| 28 | " white | 51.25 | 25.62 | 0.12 | None | None | Tr. | 1.91 | 10.65 | 1.60 | | | |
| 29 | " Brdr.muscovite | 50.85 | 26.78 | 0.60 | | Tr. | 0.10 | 1.41 | 10.30 | 1.74 | | | |
| 30 | Lepidolite | | | | | | | | | | | | |
| 31 | " red purple | | | | | | | None | Mod. | | | | |
| 32 | Cookeite | 35.53 | 44.23 | | | Tr. | Tr. | 2.11 | 0.31 | 13.57 | 0.61 | | |
| 33 | Garnet, lt. brown | | | | Str. | None | Extr. | Weak | None | | | | |
| 34 | " line rock | | | | | | | Str. | Extr. | Str. | | | |

\* Partly altered
\*\* About completely altered

PLATE XXVII

PEGMATITES OF SAN DIEGO COUNTY, CALIFORNIA

| MnO | Li$_2$O | Rb$_2$O | Gs$_2$O | B$_2$O$_3$ | | Total | Locality | Analyst | Reference |
|---|---|---|---|---|---|---|---|---|---|
| 0.13 | None | | | 10.61 | F None | 100.75 | Lost Valley | W.T.Schaller | USGS Bull.419 1910 |
| 0.98 | Tr. | | | 10.48 | | 99.95 | Ramona | " " | " " " " |
| | Weak | None | None | | | | Mesa Grande | M.Donnelly | Spectroscopic determ. |
| 1.48 | 1.76 | | | 10.60 | F 0.31 | 99.76 | " " | W.T.Schaller | USGS Bull. 419 1910 |
| | Str. | None | None | | | | " " | M.Donnelly | Spectroscopic determ. |
| Extr. | Str. | None | None | | | | Pala | " " | " " |
| Mod. | Str. | None | None | | | | " | " " | " " |
| Str. | Str. | None | Tr. | | | | " | " " | " " |
| 0.24 | 1.92 | | | 10.65 | F 0.29 | 99.77 | Mesa Grande | W.T.Schaller | USGS Bull. 419 1910 |
| Tr. | 1.28 | | | 7.66 | F Undet. | 98.84 | Pala | " " | " " " " |
| Tr. | 1.27 | | | 2.46 | F Undet. | 99.17 | " | " " | " " " " |
| 0.15 | 7.20 | | | | | | " | " " | UCPBDG 3:274 1903 |
| | Str. | None | Str. | | | | Mesa Grande | M.Donnelly | Spectroscopic determ. |
| 0.09 | 9.89 | | | | F 2.29 | | Pala | W.T.Schaller | Am.J.Sci(4)17:192 1904 |
| | Extr. | None | None | | | | " | M.Donnelly | Spectroscopic determ. |
| | Mod. | None | None | | | | " | " " | " " |
| | Mod. | None | None | | | | " | " " | " " |
| | Str. | None | None | | | | " | " " | " " |
| | Mod. | None | None | | | | Pala | " " | " " |
| | Str. | None | None | | | | " | " " | " " |
| | Mod. | Str. | None | | | | Mesa Grande | " " | " " |
| 0.26 | 0.23 | | | | | | Pala | W.T.Schaller | Am.J Sci(4)17:191 1904 |
| 0.06 | 0.20 | | | | | | Mesa Grande | " " | USGS Bull. 419 1910 |
| Tr. | Str. | Tr. | Tr. | | | | Pala | M.Donnelly | Spectroscopic determ. |
| | 5.12 | | | | | | " | W.T.Schaller | USGS Bull. 419 1910 |
| | 4.63 | | | | | | " | " " | " " " " |
| 0.50 | 2.39 | | | | | | Mesa Grande | " " | " " " " |
| 0.05 | 4.31 | | | | | | " " | " " | " " " " |
| 0.07 | 4.27 | | | | | | " " | " " | " " " " |
| | | 0.67 | 0.16 | | | | Pala | T.G.Kennard | Am.J Sci 28:102 1934 |
| | Extr. | Faint | Faint | | | | " | M.Donnelly | |
| Tr. | 2.73 | | | | | | " | | USGS Bull. 419 1910 |
| Str. | None | None | None | | | | " | | Spectroscopic determ. |
| | Tr. | None | None | | | | " | " " | " " |

Extr. = Extreme      Str. = Strong      Mod. = Moderate

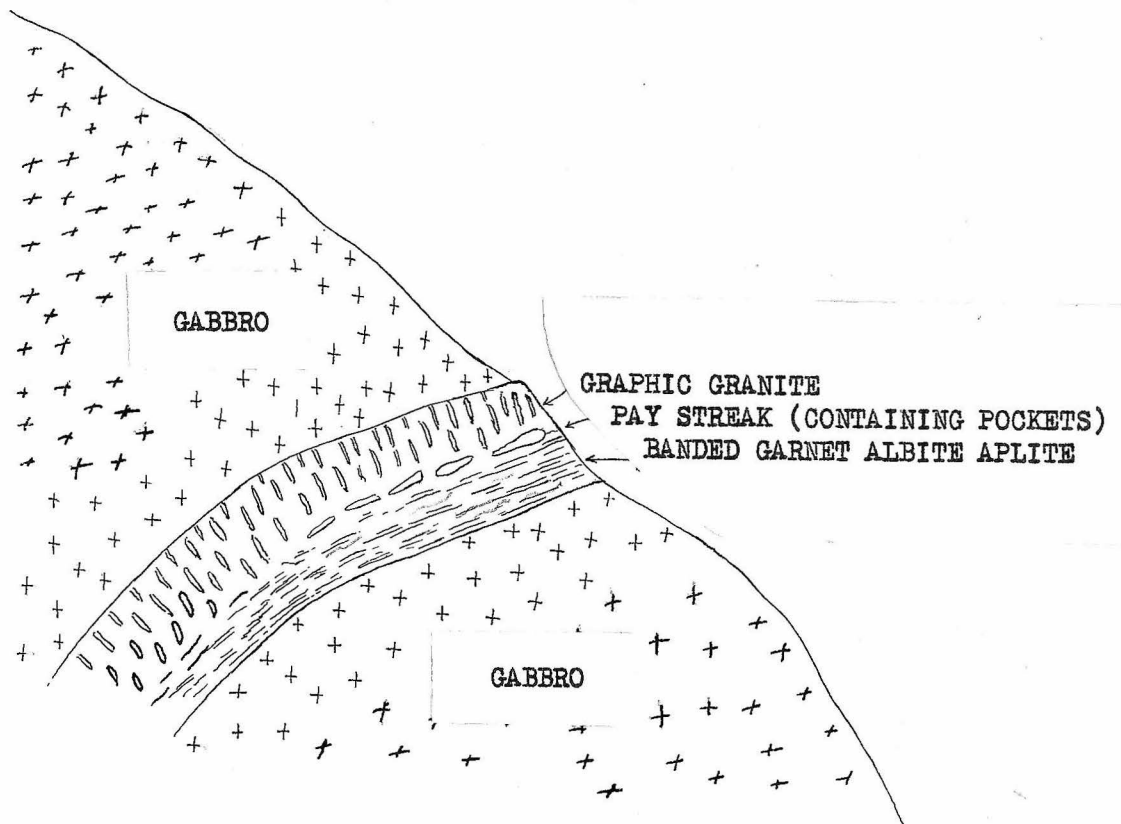Figure 1.— Idealized cross-section of pegmatites of Tourmaline Queen Mountain, Pala. The thickness of the dikes ranges from ten to a hundred feet; the average thickness is about twelve feet. The graphic granite upper portion usually makes up slightly more than half the dike. Gem-bearing pockets range in size from a few inches to several feet in height; they are generally lenticular, with their longer dimensions parallel to the walls.

# MINERALOGY

## Graphic Granite

Although graphic granite is a mineral aggregate that answers the definition of a rock, it is convenient to describe it here.

The Abbé Haüy applied the term pegmatite to the rock now generally called graphic granite. Pegmatite was later extended to cover all igneous rocks coarser grained and usually more irregularly grained than their plutonic equivalent. Johannsen[1] considered that rocks possessing a graphic texture bear a close resemblance to Runic characters (characters used by Teutonic, or Germanic peoples from the 3rd century A.D.) and devised the term runite to replace graphic granite. He said runites consist essentially of quartz and potash feldspar, generally microcline or microcline-microperthite, intergrown in such a manner that adjacent patches of these constituents extinguish between crossed nicols at the same time.

The ideas on the origin of graphic granite are well summarized by Johannsen.[2] Two main views have dominated. In the older view graphic granite is held to represent the simultaneous crystallization of two minerals at the eutectic point of these two minerals. For quartz and microcline this point is 26% quartz, 74% microcline. The points in favor of an origin by eutectic crystallization are (1) the rather uniform composition of graphic granite, (2) the frequent occurrence of a feldspar (usually perthite) crystal which passes with a rather sharp boundary into graphic granite, (3) the character of the quartz in the intergrowth, it being almost always high quartz.

[1] Johannsen, A. Petrography, vol. II, p. 84 (1932)

[2] Idem, pp. 84-91.

A more recent view ascribes a replacement origin to the quartz in graphic granite. Besides the evidence cited by Johannsen[1] in favor of this view two additional facts may be mentioned. Dr. W. T. Schaller (oral communication) found that the angles present in the quartz in graphic granite are not the same as those found in quartz which has grown in free space-- he believed this indicated the influence of the pre-existing space lattice of the feldspar in modifying the secondarily-deposited quartz. He also stated that during the course of petrogenetical experiments conducted in the Geophysical Laboratory over 1500 mixtures of eutectic proportions had been made and examined and in none of them had been found a graphic texture. It should be noted, however, that all of these mixtures were dry melts, a chemical condition which probably did not obtain during the crystallization of graphic granite in nature.

The writer is disposed to consider graphic intergrowths of quartz and feldspar to be an expression of the same phenomena as intergrowths of feldspar, i.e., perthites. As discussed elsewhere in this report, Olaf Andersen, concluded that most perthites are a result of replacement and certainly one gains the impression from microscopic study that the albite in microcline-microperthite has replaced microcline. There is, however, no preponderance of evidence in favor of origin by replacement or by eutectic crystallization, and the question must still be considered open. If after an examination of an appreciable number of the crystallized products of wet melts of eutectic proportions, experiments now under way at the Geophysical Laboratory, no reasonably high percentage of graphic textures are

[1] Johannsen, A. Petrography, vol. II, pp. 89-91 (1932)

found, we may conclude eutectic crystallization has not been the controlling process.

Fine grained graphic granite from the upper portion of the Stewart dike is described as a typical example of this kind of rock. Megascopically it is a grayish-white aggregate in which quartz occurs as rod-like bodies, arranged in parallel fashion. Quartz appears as shiny slivers on fractures in the zone 010-001 of microcline, and as triangular markings on fractures nearly parallel to (100) of microcline.

Albite is usually not visible in hand specimens. Where visible megascopically it forms tiny, cross-cutting veins which are clearly later than the body of the rock. Small amounts of bluish-black tourmaline, silvery muscovite, and brown garnet frequently occur and are visible in hand specimens. The fracture parallel to the (100) face is often remarkably good and might be mistaken for either of the cleavage directions, (001) or (010) of microcline. In the field it is observed that on the whole the quartz rods are oriented normal to the walls, although many exceptions to this are found. Under the microscope the feldspar is seen to be a microcline-microperthite. A section cut about normal to the elongation of the quartz rods was found to be sensibly parallel to the (100) face of both the albite and microcline. Quartz in this section was disclosed to have irregular, rounded outlines and to be oriented with the c-axis making an angle of about 15° with the section. The albite twinning in microcline and albite is parallel, but the twinning lines in albite are straight and sharp, those in microcline are blurred, sometimes slightly curved, and almost always disc-shaped. The cleavage parallel to (001) is superior to that parallel to (010) and the cleavage lines cut across microcline and albite without offset at the boundary.

Another section of the same rock cut nearly parallel to the elongation of the quartz rods was found to be nearly parallel to the (001) face of microcline. The quartz rods were disposed in sharp-pointed lentils which were parallel to or at high angles with the (010) -- microcline -- cleavage direction. The (010) cleavage of microcline was not well developed in the section. The grating structure due to albite and microcline twinning was well shown in the microcline seen in this section. An interesting feature brought out in the appended Rosiwal analysis is the difference in proportion of albite in the sections, it being noticeably higher in the transverse than in the longitudinal one.

The question of the orientation of the quartz rods in the graphic granite from the gem tourmaline field of southern California has been carefully investigated by W. T. Schaller. The accompanying diagram is based on oral information from Dr. Schaller.
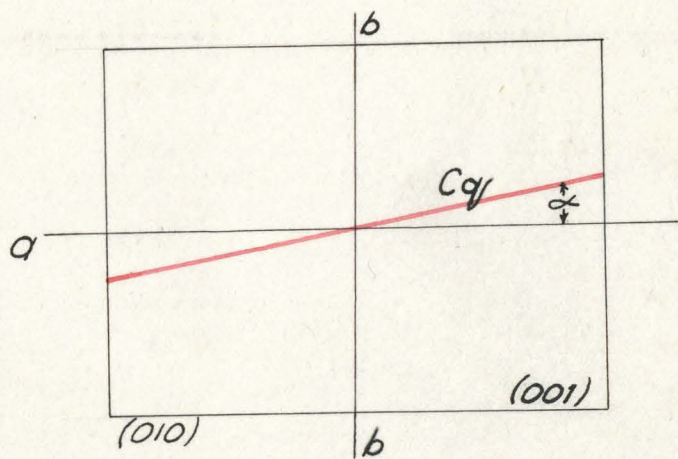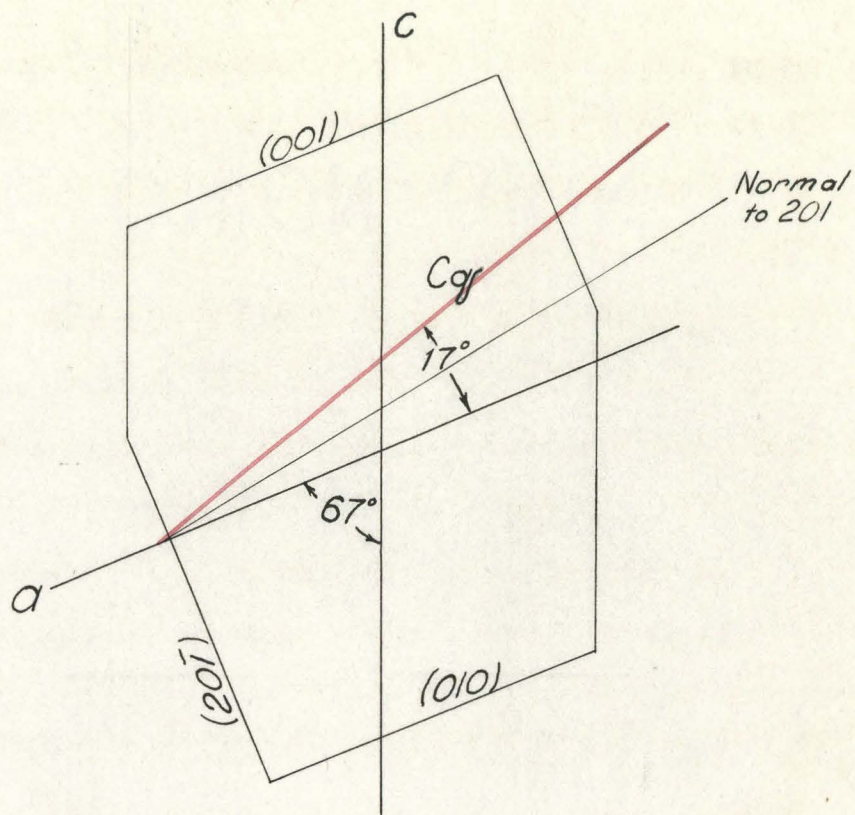
Figure 2.— Diagram showing orientation of quartz rods in graphic granite. In the figures a, b, and c are the three crystallographic axes of microcline. $C_q$ is the vertical crystallographic axis of quartz. Alpha is a small angle, whose value is not known.

Johannsen[1] cites 17 modes (mineral composition) of graphic granite. In 16 of these the feldspar is microcline-microperthite (evidently there is an error in this table as he states on page 88 that Holmes found the constituents of graphic granite from Mozambique to be quartz and microcline-microperthite, whereas in the table on page 85 the feldspar is listed as microperthite). Only one specimen cited has microcline as the feldspar. The average of sixteen modal analyses of microcline-microperthite is

|          | Average | Range        |
|----------|---------|--------------|
| Quartz   | 25.37   | 34.00 -17.65 |
| Feldspar | 74.63   | 81.42 -66.00 |

The average of 10 chemical analyses of graphic granite cited by Johannsen[2]

|           | Average | Range          |
|-----------|---------|----------------|
| $SiO_2$   | 73.48   | 74.58 - 71.00  |
| $Al_2O_3$ | 14.57   | 16.31 - 13.37  |
| $Fe_2O_3$ | .13     | .30 -          |
| $CaO$     | .27     | .72 -    .00   |
| $Na_2O$   | 2.28    | 3.44 -   1.16  |
| $K_2O$    | 9.00    | 10.09 -  7.06  |
| $H_2O$    | .17     | .57 -          |

[1] Johannsen, A. Petrography, vol. II, p. 85 (1932)

[2] Idem. p. 87.

The results of three Rosiwal analyses, two of them on the same rock, are here set forth. A megascopic planimetric analysis of the coarse grained graphic granite was made on a smoothly ground section normal to the quartz elongation. The procedure was as follows: The section was coated with ambroid, a fast drying cellulose compound. The areas underlain by quartz were cut away and the scraps of ambroid collected and weighed. The remaining ambroid, which was underlain by feldspar, was peeled off and weighed. The weight of the ambroid which overlay quartz and the weight of the ambroid which overlay feldspar give a fair measure of the respective quantities of these two substances.

Larsen and Miller[1] have recently evaluated the Rosiwal method for determining the modal composition of a rock. They conclude that a Rosiwal analysis should not be expressed closer than the nearest per cent. With this conclusion the writer is in accord, but the appended figures on several Rosiwal analyses are allowed to stand as they were computed, to the nearest tenth of a per cent. It is to be understood that their accuracy is only to the nearest percent.

[1]
Larsen, E. S. and Miller, F. S. The Rosiwal method and the modal determination of rocks. Am. Mineralogist, vol. 20, pp. 260-273, April (1935).

## ROSIWAL ANALYSIS OF COARSE GRAINED GRAPHIC GRANITE

| Mineral | Vol. % | Wt. % |
|---|---|---|
| Microcline | 60.1 | 59.5 |
| Quartz | 18.2 | 18.7 |
| Albite | 21.7 | 21.8 |
| | 100.0 | 100.0 |

| | Microcline | | Quartz | | Albite | | Graphic Granite |
|---|---|---|---|---|---|---|---|
| | A | Ax59.5% | A | Ax18.7% | A | Ax21.8% | |
| Silica | 64.7 | 38.4 | 100 | 18.7 | 68.7 | 15.0 | 72.1 |
| Alumina | 18.4 | 10.9 | 0 | 0 | 19.5 | 4.25 | 15.2 |
| Potash | 16.9 | 10.1 | 0 | 0 | 0 | 0 | 10.1 |
| Soda | 0 | 0 | 0 | 0 | 11.8 | 2.57 | 2.6 |
| | | 59.4 | | 18.7 | | 21.82 | 100.0 |

Analysis of same rock but larger section (50mmx50mm), made by painting with ambroid, separating areas underlain by quartz from those underlain by feldspar. The agreement between the two analyses is very close.

| Mineral | Wt. % |
|---|---|
| Quartz | 18.8 |
| Feldspar | 81.2 |

# ROSIWAL ANALYSIS OF FINE GRAINED GRAPHIC GRANITE

## Section cut parallel to elongation of quartz rods

| Mineral | Vol. % | Wt. % |
|---|---|---|
| Microcline | 56.6 | 55.9 |
| Quartz | 22.1 | 22.7 |
| Albite | 21.3 | 21.4 |
| | 100.0 | 100.0 |

| | Microcline | | Quartz | | Albite | | Granite |
|---|---|---|---|---|---|---|---|
| | A | Ax55.9% | A | Ax22.7% | A | Ax21.4% | |
| Silica | 64.7 | 36.2 | 100 | 22.7 | 68.7 | 14.7 | 73.6 |
| Alumina | 18.4 | 10.3 | | | 19.5 | 4.2 | 14.5 |
| Potash | 16.9 | 9.5 | | | 0 | 0 | 9.5 |
| Soda | 0 | 0 | | | 11.8 | 2.5 | 2.5 |
| | | 56.0 | | 22.7 | | 21.4 | 100.1 |

## Section cut normal to elongation of quartz rods

| Mineral | Intervals | Vol. % | S. G. | Product | Wt. % |
|---|---|---|---|---|---|
| Microcline | 122.17 | 51.4 | 2.56 | 132.0 | 50.8 |
| Quartz | 54.44 | 22.9 | 2.66 | 61.0 | 23.4 |
| Albite | 60.84 | 25.7 | 2.61 | 67.0 | 25.8 |
| | 237.45 | 100.0 | | 260.0 | 100.0 |

| | Microcline | | Quartz | | Albite | | Granite |
|---|---|---|---|---|---|---|---|
| | A | Ax50.8% | A | Ax23.4% | A | Ax25.8% | |
| Silica | 64.7 | 32.8 | 100 | 23.4 | 68.7 | 17.7 | 73.9 |
| Alumina | 18.4 | 9.4 | 0 | 0 | 19.5 | 5.0 | 14.4 |
| Potash | 16.9 | 8.6 | 0 | 0 | 0 | 0 | 8.6 |
| Soda | 0 | 0 | 0 | 0 | 11.8 | 3.1 | 3.1 |
| | | | | | | | 100.0 |

Although there is probably some soda in microcline and some potash in albite, it was not possible to estimate the percentage in each case. It seems likely that if both factors are neglected, the results are reasonably correct.

PLATE XIX

A.  PHOTOMICROGRAPH OF GRAPHIC GRANITE

The dark twinned areas are microcline.
The light twinned areas are albite.
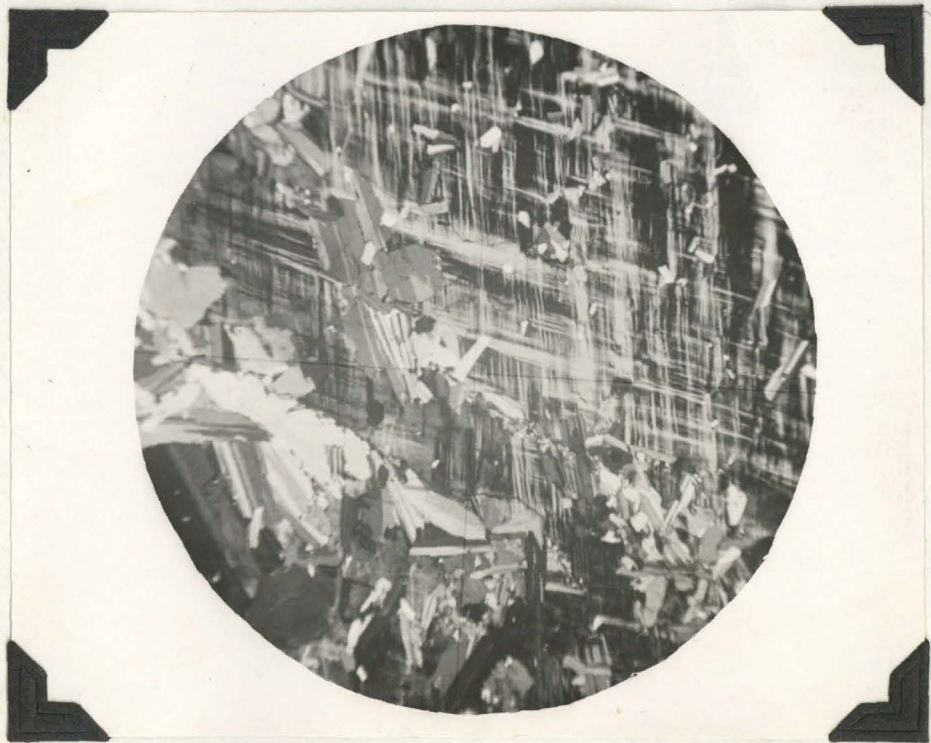The untwinned areas are quartz
                    Crossed nicols x22

B.  CLEAVELANDITE VEINING MICROCLINE

Photomicrograph showing microcline
beined by cleavelandite.  The micro-
cline is recognized by its grating
structure
                    Crossed nicols x22

## Orthoclase

It has only recently been recognized that the dominant feldspar of granite pegmatites is microcline. Some writers give the reader the impression, at least, that orthoclase is predominant, or is found in amounts about equal to microcline. Hatch and Wells[1] state granite-pegmatites consist essentially of quartz, feldspar(orthoclase or microcline) and mica(muscovite and biotite). Rastall[2] states the feldspar(of pegmatites) is usually of the most alkaline type, orthoclase, microcline, albite, and perthite. Tyrrell[3] is less specific, he notes that "granite pegmatites are mainly composed of alkali-felspars and quartz." Pirrson-Knopf[4] state the "chief minerals(of granite pegmatites) are quartz and feldspar, the latter being mostly orthoclase or the variety of it called microcline, though albite also occurs." Bastin[5] lists orthoclase as one of the minerals reported from the pegmatite deposits and says "orthoclase—present with microcline is nearly all of the pegmatites, the two being commonly intergrown in the same crystal."

[1]Hatch, F. H., and Wells, A. K. The petrology of the igneous rocks. pp. 342-344 (1926)

[2]Rastall, R. H. The geology of the metalliferous deposits, p.44 (1923)

[3]Tyrrell, G. W. The principles of petrology. p. 162 (1926)

[4]Pirrson, Louis V., and Knopf, A. Rocks and rock minerals. 2nd ed. rev., p. 217 (1926)

[5]Bastin, Edson S. Geology of the pegmatites and associated rocks of Maine. U.S.G.S. Bull. 445, p. 17 (1911)

On the other hand, in describing the pegmatites of central Maine, Landes[1] wrote "potash feldspar, usually microcline, is a leading mineral in the granite pegmatites of central Maine, and elsewhere." Although Landes[2] does not definitely state that he did not find orthoclase in the pegmatites of central Maine, he does not list or describe it. Johannsen[3] has recently summarized the literature on pegmatites and correctly, in the opinion of the present writer, states that microcline-microperthite is the most common feldspar of granite-pegmatites. Johannsen[4] considers the essential constituents of granite-pegmatites to be quartz, orthoclase, microcline, and perthite. In a communication to the editor of Ward's Mineral Bulletin, Dr. H. L. Alling[5] wrote "Microscopically they(meaning orthoclase and microcline) are quite distinct because microcline is usually twinned in its characteristic way. You will never find in a pegmatite true orthoclase in large cleavable masses because it does not exist."

[1]Landes, Kenneth L. The paragenesis of the granite pegmatites of central Maine. Am. Mineralogist, 10, p. 368 (1925)

[2]Idem, p. 355-405

[3]Johannsen, A. A descriptive petrography of igneous rocks. 11: 72-84 (1932)

[4]Idem, p. 74

[5]Alling, H. L., in notes from dorrespondents: Ward's Mineral Bulletin, 11: p. 2 (1934)

In this connection it may be recalled that Landes[1] found the characteristic albite and pericline twinning to be commonly absent from the microcline he examined from the pegmatites of central Maine. Prof. Charles Palache[2] writing to the editor of Ward's Mineral Bulletin said, "I am inclined to think you are quite right that orthoclase does not occur in pegmatites."

The question as to the abundant occurrence of orthoclase in cleavable masses in granite pegmatites is complicated by the belief of some workers that microcline and orthoclase are not separate species, orthoclase being viewed by them as a sub-microscopically twinned variety of microcline. Mallard and Michel-Levy strongly advocated this view. It has also received support in the writings of H. L. Alling.[3] Schaller,[4] one of the most experienced of the pegmatite investigators, believed orthoclase should be regarded as a sub-microscopically twinned variety of microcline. The recent work of Alexander Kohler,[5] who heated microcline nearly free from albite to 1000° C for 500 hours and found no evidence of a monoclinic modification in the material so treated; taken with (1) the X-ray evidence reported by Barth,[6] (2) the previous studies on specific

[1] Landes, Kenneth K., The paragenesis of the granite pegmatites of central Maine. Am. Mineralogist, 10, p. 367 (1925)

[2] Palache, Charles, in Notes from correspondents: Ward's Mineral Bulletin, vol. II, p. 2 (1934)

[3] Alling, H. L., The mineralography of the feldspars. Jour. Geol. 29: 194-294 (1921)

[4] Schaller, W. T., Oral communication (1934)

[5] Kohler, Alexander., The dimorphism of potash feldspar: Centr. Mineral. Geol. A. pp. 113-21 (1933)

[6] Barth, Tom. F.W., Polymorphic phenomena and crystal structure: Am. Jour. Sci., vol. XXVII pp.278-283 (1934)

gravity, optic angle, and refractive indices, and (3) the experimental observation that orthoclase does invert at about $900^{\circ}C$., would seem to sufficiently establish a separate identity of orthoclase and microcline. As used by the present writer orthoclase is the potash feldspar which is not multiple twinned and has an extinction angle on (001) of $0^{\circ}$. Microcline is the potash feldspar, which may or may not be multiple twinned and has an extinction angle on (001) of $15-18^{\circ}$.

Much orthoclase has been found in the complex pegmatites of Mesa Grande and Pala, California. It occurs mainly in the middle portion, or pay streak of the dikes, and forms euhedral perthitic crystals of considerable size. Oriented thin sections cut from a specimen collected at Pala show the mineral to be orthoclase, with perthitic inclusions of albite. No twinning of any kind is perceptible in sections of orthoclase cut parallel to the side pinacoid (Cl0) and only very faint microcline twinning on those cut parallel to the base (001). The sections cut parallel to the base show parallel extinction to the trace of the 010 cleavage. In this specimen inversion of orthoclase to microcline has been very slight and may be due wholly to thin section grinding.

A specimen of potash feldspar from Pala was examined in considerable detail. Several thin sections were ground. Some were made with the utmost care, using as fine abrasive as possible and as little pressure as possible throughout the operations. Others were ground with the application of considerable pressure and with the use of as coarse abrasive as possible. One of the sections was made by encasing the mineral chip in a sheath of solder and grinding the chip so protected in a slow, careful manner. All of these sections were found to show perceptible microcline

twinning and no difference could be noted in the amount of microcline twinning in the various slides, regardless of the way they were ground. Most of the sections from the interior of the specimen cut parallel to the base extinguish between cross nicols to the trace of the 010 cleavage indicating the mineral is orthoclase. The structure and composition of the transparent end of a specimen collected at Pala show a number of interesting features. It can be seen megascopically that the transparent portion is not perthitic. The microscope reveals this part to be strongly twinned on the albite law and the lamellae are plainly visible both in thin section and in powdered fragments. This part of the crystal is obviously microcline. Spectroscopic examination of the transparent and of the perthitic parts disclose a higher percent of lithium in the transparent part than in the main body. The relation between transparency, microcline inversion, absence of perthitic albite, and percent of lithium is noteworthy, but its natural history is not clear. The mineral being discussed is mainly orthoclase, which has inverted partly to microcline. The inversion has been accelerated or accompanied by increase in the lithium content. It seems probable that the strains set up during thin section grinding have increased the inversion of orthoclase to microcline; how much this increase has been it is not possible to state, except that it appears certain that the stresses applied even in very careful grinding are sufficient to produce twinning striations in the orthoclase examined during this study.

Admittedly, microcline perthite is the predominant feldspar in the complex pegmatites of southern California and makes up a large proportion of these dikes. Orthoclase, however, in several stages of inversion to microcline, does occur abundantly in coarse cleavable masses. It is freq-

uently not possible to determine the extent of natural inversion of orthoclase to microcline because strains induced by thin section grinding may develop or increase the extent of inversion.

## Microcline

Microcline is found in all the simple lithia pegmatites of southern California. With quartz, it makes up the bulk of these pegmatites. Microcline is found in graphic intergrowth with quartz and as rather large coarse masses associated with graphic granite and quartz masses in the middle and upper part of the dikes; as fine-grained anhedrons in the garnet-albite-aplite in the bottom of the dikes; and as euhedral or subhedral crystals in the pay-streak. The coarse-grained varieties are almost always perthitic, the guest feldspar is, in all cases examined microscopically, albite or highly albitic plagioclase. The occurrence of perthitic texture produced under a variety of conditions may, with careful study, lead to a better understanding of their origin.

The microcline of graphic granite is commonly white or a very light grey. Frequently it is faint pink; the typical rather strong shade of pink or red seen in microcline from most pegmatites has not been found common in the pegmatites herein described. Microcline, in coarse masses in the middle and upper part of the dikes, forms two rather different types. One type of microcline is white or very light in color and seems to be characteristic of the dikes or parts of dikes in which the pay-streaks are small or restricted and lepidolite is absent or exiguous. In the dikes that show much hydrothermal effects, usually but not always indicated by lepidolite, lithia tourmaline, or other lithia-bearing minerals, a grey colored microcline is prevalent. Both are perthitic, the white variety probably more highly albitic than the grey. It seems clear that the grey microcline is younger than the white and one might suspect a slightly different alkali composition for it. With this in

mind, specimens of white and of grey microcline were examined by qualitative spectral analyses for lithium, caesium, and rubidium. Rubidium and caesium were found to be absent, except perhaps in extremely small amounts. Lithium was found in both and while it was not possible to even approximately estimate the percent of lithium in the specimens, the intensity of the lines of lithium in the visible spectrum was about the same in both types of microcline.

Most, but not all, the microcline examined microscopically is twinned on the albite and microcline twinning lows. The polysynthetic twinning in all the feldspar examined which exhibit it, is always much more pronounced in thin section than in powdered grains.

Where the deposition of hydrothermal, post-consolidation minerals has been most pronounced a peculiar feature is often found in the structure of grey microcline. A large individual crystal of grey microcline is seen to be surrounded on all sides by hydrothermal minerals - white and bluish-white albite, black tourmaline, brown garnet, green muscovite, and quartz - in such a way as to suggest very strongly that grey microcline was deposited earlier and replaced by the later minerals, replacement being less around each large microcline individual. The preservation of earlier formed minerals as residuals in later minerals is, of course, one of the best criteria of age relations wherever the evidence, which usually is best seen in the field, is clear. Dr. Schaller conceived the hypothesis that residuals of microcline found in the lower part of the dikes, in the so-called line rock, could be used to prove that the lower part of the dikes were once composed of microcline, most of which has been replaced by quartz and albite rock. During the course of a field

trip with Dr. Schaller the writer had pointed out to him many examples
of textures in the lower part of the dike which suggested to Dr. Schaller
the foregoing interpretation, but the writer regards these as inconclusive.

PLATE XX

A.  CLEAVELANDITE

Photomicrograph showing cleavelandite,
the platy variety of albite
                    Crossed nicols x22

B.  CLEAVELANDITE, QUARTZ, AND LEPIDOLITE

Photomicrograph showing (a) cleavelandite,
(b) quartz, and (c) lepidolite
                    Crossed nicols x22

Average trend
of Albite Veins

010

Average trend
of Albite Veins

70°   001

(010)

75°

(1̄1̄0)   (001)   (11̄0)

Black lines - albite veinlets
Groundmass - microcline

x1
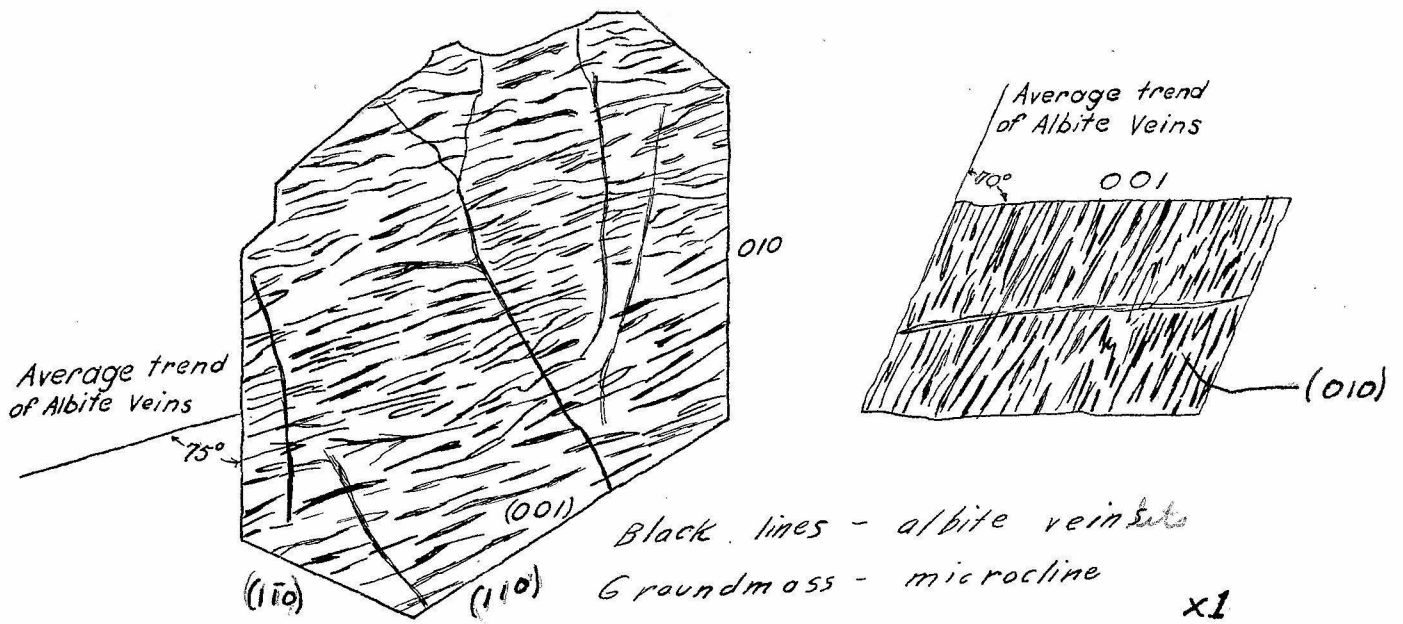
**Figure 3.—**

    A sketch illustrating the appearance of perthitic veinlets

of albite on cleavage surfaces of microcline perthite.

## Albite

Albite is found in the lithia pegmatites of southern California in several different forms. As a perthitic intergrowth with microcline in microcline-microperthite, which may or may not contain quartz and hence constitute graphic granite, it makes up an appreciable proportion of the coarse grained upper part of the dikes. Albite is also found as a perthitic intergrowth in euhedral microcline and orthoclase from the pay-streak. Frequently the twinning striae on albite are visible on the cleavages of these crystals.

Albite is abundant in garnet albite aplite, which occurs in the bottom parts of most of the lithia pegmatite dikes.

The variety of albite called cleavelandite is abundant in lithia pegmatite. It is found in the pay-streak as platy aggregates that obviously have replaced part of the associated minerals. It also occurs at numerous veinlets cutting older minerals. The lithia minerals are almost always accompanied by more or less cleavelandite and its presence, generally clearly visible, is a definite sign that the particular section of the dike in which it occurs has undergone a post-consolidation history. Many, but not all, of the large crystals of black tourmaline are rimmed by albite.

## Quartz

Quartz is, after microcline, the most important mineral of the pegmatites from the standpoint of bulk. It is an essential constituent of the line rock and of graphic granite. It has been introduced at practically every hydrothermal stage and in well-crystallized form has
in
been found most of the pockets. Lepidolite is always associated quartz and is never found absolutely pure.

In the dikes in which hydrothermal action has been most intense, for example in the Pala Chief dike and in some of the dikes on Hiriart Hill, quartz formed large, euhedral crystals, some weighing more than a hundred pounds. Most of these crystals were smoky.

## Muscovite

Muscovite is an abundant and widespread mineral in the pegmatites herein discussed. It occurs in two forms. In the graphic granite and line rock it occurs as fine grained white plates. In the pay streak muscovite occurs in coarse grained green crystals. It is believed that the green coloration indicates a higher proportion of fluorine than is present in the white variety of muscovite.

## Biotite

Biotite is found in some of the lithia pegmatites of Pala and Mesa Grande. It almost always occurs in association with graphic granite in the upper portions of the dikes. Where present in this environment it usually forms flat, thin plates which seem to line fractures in the graphic granite. These plates are generally oriented normal to the walls of the dike. From the field relationships the writer has gained the impression that biotite in the lithia pegmatite dikes has been formed by reaction with the gabbroic wall rock.

## Lepidolite

Lepidolite, the lithium mica, in small quantities is a common constituents in many of the dikes at Pala and Mesa Grande. It is found both fine grained and coarse grained. Wherever it occurs in large masses it is usually fine grained. At the Stewart mine, at Pala, lepidolite occu rred in large amounts. Rubellite, albite, and quartz are found with it. Lepidolite is almost always found where gem tourmaline has been deposited; the miners found this to be so constant an association that they believed that where lepidolite was absent, gem tourmaline would not be found.

## Garnet

Red or brown garnet is abundantly developed in most of the lithia
pegmatite. It is one of the chief constituents of the so-called line rock,
or garnet aplite, where it occurs as small, euhedral crystals which are
banded in layers roughly parallel to the footwall, or in curved layers
which resemble open folds. In the pay streak garnet is common as rather
large crystals, of the order of a centimeter or two in diameter. Some of
these garnet crystals in the paystreak are clear and unflawed, but most
of them are badly fractured. Most of the reports on the gem stones of
San Diego County refer to these garnets as being essonite (grossularite).
Those examined by the present writer are all spessartite, the manganese
garnet.

# Tourmaline

Tourmaline is extensively and abundantly developed in the complex and lithia pegmatites of southern California. In the pegmatites of Mesa Grande and Pala it occurs in two chief classes, (1) ordinary black or bluish-black, and (2) lithia-bearing. The lithia-bearing class is always more or less transparent and is colored or colorless. As will be understood from the later discussion of the origin of some of the lithia tourmaline, patches or residual ends of black tourmaline are often found on single crystals of lithia tourmaline. Several colors may be present in a single lithia tourmaline crystal. These colors may be arranged in bands parallel to the base, or in concentric zones about the vertical axis, or in an irregular, random fashion. Both the lithia and common tourmaline are frequently bent and broken and the fractures sealed. In the case of black tourmaline the cementing material is commonly quartz or albite; in the case of lithia tourmaline the cementing material may be quartz, or albite, or later tourmaline.

Black tourmaline is an important constituent of much of the upper part of the dikes and of the paystreak material. In the upper part of the dikes it is frequently associated with quartz, with which it often forms clumps that seem to have been introduced into the body of the dike from some point near the middle and have made their way upward. Albite is also frequently found associated with black tourmaline, often as a corona or rim about the sides of a crystal of black tourmaline. The various kinds of colored tourmaline, in addition to having lithium as a common character, are restricted to the pay streak of the dikes, generally

to pockets which appear along the pay streak.

No published chemical analyses of black tourmaline from Mesa Grande or Pala are available. Schaller[1] has given us the results of analyses made on black tourmaline from Lost Valley and from Ramona, San Diego County. These analyses are reproduced on Plate XXVII. A feature of interest in comparison of these two analyses is the rather high percentage of magnesium, 3.48%, in the Lost Valley material, in contrast to the low percentage of magnesium, 0.19%, in the Ramona material. Like most of the black tourmaline reported in the literature, the specimens from Lost Valley and Ramona are low in fluorine. It is not possible by optical means alone to throw much light on the composition of black tourmaline from Mesa Grande and Pala. Ward,[2] who has recently made a detailed chemical and optical investigation of the black tourmalines, was able to conclude that an increase in total iron yielded an increase in refringence and birefringence, but this fact in itself is of little use in estimating the chemical composition of a particular specimen. Ward also noted that the more the iron in the black tourmaline, the blacker the color. The chemical analyses of black tourmaline reproduced on Plate XXVII appear to the writer to be of value in establishing the point that during the early crystallization fluorine was either in a too active state to be "frozen" out of the pegmatitic magma, or it has not yet been introduced. Of these two hypotheses the latter seems to be more probable.

The black tourmaline examined optically by the present writer was

[1]Schaller, W. T.  Bull. 419, U. S. G. S.  p. 280  (1910)

[2]Ward, George W.  A chemical and optical study of the black tourmalines.
    Am. Mineralogist, vol. 16, pp. 145-189  (1931).

dichroic in blue (Z) and violet (X) tints. Absorption parallel to Z varies in different specimens, in some it is much less strong than in others. Where the absorption is less strong the dichroism exhibits lighter tints, the color of the X ray approaching the colorless state of lithia tourmaline, the color of the Z ray approaching the light blue of the lithia tourmaline. The generalization may be made that an increase in total alkali (principally sodium, but possibly some potassium and lithium) causes a diminution in the amount and nature of absorption, which, of course, results in a change in the dichroism.

Colored or colorless tourmaline always has in it more or less lithium. This fact is attested by the chemical analyses made by Schaller and reproduced on Plate XXVII and by supplementary spectral analyses made by the present writer, the results of which are also set forth on Plate XXVII. The principal colors found in tourmaline are pink (or red), green, and blue. These are known as rubellite, emeralite, and indicolite, respectively. The colorless variety is known as achroite. In the Pala and Mesa Grande dikes all or nearly all of the color phases occur, although one dike or a particular section of a dike may have a preponderance of tourmaline of one color.

The colored, or lithia tourmaline, appears to have been formed in the pay-streak both by replacement of earlier formed black tourmaline and by deposition of initially lithia tourmaline. There is positive evidence for the first type of formation as some specimens show a gradation from black into colored phases in the same crystal. Origin by deposition of material, either by replacement or cavity filling, as initially lithia tourmaline seems likely.

Since all colored tourmaline contains lithia, some other reason

should be looked to for the cause of color variation. To be sure, one might hypothesize that variations in the percentage of lithium or in the alkali ratio causes the color changes, but this seems unlikely. Schaller has done a large amount of work on this problem, but his results are not available. The writer attempted to apply spectral methods to disclose the elements present in the various colored phases of tourmaline in the hope that light might be thrown on the problem of color variation. While spectral methods are not of great value here, because the radiations given off by manganese and iron are not easily and surely detectable with the visual spectrometer, it seems possible to draw the following conclusions on the cause of color and of color variation in the lithia tourmaline of Mesa Grande and Pala. If we take as our starting point a multicolored or zoned crystal of tourmaline which has in it black, greenish or bluish, pink and colorless phases, these changes in composition appear probable. The introduction, by replacement, of lithium and manganese converts the black tourmaline into green tourmaline. Aluminum, although not ordinarily considered to be a mobile element, is also evidently introduced at this stage. Obviously none of these reactions go to completion over the whole crystal, otherwise it would not now be multicolored. The chief element lost during this process is iron, presumably most of this was in the ferrous state. With further decrease in iron, increase in manganese and lithium and aluminum, part of the crystal becomes colorless.

With further decrease in iron and an increase in the manganese-iron ratio (manganese increasing), the part of the tourmaline so affected becomes pink or red. Potassium may or may not be introduced at this stage. Fluorine and water have been introduced from the start; a considerable am-

ount of water was already existent in the black tourmaline and this amount has been relatively and absolutely increased. The deep shades of blue are thought to be due to a high iron content, plus a considerable amount of introduced lithium. It should be emphasized that the chief role of the lithium seems to be in rendering the crystal transparent. Just how this is accomplished is not known. T. G. Kennard (personal communication) found that there exists a direct relation between the transparency of smoky quartz from the Rincon pegmatites and the proportion of lithium; the higher the lithium content the clearer the quartz. The writer has shown that pocket orthoclase (partly inverted to microcline) is clearer in those portions in which the lithium content is higher. The clear variety of beryl, morganite, from Mesa Grande has been determined by the writer to contain lithium as an important constituent. Finally, mention may be made of the transparent varieties of pocket spodumene, kunzite and straw-colored and colorless spodumene, which have a very high proportion of lithium. It is granted that hydrothermal conditions of deposition are needed for the development of transparency in these minerals.

## Beryl

Beryl is found in sparing amounts in the pay streaks of some of the dikes. It is found both as the common green beryl and as the pink beryl. The latter variety is known as morganite. Morganite has been found at the Pala Chief mine, Pala, and at the Himalaya lode. In both of these occurrences it existed in pockets. Pink beryl has also probably been found in small quantities at the Tourmaline Queen mine and the Tourmaline King mine.

## Spodumene

The colorless, yellow, and lilac varieties of spodumene, which are found in gem form in only one other region of the world, the island of Madagascar, were first discovered at Pala in 1902 on Hiriart Hill. Early in 1903 the Pala Chief mine was discovered and has yielded a large number of beautiful specimens of delicately tinted transparent spodumene. All of the transparent varieties of spodumene, except green, are called kunzite, although to the popular view this name refers to the lilac tinted material only.

Many of the crystals from the Pala Chief mine were large. The writer has seen a tabular crystal of a deep lilac color that is an inch and a half wide, about a half inch thick, and over a foot and a half long. Schaller[1] has described the clear spodumene from the Pala Chief mine and the specimens available to the writer do not show any unusual or different features from those mentioned by him. The pronounced pleochroism is an attractive property. Clear pieces may be nearly colorless when examined in light coming through the crystal at right angles to the cleavage (perfect 110). In the same crystal, when the light travels parallel to the cleavage, a rather deep lilac tint is revealed. The X and Y rays of the lilac varieties are both colored amethystine; their directions of vibration are nearly at right angles to the cleavage.

The cleavage of kunzite renders it difficult to cut. As elsewhere pointed out it is rather soft (H 6-7) for a gem stone and in some

[1] Schaller, W. T.
    Univ. Cal. Dept. Geol. Bull. 3:  265-275

cases loses its color after long exposure to sunlight.

The lilac color of kunzite may be due to manganese. Schaller[1] has determined 0.15% of $Mn_2O_3$ in kunzite from the Pala Chief mine, Pala. On the other hand, the color may be due to the state of ionization of one of the elements in the mineral. It is tentatively suggested that a very minute quantity of one element, the writer is inclined to think it is lithium, has been reduced to a neutral state in the space lattice of the spodumene molecule. The element may be manganese, however, in such a neutral state. Such view is taken because of the action of radiations of low wave length on kunzite. Some crystals of kunzite after exposure to sunlight have lost their pink color. It has been observed that radium emanations and X-rays also have the power of rendering pink kunzite, colorless. Mrs. F. A. Salmons, of Pala, showed the writer a cut kunzite gem that had been initially pink and after exposure to radium emanations for a certain period of time was rendered colorless. Baskerville and Kunz[2] report the phosphorescent effect on kunzite by various radiations, but they do not state the color of the mineral after exposure.

[1]
Schaller, W. T.
    Spodumene from San Diego County, Calif. U.C. Publ. Dept. Geol.,
        vol. 3: 265-275 (1903)

[2]
Baskerville, C. and Kunz, G. F.
    Kunzite and its unique properties. Am. J. Sci. (4) 18: 25 (1904)

# BISMUTH MINERALS

## Bismuth

A mass of native bismuth weighing about a hundred pounds, was found embedded in a large quartz body in the Stewart mine, Pala. The quartz body was near the main shoot of lepidolite ore. A large mass of amblygonite, mined for lithium, was also found embedded in the quartz body. The bismuth was entirely removed during mining operations. Most of it, presumably was used as specimen material.

According to Kunz[1] "overlying the great mass of amblygonite at the lepidolite mine (the Stewart mine, Pala) is a heavy capping of coarse granite, throughout which both metallic bismuth and bismite are present in more or less profusion.... The native bismuth is generally in long irregular crystals, always forming a capping over another mineral, evidently tourmaline; it also appears in platy crystalline masses, several millimeters in length and breadth, up to 12 or 15 .......... One bismuth crystal, an inch in length, was evidently a pseudomorph or replacement of bismuth after a feldspar(?)."

## Bismuthinite

Schaller (160) reports bismuthinite occurring as an oxidation product of native bismuth at the Stewart mine. Associated with it is bismutosphaerite ($Bi_2CO_3$). Schaller described both bismuthinite and bismutosphaerite as oxidation products of native bismuth. The amount of bismuthinite found at the Stewart mine was very small and there is no record of it

[1]Kunz, Geo. F.
   Native bismuth and bismite from Pala, California.
   A. J. Sci., 4th ser. 16: 398-399 (1903)

having been found elsewhere in San Diego County.

## Bismutosphaerite

This very rare mineral was found in small amount as an alteration product of native bismuth at the Stewart mine. It occurs as grayish-black masses and as a yellow powder.

## Bismite

Although the formula of this mineral is given in Dana-Ford, Textbook of Mineralogy (4th ed.) as $Bi_2O_3$, it is noted that the anhydrous oxide may not occur in nature and the mineral may be bismuth hydroxide, $Bi (OH)_3$. This was Schaller's[160] conclusion after a study of the bismuth ochers from San Diego County. At Pala bismite is found, usually admixed with more or less pucherite ($Bi VO_4$), as an earthy alteration product of native bismuth, or bismuthinite. According to Kunz[140] bismite was found (1) as a coating, orange-yellow to grey, permeating the quartz and associated minerals; and (2) between the crystalline platy masses of the bismuth, from which it is unquestionably derived.

Bismuth ocher, containing bismuth hydroxide, has been identified in specimens from the Stewart, Tourmaline King, and Tourmaline Queen mines, all at Pala; and from the Victor mine at Rincon.

## Bismutite

Bismutite is an amorphous earthy mineral ($Bi_2(CO_3)$ $H_2O$) found as an alteration product with other bismuth minerals at Pala. Bismutite has been found at the Stewart mine and may occur at the Tourmaline Queen

mine and Tourmaline King mine.

## Pucherite

At Pala pucherite was found by Schaller[160] as a yellow or gray ocher, mixed with bismite, bismuth hydroxide.

Schaller thought that the vanadium in pucherite, $BiVO_4$, an alteration product of native bismuth, may have come from the gabbroic wall rock. The writer planned to qualitatively analyse for vanadium a sample of gabbro from Pala by spectroscopic methods. Inasmuch as the principal lines of vanadium lie in the ultra-violet region it was not feasible to do so. It is entirely reasonable to suppose that the vanadium in pucherite at Pala may have come from the enclosing gabbroic wall rocks. H. S. Washington[1] reproduces numerous analyses of fresh basic rocks in which vanadium oxide, $V_2O_3$, was reported in small amounts, usually 0.01% to 0.05%. In answer to the obvious criticism that so small amount of material in a rock would not likely be concentrated in a mineral, it should be pointed out that pucherite is found in very sparing quantities.

[1] Washington, H. S. Chemical analyses of igneous rocks; U.S. Geol. Survey, Prof. Paper 99 (1917)

## Triphylite - Lithiophilite

From these two primary lithium-iron-manganese phosphates all the other secondary phosphates have been derived. Pure triphylite is Li Fe $PO_4$; pure lithiophilite is Li Mn $PO_4$. As found in nature triphylite always contains some manganese and lithiophilite always contains some iron. A t Pala triphylite apparently altered more readily than lithiophilite.

The most notable locality for manganese phosphate minerals is the Stewart mine, Pala. Here lithiophilite, polarite, hureaulite, stewartite and associated phosphate minerals were found in a fine-grained mass of albite and lepidolite.

## Triplite

Triplite, a massive and probably primary phosphate, is mentioned by Shaller (161) as occurring at Pala with other phosphates.

# FOUR MANGANESE PHOSPHATES FOUND ONLY AT PALA

In 1912, W. T. Schaller[1] described four new manganese phosphates found in the lithia pegmatites at Pala. Pala is still the only locality from which they have been indubitably reported. Because of the uniqueness of these minerals, the original descriptions given by Schaller are summarized here.

## Palaite

Palaite is a flesh-colored hydrous manganese phosphate, resulting from the alteration of lithiophilite. It forms crystalline masses in the cavities of which are found distinct crystals. Palaite alters to hureaulite. It occurs in the Stewart mine at Pala, from which the name of the mineral is derived.

## Salmonsite

Salmonsite is found at the Stewart mine, Pala. It results from the partial oxidation and hydration of hureaulite, and forms cleavable masses of a buff color, seamed by small veins of fibrous palaite and sprinkled with small masses of blue strengite.

## Sicklerite

Sicklerite is found in cleavable masses at the Vanderburg-Naylor mine on Hiriart Hill near Pala. It is dark brown in color, with a light yellow-brown streak. Sicklerite results from the alteration of lithiophilite.

[1]Schaller, W.T. New manganese phosphates from the gem tourmaline field of southern California. J. Wash. Acy. Sci. 2: 144-145 (1912)

# Stewartite

Stewartite is a hydrous manganese phosphate found at the Stewart mine, Pala, after which it is named. It is very abundant as an alteration product of lithiophilite which it replaces along its cleavage cracks. The first formation of stewartite is in fine fibers arranged normal to the cleavage cracks of the lithiophilite. Irregularly bounded areas and minute but distinct crystals of stewartite also occur. Although abundant, it is intimately intermingled with the other minerals. Stewartite has also been reported from the Tourmaline King, Tourmaline Queen, and Sickler mines (Hiriart Hill) at Pala and from the Mack Tourmaline mine at Rincon.

# Strengite

Strengite is found rather frequently at Pala as an alteration product of triphylite, and perhaps, lithiophilite. It is orthorhombic; usually forms a blue crystalline coating on triphylite. Schaller states strengite is equivalent to angelardite described by Lacroix.[1] Of angelardite Lacroix[2] says, "Les phosphates résultant de la transformation de la triphylite et de la triplite des Huréaux en Saint Sylvestre,...." Strengite has been reported from the Stewart, Tourmaline King, Tourmaline Queen, and Sickler mines at Pala, and from the Mack Tourmaline mine at Rincon.

[1] Lacroix, A.
    Mineralogie de France et des Colonies. Tome IV, pp. 522-524 (1910)

[2] Idem   p. 522

## Hureaulite

Schaller identified from Pala this uncommon acid hydrous phosphate as an alteration product of palaite. In turn hureaulite alters to salmons-ite. It seems probable that hureaulite also occurs as a direct alteration product of lithiophilite. Hureaulite is listed as monoclinic, the Pala material is mostly massive or compactly fibrous. Hureaulite has been re-ported from the Stewart mine, Tourmaline King mine, Tourmaline Queen mine, and Hiriart Hill, all at Pala, and from the Mack Tourmaline mine at Rincon.

## Purpurite

Scanty amounts of this rare secondary phosphate, first described by Schaller and Graton,[1] have been found on Hiriart Hill, associated with triphylite. It is probably orthorhombic, has a deep purplish color, and is near the manganese end of the isomorphous series $2(Fe, Mn) PO_4 \cdot H_2O$.

[1]Schaller, W. T., and Graton, L. C.
    Purpurite, a new mineral. A. J. S. (4) 20:146-161 (1905)

### Manganite, Psilomelane

Hydrous oxides of manganese are found associated with other manganese minerals in the lithia pegmatites at Pala. Manganite, and psilomelane have been identified.

## Zeolites

Heulaudite, stilbite, and laumontite have been reported by Rogers[1] from the Victor mine, Rincon. Probably careful search would reveal zeolites elsewhere in the pegmatites of southern California.

[1] Rogers, A. F.
Minerals from the pegmatite veins of Rincon, San Diego County, Calif. School of Mines Quarterly 31: 208:218 (1910)

## MISCELLANEOUS MINERALS

Included in the list of minerals on Plate III are a number which fall into one of three categories:

1. Interesting or unusual minerals which have been found in small amounts in only one or two localities. In this group is fluorite, occurring at the Mt. Lily mine on Aguanga Mt., and spinel, reported by Rogers to occur at the Mack mine, Rincon.

2. Mineral occurrences unreliably reported. Pyrite, molybdenite, and siderite have been reported to occur at Pala. They may actually occur there, but the report needs confirmation.

3. Minerals customarily found everywhere as hydrothermal or supergene products associated with rock assemblages similar to those exposed in the region herein described. Among these are epidote and the closely related zoisite. Hematite and manganese oxides are frequently found coating and filling tiny fractures in other minerals and rocks.

PLATE XXI



NORTHERN END, HIMALYA LODE, MESA GRANDE

The northern end of the Himalya lode terminates
in an erosional surface. The ground here and
for several hundred feet to the southeast along
the strike, has been excavated by open pit mining
operations to a depth of about twenty-five feet.
Beyond this depth the amount of overburden neces-
sitated underground mining methods.

PLATE XXII



A. TUNNEL PORTAL, HIMALAYA LODE,
                    MESA GRANDE

Portal of one of the numerous tun-
nels that have been driven in a
southwesterly direction to tap the
Himalaya lode at depth.  This tun-
nel is on the ground of the San
Diego Mine.
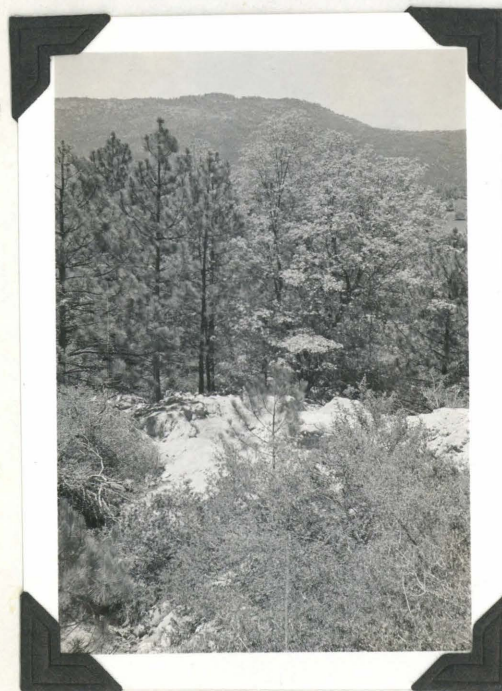


B. OPEN PIT, HIMALAYA LODE, MESA
                    GRANDE

Part of the open workings along
the Himalaya lode.  Open pits, now
evergrown with trees and brush, ex-
tend continuously for over seven
hundred feet southeasterly from the
northern end of the lode.

PLATE XXIII
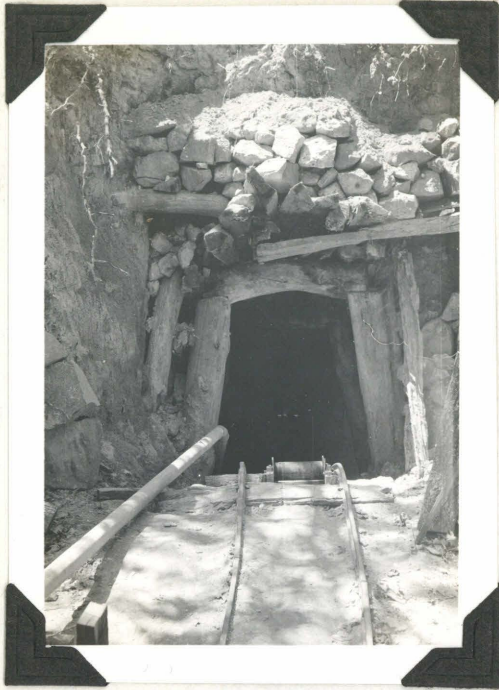


A. SHAFT PORTAL, HIMALAYA LODE,
                    MESA GRANDE

Portal of the Over and Montgomery in-
cline shaft on the San Diego Mine,
near the middle of the Himalaya lode.
This shaft was being cleaned out and
reconditioned during the spring of
1935.



B. The hoist and surface plant of the
above shaft.

Classification of the Pegmatites of Pala and Mesa Grande

A classification adapted from Landes(80) of the pegmatites of
Pala and Mesa Grande is used by the writer. There are in these districts
many pegmatites which do not contain minerals deposited by hydrothermal
replacement. With these pegmatites this report is little concerned. In
the main they consist of microcline perthite and quartz. These two
minerals are found intergrown in graphic granite and in nearly pure
masses. Such pegmatites are called simple alaskite pegmatites.

The pegmatites which indicate that they have undergone some hydro-
thermal replacement are called complex pegmatites. They are subdivided
by the writer into (a) barren pegmatites, (b) gem-bearing without lepido-
lite, and (c) lepidolite-bearing. The barren complex pegmatites which
show considerable albitization and tourmalinization, but contain no pay
streak. Gem bearing, non-lepidolite pegmatites are those which have yielded
gemworthy specimens, but do not show lepidolite. Spectral analysis reveals
that lithium has been introduced into these dikes but not in sufficient
amounts to form lepidolite. The majority of the pegmatites discussed in
this report contain more or less lithium at some point in their exposed
length.

PLATE  XXIV



A. NORTH SIDE OF TOURMALINE
        QUEEN MOUNTAIN, PALA

The Tourmaline King mine,
which is on the north side of
this mountain near its summit,
is indicated by the arrow.



B.  PALA CHIEF MOUNTAIN, PALA

View looking eastward from Salmons camp
site.
a--Pala Chief Mine
b--Margarita mine

PLATE XXV



A. BANDED GARNET APLITE,
    STEWART DIKE, PALA

Taken near Sicker's tunnel,
which is the first drift tun-
nel encountered in going along
the dike from north to south.
The banding, here rather faint,
is parallel to the footwall,
which is just out of sight at
the bottom of the photo.
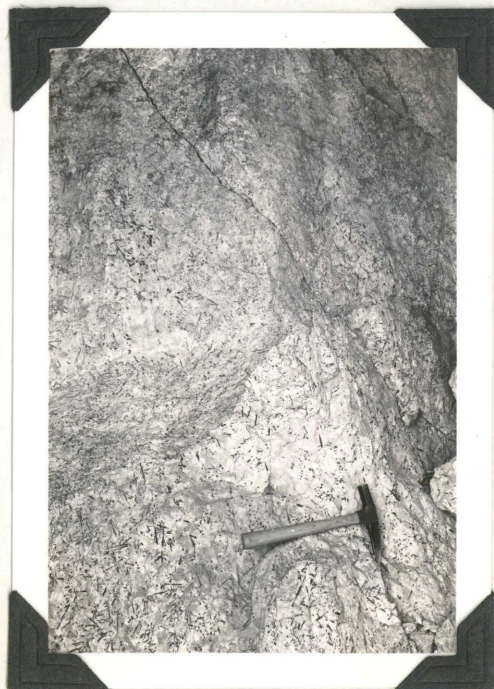


B. BLACK TOURMALINE IN AL-
    BITIZED PEGMATITE, STEWART
    DIKE, PALA

The tourmaline crystals show a
rude orientation normal to the
walls (which are parallel to the
top and bottom of the photo)

PLATE XXVI
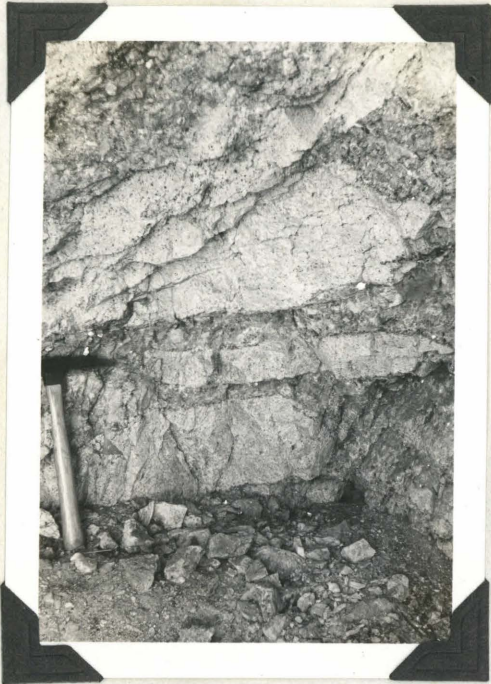


A.  DETAIL OF STEWART DIKE, PALA

At this point is exposed the first lithia
mineral assemblage found in going from
north to south along the dike.  The fine
grained rock (f) has been fractured and
replaced by veinlets (r) of complex miner-
als (grey microcline, muscovite, quartz,
lepidolite, albite, black tourmaline,
pink tourmaline.)



B.  MICROCLINE REPLACED BY ALBITE VEINLETS

Large fragment of complex pegmatite, Stew-
art mine, Pala.  Microcline (m) cut by
veinlets (a) of albite, tourmaline, and
lepidolite.  Scale, about one inch to the
foot.

GENESIS OF THE LITHIA PEGMATITES OF PALA AND MESA GRANDE

Origin of the Openings Now Occupied by Lithia Pegmatites

The openings now occupied by lithia pegmatites have had a tectonic origin. This is attested to in part by their parallel arrangement. They all strike northwesterly and dip westerly. To be sure, the westerly dip is variable, but for the majority of the cases studied, it is between $10^{o}$ and $45^{o}$. Further, the openings have the same strike as that of most of the faults of the Peninsular Range, i.e. northwest. These structural relations do not appear explicable except on tectonic grounds.

The fracturing which produced the openings later filled with pegmatite magma, seems to have yielded clean cut breaks. In many of the dikes examined the hanging wall shows step-like offsets, which are clearly pre-mineral. There are many occurrences of horses of altered gabbro within the pegmatite. These give the impression that they have retained, roughly, an orientation in which their longer dimensions, being once parallel to the walls, remained so after pegmatitic intrusion. This might, possibly, indicate to some that they are supported fragments remaining after the rock which once attached them to the main body of gabbro had been replaced by pegmatite. To the writer this does not seem to explain the field relations as well as the above explanation.

## Source of the Pegmatitic Material

There is ample evidence that the pegmatitic material which now forms the lithia pegmatites of Pala and Mesa Grande had its source in a magmatic reservoir. The pegmatites are viewed by the writer as an integral part of the igneous phenomena which began with the differentiation of a magma that yielded the San Marcos gabbro, the Angel and Luis quartz diorite, and the Carver and Pilot Butte granodiorite. The end products of this differentiation was a rest-magma rich in volatile constituents and in rarer elements. After the solidification of the eralier plutonic phases of igneous activity, these more aqueous and mobile constituents moved out of the magma chamber. One of the most convincing arguments of the source of the material in the pegmatites being discussed is furnished by a consideration of the wall rocks in which they lie. The material could not have come from gabbro, which contains most of the lithia pegmatites. Therefore, it came either from above or below. It could not have come from a source higher up. All geologists today are in agreement that such mineral concentrations as the pegmatites are not formed by downward-moving waters. There remains only one source, a body of material at depth, which for some reason moved upward sometime after the consolidation of the plutonic series of rocks discussed earlier in this report.

## Nature of the Depositing Solutions

There are not many data available on the chemical nature of the depositing solutions. It is the writer's opinion that, judged by the large amounts of quartz carried during the earlier or magmatic phase, the solutions were alkaline. During this magmatic phase the solutions, which were mainly water and dissolved rock-forming minerals, had a low content of such fugitives as fluorine and boron. Iron was introduced at an early stage, but later was dissolved and carried away. This apparently indicates that the solutions became more acid in the later stages. Manganese was not commonly introduced during the earlier phases, but became a prominent constituent in the later phases. All of the rarer elements, lithium, beryllium, caesium, rubidium, phosphorus, and bismuth were brought in during the later or hydrothermal phases of deposition.

It might be pointed out that the solutions are believed to have contained more or less water from the start. This being the case, the question of the use and meaning of hydrothermal might be raised. As will be discussed under the sequence of the minerals, the initial injection of aqueous magma is believed to be pyrogenic. It yielded a solidified mass which was not much smaller than the introduced body of liquid. All later changes, which were mostly by replacement, are considered to be hydrothermal. In this process the volume of dissolved solid substance is much smaller than the total volume of liquid. The ratio of liquid to solid becomes increasingly larger as the later phases of hydrothermal deposition are reached.

## Sequence of Mineral Deposition

Mineral deposition is divided into two phases: (1) an earlier, magmatic period, and (2) a later, hydrothermal period. The hydrothermal period is divided into several stages.

### Period of Magmatic Deposition

1. The injection into curved openings of a liquid mass. The openings flattened in dip upward and acted as a trap for the solutions. As a result differentiation took place in the stagnant liquid. Where the dip was sufficiently low this resulted in a separation of a coarse grained graphic granite upper part and a fine grained banded garnet aplite lower part. The mother liquor was concentrated in the middle of the dikes and crystallized to form clumps of quartz and black tourmaline. Muscovite was formed as small white flakes, mainly deposited in the upper part. Where biotite has been formed, it appears to be a reaction product with the gabbroic wall rock.

At some time during the hydrothermal phases, it is not possible to say when, the graphic granite underwent an increase in crystal size. This process, known as sammelcrystallization, probably became increasingly active at about the time lithium was first introduced.

## Period of Hydrothermal Deposition

1. Albitization and tourmalinization are among the earliest hydro-thermal phases. Although mostly commonly developed in the central part of the dikes, albite and black tourmaline frequently replace both the line rock and much of the graphic granite.

2. Fracturing of the dikes. Complex minerals deposited along these fractures replacing the earlier formed rock. The lithia minerals are lepidolite and lithia tourmaline, associated with them are grey micro-cline, muscovite(green), quartz, albite, clear garnet and black tourmaline. The albite produced during this and the subsequent stages is the platy variety, cleavelandite. Small bodies of massive quartz were deposited during this phase.

3. Formation of pockets. Dissolution for the first time seems to have predominated over deposition. The earlier replacements are not con-fined to any part of the dike, although they are more pronounced in the middle part. In the phase in which pockets were developed replacement activity is largely confined to the middle part of the dikes. Only rarely is it found in the upper and lower part. The pocket minerals, gem beryl, gem tourmaline, euhedral quartz and feldspar, coarse cleavelandite, musco-vite(green), and spessartite were deposited.

4. Large masses of quartz, lepidolite, and amblygonite were de-posited. Quartz was deposited during nearly every stage.

5. Manganese phosphate and bismuth minerals replace pre-existing minerals.

6. Supergene alteration of many of the above minerals, particularly the manganese phosphate, bismuth, and some of the pocket minerals. These pocket minerals were probably already altered by hypogene solutions.

PLATE XXVIII

# SEQUENCE OF THE MANGANESE PHOSPHATE MINERALS

PRIMARY

SECONDARY

**TRIPLITE**
Massive
Brown, dark brown
Monoclinic   $(RF)RPO_4$
R = Mn,Fe,Ca,Mg

**AMBLYGONITE**
Cleavable masses; white, bluish
Triclinic   $LiAl(F,OH)PO_4$

**LITHIOPHILITE**
Cleavable, clove brown
Orthorhombic   $LiMnPO_4$ + Fe

**SICKLERITE**
Cleavable masses
Dark brown, bright yellow
Orthorhombic(?)
$Fe_2O_3 \cdot 6MnO \cdot 4P_2O_5 \cdot 3(Li,H)_2O$

**PURPURITE**
Deep red coating
on lithiophilite
Orthorhombic
$2(Fe,Mn)PO_4 \cdot H_2O$

**PALAITE**
Crystalline, flesh pink
Monoclinic   $5MnO2P_2O_5 \cdot 4H_2O$

**HUREAULITE**
Crystalline, massive, fibrous
Yellow, red, grayish
Monoclinic   $H_2Mn_5(PO_4)_4 \cdot 4H_2O$

**SALMONSITE**
Cleavable masses
Blue
Orthorhombic
$Fe_2O_3 \cdot 9MnO \cdot 4P_2O_5 \cdot 14H_2O$

**TRIPHILITE**
Crystalline, cleavable
Bluish gray
Orthorhombic
$LiFePO_4$ + Mn

**STRENGITE**
Coating, blue
Orthorhombic
$FePO_4 \cdot 2H_2O$

**STEWARTITE**
Fibers, minute crystals
Triclinic
$3MnO \cdot P_2O_5 \cdot 4H_2O$

Figure 4.— Vertical airplane photo of Gem Mountain, Mesa Grande, showing location of the Himalaya lode. The lode is marked in green.

Figure 5.— Vertical airplane photo showing location of the Esmeralda mine, Mesa Grande. The pegmatite outcrop is marked in green.
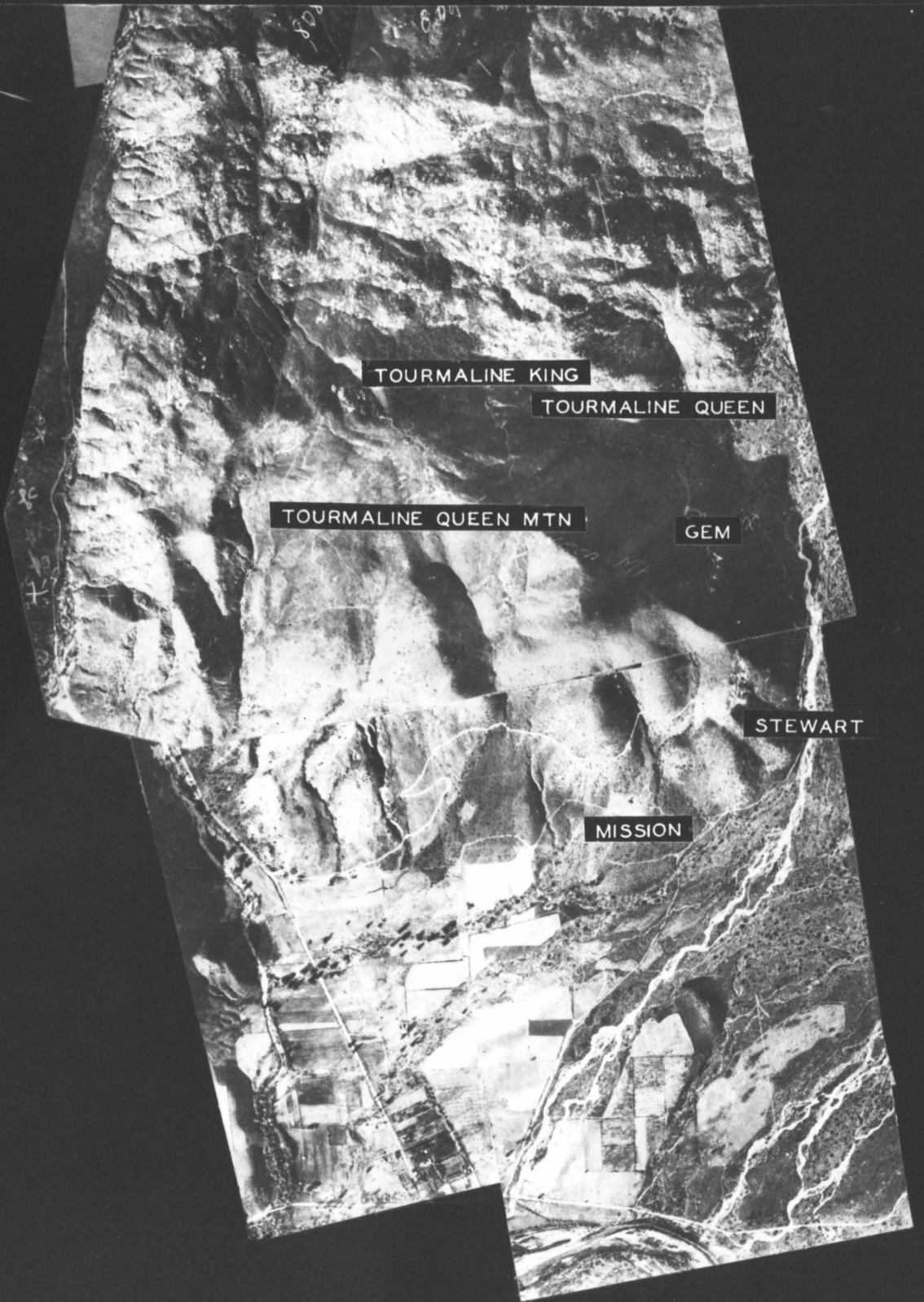
TOURMALINE KING

TOURMALINE QUEEN

TOURMALINE QUEEN MTN

GEM

STEWART

MISSION

Figure 6.--Vertical airplane photo of Tourmaline Queen Mountain, showing location of principal mines, Pala

Figure 7.--Vertical airplane photo of Pala Chief Mountain, and
Hiriart Hill, Pala, showing location of principal
mines

Pala Chief

PALA CHIEF MOUNTAIN

HIRIART HILL

Sickler tunnel

## GEOLOGIC MAP OF THE MESA GRANDE DISTRICT
## SAN DIEGO COUNTY, CALIFORNIA
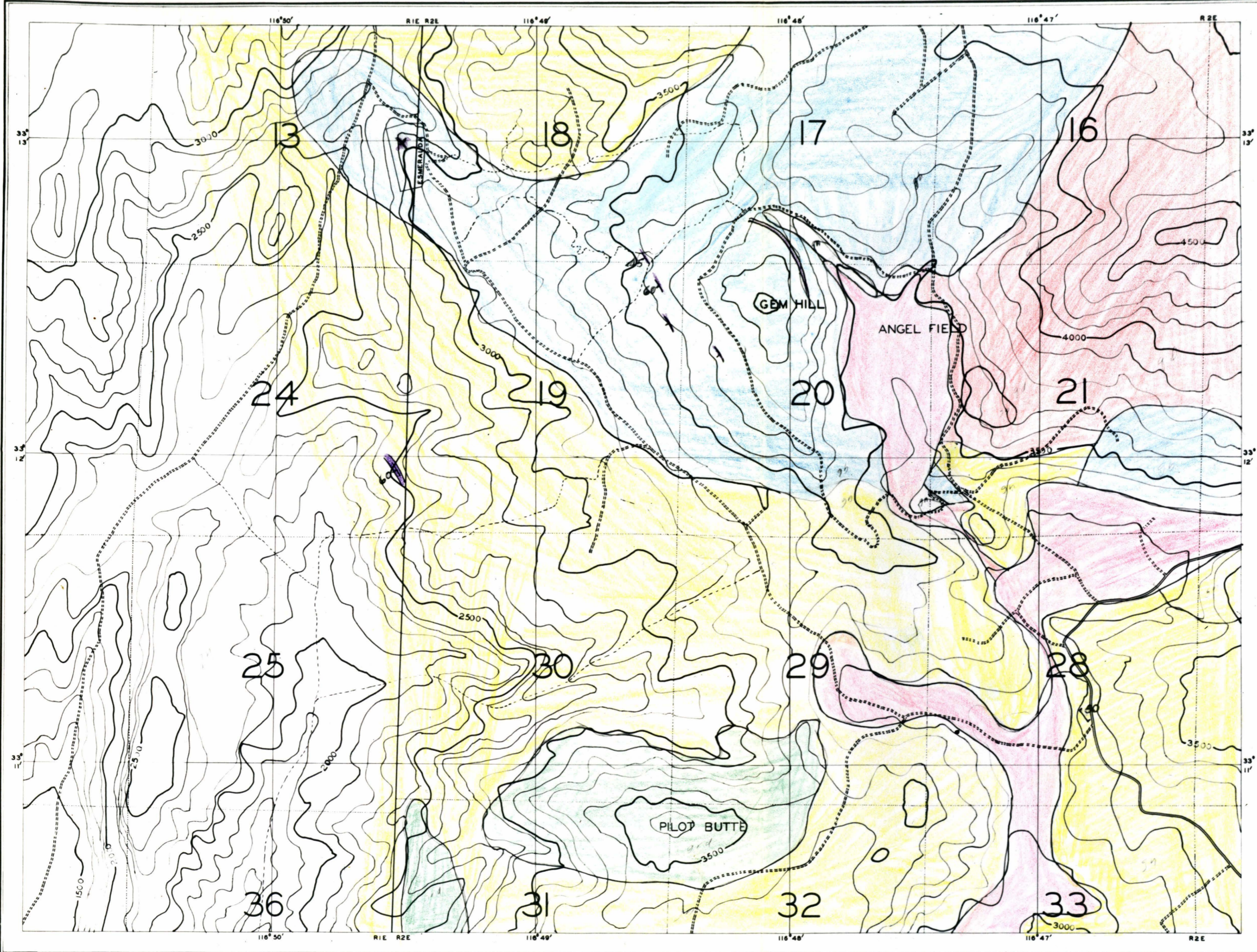
EXPLANATION

QAL
ALLUVIUM

PG
PEGMATITE DIKES

PILOT BUTTE
GRD
GRANODORITE

ANGEL
QD
QUARTZ DIORITE

SAN MARCOS
GB
GABBRO

INDIAN
GN
GNEISS

STRIKE AND DIP

STRIKE AND DIP
OF
SCHISTOSITY OR FOLIATION

GEM HILL
ANGEL FIELD
PILOT BUTTE
ESMERALDA

BASE FROM U.S. GEOLOGICAL SURVEY
RAMONA QUADRANGLE
GEOLOGY MAPPED ON AIRPLANE
PHOTOGRAPHS.   SCALE 1/12000 (±10%)

GEOLOGY BY MAURICE DONNELLY
SURVEYED IN 1934-1935

0    1 MILE
CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

TRUE NORTH
MAGNETIC NORTH

13  18  17  16
24  19  20  21
25  30  29  28
36  31  32  33

R1E R2E
116°50'  116°49'  116°48'  116°47'
33°13'  33°12'  33°11'

Gabbro

**EXPLANATION**

| PCA | PALA CONGLOMERATE AND ALLUVIUM |
| PG | PEGMATITE DIKES |
| CARVER GRD | GRANODIORITE |
| LUIS QD | QUARTZ DIORITE |
| SAN MARCOS GB | GABBRO |
| PQ | PALA QUARTZITE |

STRIKE AND DIP

STRIKE AND DIP OF SCHISTOSITY OR FOLIATION

CARVER HILL

TOURMALINE QUEEN MTN.

PALA CHIEF MTN.

HIRIART HILL

STEWART

16  15  14  13  18
21  22  23  24  19
28  27  26  25  30

GEOLOGIC MAP OF THE PALA DISTRICT
SAN DIEGO COUNTY CALIFORNIA

TRUE NORTH
MAGNETIC NORTH

0                    1 MILE

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

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APPENDIX A

## Mineralogical Spectroscopy
### General Principles

The chief interest of the mineralogist in spectroscopy is in
(a) determination of minerals, (b) a rapid detection of elements present
in a mineral or in a chemical product derived from a mineral, (c) the de-
tection of small amounts of elements difficult or laborious to detect by
ordinary chemical methods, and (d) a quantitative measure of elements pres-
ent in a mineral or derived product.

There are two kinds of radiation with which mineralogical spectros-
copy is concerned, namely, radiations absorbed by a mineral and those om-
itted by a mineral. If a beam of white light is passed through a mineral,
bands of certain wave lengths may be absorbed more than others. The kind
and amount of light that is absorbed depends in anisotropic minerals on the
direction which the light takes in passing through. The light which is
transmitted to the observer will be a composite of all the visible light
which has not been absorbed. This phenomenon of differential absorption
of white light is discussed in the elementary textbooks of optical mineral-
ogy as absorption and pleochroism. The kind of light absorbed in passing
through a mineral is not necessarily the same as that absorbed when light
is reflected from its surface, which is to say that the color of a mineral
in the hand specimen is not necessarily the same, even in isotropic miner-
als, as the color in thin section. This subject need not be pursued fur-
ther; suffice to say that a study of the gross effects of absorption is
constantly employed in thin section observations. More refined methods

for the study of absorption spectrum with the microscope call for a
microscope eyepiece fitted with a direct-vision spectrometer. The
spectrometers in use for this purpose are of two kinds, one with rela-
tively small dispersion which yields the more intense effects, but does
not permit of wave length measurement, the other with relatively large
dispersion, yielding fainter bands of light but providing for accurate
measurement of their wave lengths.

The subject of absorption spectrum applied to mineralogy has been
investigated by several workers. Wherry[1] gives an up to date account
which is generally accessible. Speaking generally, it may be said that
absorption in narrow bands or lines is shown by certain of the rare-earth
metals and by uranium, absorption in broader bands by chromium, cobalt,
copper, iron, manganese, vanadium, and occasionally others.

A possibility in mineralogical spectroscopy which has probably
already been suggested or applied by other investigators, although the
present writer has not found reference to it in print, lies in the analy-
sis of absorption spectra of solutions prepared from minerals. In this
type of work, and in all studies of absorption spectra for that matter, the
spectrophotometer as now designed for biological and biochemical investiga-
tions should be found useful. The spectrophotometer not only breaks light
into its component parts, but also measures the quantity of light of any
particular wave length. If a non-opaque body be placed in the light path
of a spectrophotometer the kind and amount of light absorbed may be measured.

Atoms and molecules under proper conditions send out radiations

which are known as their emission spectra. The study of emission spectra has become so important and the literature on it so voluminous that it constitutes almost an independent science. All that physicists know of the composition of celestial bodies, with the exception of the testimony of meteorites, is gained from spectrum analysis of light emanating from celestial bodies. T. G. Kennard[1] has written a rather popular, yet scientific summary of the chemical aspects of spectral analysis and Fitch[2] has given us a brief, concise statement of spectrum analysis in mineralogy. The latter paper contains a bibliography on mineralogical spectroscopy.

Spectrum analysis in its mineralogical aspects is most conveniently discussed as to methods of producing the emission, in other words the method of excitation, and the instruments for observing the radiations produced. The commonest means of excitation, heating in a high-temperature flame, is familiar to all who have manipulated the blowpipe. The ordinary gas flame does not give a sufficiently high heat for most observations. Any of the flames fed with pure oxygen, such as the oxy-coal gas flame, the oxy-hydrogen flame, and the oxy-acetylene flame are suitable. The electric arc is the best and probably the most convenient method of excitation. Excitation by the condensed spark is not generally employed in mineralogical spectroscopy, except for the detection of some elements whose arc spectrum is not well marked. The characteristics of the radiation emitted by an atom by the various methods of excitation is in general not identical, some lines being

[1]Kennard, T.G.
Chemical spectral analysis, the Hexagon of Alpha Chi Sigma, XXII, 115-130, 1931.

[2]Fitch, A.A.
Spectrum analysis in mineralogy, Adma Hilger, Ltd., London, England

visible, for example in the spark spectrum which are not visible or are weak in the arc spectrum.

Two types of instruments are employed for observing emission spectra. The first is a direct-vision spectrometer, or spectroscope. A monochromator may also be used for the same purpose. The other type of instrument is a spectrograph, on which is photographed the spectrum of the subject. A prism, rather than a grating, is used to disperse the light because only one spectrum is produced by a prism, hence the intensity of the light is greater and no overlapping takes place. Quartz, which is transparent to ultra-violet rays, is utilized almost exclusively in the prisms of spectrographs because many of the elements have their major lines in the ultra-violet region. Most of the spectrographs in use in chemical and mineralogical laboratories cover the range between $2000^\circ$ and $10,000^\circ$. The ordinary photographic plates are sensitive to ultra-violet light down to about $2100^\circ$. The band between $8000^\circ$ and $10,000^\circ$ is not very broad as quartz has a small dispersion for light in this region. Visual observations are limited to the region between $4000^\circ$ and $8000^\circ$. The exact limits depend on the individual. The medium quartz spectrograph as manufactured by Adam Hilger, Ltd., covers the range $2000^\circ$ to $10,000^\circ$ on a 4x10 inch plate. This suffices for most work. Where the dominant constituent is one of the following metals; chromium, cobalt, iron, molybdenum, nickel, titanium, tungsten, uranium, or zirconium, an instrument having a wider dispersion is needed. This larger instrument is preferable, but not essential for the analysis of minerals whose major constituent is one of the following; manganese, thorium, or vanadium. In the larger instrument the range $2000^\circ$ to $10,000^\circ$ is photographed on four 4x10 inch plates. An

instrument manufactured by Gaertner and in use in the chemical laboratory at Pomona College photographs the range $2000^{\circ}$ to $8000^{\circ}$ in two parts, the visible spectrum on a 4x10 inch plate and the ultra-violet spectrum on a plate of the same size.

The writer has made qualitative use of arc spectral analysis on minerals from the pegmatites of San Diego County. This method has yielded many data discussed in the main body of this paper. It is the writer's opinion that spectroscopic methods, both qualitative and quantitative, are especially well adapted to the mineralogical investigations of the pegmatites.

## Bibliography of Mineralogical Spectroscopy

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# APPENDIX B

## Staining Minerals

The principles underlying the staining of minerals are three:

(a) The mineral is a natural absorbent of certain dyes or can be made so by etching with certain acids. In the case of silicates the action of the acid is usually to precipitate a layer of colloidal or gelatinous silica which has high absorptive powers for some dyes.

(b) The mineral has in it an element or elements which form colored compounds. In dealing with silicates the element forming the colored compound must usually be rendered soluble by etching in a strong acid, such as hydrofluoric or hydrofluosilicic acid.

(c) The mineral exhibits the phenomenon of surface polarity, i.e. its surface has an electrical charge which renders it positive or negative. Certain aniline dyes are also polar. A negative dye will be retained by a positively polar mineral, and vice versa. This fact is utilized in biology, but so far as the writer knows, has never been investigated in mineralogy.

Gabriel and Cox[1] evolved a method for separating certain rock minerals by rendering potassium in some of these minerals soluble and precipitating on the surface a yellow insoluble compound of potassium, potassium cobaltinitrite. The reagent is sodium cobaltinitrite and there is some sodium in the precipitated potassium cobaltinitrite.

The writer has been interested in methods for staining and separa-

[1] Gabriel, A. and Cox, E. P. A staining method for the quantitative determination of certain rock minerals. Am. Mineralogist 14: 290-292 (1929)

ting the feldspar. The method of Gabriel and Cox was tested on numer-
ous feldspar grains. The results may be stated, tentatively, as follows:

1. The method may be used successfully to separate potash
from soda-lime feldspars.

2. The petrological problem of estimating the amount of potash
in the more acid plagioclase feldspar and the amount of soda in potash
feldspar may be attacked with hope of some success by staining methods.

Other conclusions, tentative in part, from the staining investi-
gations carried on by the writer are

1. The separation by staining methods of the plagioclase feld-
spars into compositional varieties comparable with those disseminated
optically, does not appear feasible.

2. Etching by liquid HF or liquid $H_2SiF_6$ has proved to be more
uniform and more convenient than etching with gaseous HF.

3. The separation of potash and plagioclase feldspars by staining
the etched surfaces with certain aniline dyes appears feasible.

4. Etching frequently brings out twinning and other structures
in feldspar not readily visible megascopically.

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| STAINS | Etching & Staining | Orthoclase | Microcline (perthite) | Perthite | Microperthite |
|---|---|---|---|---|---|
| Sodium Cobaltinitrite | Etch: HF, 12 min. Stain: 10 min. Wash: water | Dist. yellow | Dist. yellow | Dist. yellow | Dist. yellow |
| " | Etch: HF, 12 min. Stain: 10 min. Wash: alcohol | Dist. yellow | Dist. yellow | Dist. yellow | Dist. yellow |
| " | No etch Stain: 10 min. Wash: water | No stain | No stain | No stain | No stain |
| Gentian violet | Etch: HF, 12 min. Stain: 10 min. Wash: water | Mod. violet | Dist. violet | Dist. violet | Mod. violet |
| " " | No etch Stain: 10 min. Wash: water | Mod. violet | Mod. violet | Dist. violet | Mod. violet |
| Malachite green | Etch: HF, 12 min. Stain: 10 min. Wash: water | Dist. green | Dist. green | Dist. green | Dist. green |
| " " | No etch Stain: 10 min. Wash: water | Mod.-weak green | Dist. green | | Dist.-Mod. green |
| Methylene blue | Etch: HF, 12 min. Stain: 10 min. Wash: water | Dist. blue | Dist. blue | Dist. blue | Mod. blue |
| Hematoxylene | Etch: HF, 12 min. Stain: 10 min. Wash: water | Weak tint | Weak tint | Weak tint | Weak tint |
| " | No etch Stain: 10 min. Wash: water | No stain | No stain | Weak tint | |
| Congo red | Etch: HF, 12 min. Stain: 10 min. Wash: water | No stain | Trace of pink | No stain | Brownish tint |
| Safraneen | Etch: HF, 12 min. Stain: 10 min. Wash: water | Faint pink | Light pink | Light red | Light pink (edges pink) |
| Eosin dye | Etch: HF, 12 min. Stain: 10 min. Wash: water | Pink | Light red | Light red | Pink |
| " " | Etch: HF gas 4min. Wash: dil.HCl. Stain: 10 min. | Med. pink | | | |
| " " | Etch: HF gas 4min. No wash Stain: 10 min. | No stain | | | |

Dist. = Distinctly          Mod. = Moderately

| Anorthoclase | Albite | Albiclase | Oligoclase | Labradorite | Anorthite |
|---|---|---|---|---|---|
| Dist. yellow | Slightly yellow | Dist. yellow | Mod. yellow | Mod. yellow | No stain |
| Dist. yellow | Slightly yellow | Dist. yellow | Mod. yellow | Weak yellow | No stain |
| No stain | No stain | No stain | No stain | No stain | No stain |
| Dist. violet | Mod. violet | Weak violet | Mod. violet | Mod. violet | Dist. violet |
| Mod. violet | Dist. violet | Weak violet | Weak violet | Mod. violet | Weak violet |
| Dist. green | Dist. green | Dist. green | Mod. green | Dist.-strong green | Dist. green |
| Weak green | Mod. green | Mod. green | Dist. green | Mod.-Dist. green | Mod. green |
| Strong blue | Dist. blue | Mod. blue | Dist. blue | Dist. blue | Dist. blue |
| Weak tint | Weak-Mod. brown | Weak-Mod. brown | Mod. brown | Dist. brown | Dist. brown |
| Brownish tint | Faint brownish tint | Brownish tint | Brownish tint | Feeble pink | Brownish tint |
| Light pink | Med. pink | Reddish pink | Bright pink | Light pink | Light pink |
| Pink | Pink | Med. red | Light red | Pink | Pink |

# APPENDIX C

## Sage Pegmatite

The Sage pegmatite is in Sec. 22, T 6 S, R 1 E, San Bernardino Meridian, Riverside County, Calif. Red Mountain is about a mile and a half to the southeast. The most convenient route of access is as follows: From Hemet proceed almost due south on the road to Sage. About eight miles from Hemet turn east and follow a narrow winding road for a distance of about four miles. The Sage pegmatite outcrops as a small, rounded knoll visible from the road. Cars may be driven directly to it.

The Sage pegmatite is a tabular body that ranges in thickness from ten to fifty feet. Like most complex pegmatites of southern California the dip is gentle, in this case about $15^{\circ}$ to the west. The strike is northerly. The hanging wall has been almost entirely removed by erosion and much of the upper part of the dike itself has been cut away. The foot-wall is quartz diorite (megascopic determination). The country rock near the footwall and inclusions of the country rock within the dike are highly altered and contain a large proportion of biotite.

The Sage pegmatite is made up largely of feldspar and quartz, much of it in graphic texture, and black tourmaline. Garnet albite aplite has not been found. A small amount of lithia minerals, coarse lepidolite, green and pink tourmaline have been deposited. These are associated with albite (cleavelandite), a very light colored brown garnet, microcline, and euhedral quartz. The lithia and associated minerals seem to be confined to pockets or irregular masses in the middle and lower part of the dike.

In the upper part of the dike are found large euhedrons of micro-cline, which contain inclusions of graphic quartz, black tourmaline, and

graphic granite. Such euhedrons occur in the solid rock and are commonly surrounded by massive quartz. They range in size from a few inches to several feet in longest dimension. Such structures appear to the writer to be genetically significant as offering support to the hypothesis that sammel-crystallization, or crystal growth in the solid from material on hand, has taken place in complex pegmatites. This crystal growth has probably been dependent upon, or accelerated by, post-consolidation introduction of solutions.

In the lower part of the dike an unusual and interesting structure is found. Feldspar is found with many small, elongate cavities, partly filled with green tourmaline. Green tourmaline has also replaced part of the feldspar host. This structure seems to have been once graphic granite, from which the quartz has been leached and into which green tourmaline has been deposited partly by replacement and partly by cavity filling.

Tourmaline occurs in the Sage pegmatite in a few places as large crystals, several inches across and up to a foot long, which have a black central core and a red or green exterior. They indicate, in the writer's opinion, the alteration by replacement of initially black tourmaline to lithia tourmaline.

APPENDIX A

Mineralogical Spectroscopy

General Principles

The chief interest of the mineralogist in spectroscopy is in
(a) determination of minerals, (b) a rapid detection of elements present
in a mineral or in a chemical product derived from a mineral, (c) the de-
tection of small amounts of elements difficult or laborious to detect by
ordinary chemical methods, and (d) a quantitative measure of elements pres-
ent in a mineral or derived product.

There are two kinds of radiation with which mineralogical spectros-
copy is concerned, namely, radiations absorbed by a mineral and those om-
itted by a mineral. If a beam of white light is passed through a mineral,
bands of certain wave lengths may be absorbed more than others. The kind
and amount of light that is absorbed depends in anisotropic minerals on the
direction which the light takes in passing through. The light which is
transmitted to the observer will be a composite of all the visible light
which has not been absorbed. This phenomenon of differential absorption
of white light is discussed in the elementary textbooks of optical mineral-
ogy as absorption and pleochroism. The kind of light absorbed in passing
through a mineral is not necessarily the same as that absorbed when light
is reflected from its surface, which is to say that the color of a mineral
in the hand specimen is not necessarily the same, even in isotropic miner-
als, as the color in thin section. This subject need not be pursued fur-
ther; suffice to say that a study of the gross effects of absorption is
constantly employed in thin section observations. More refined methods

for the study of absorption spectrum with the microscope call for a microscope eyepiece fitted with a direct-vision spectrometer. The spectrometers in use for this purpose are of two kinds, one with relatively small dispersion which yields the more intense effects, but does not permit of wave length measurement, the other with relatively large dispersion, yielding fainter bands of light but providing for accurate measurement of their wave lengths.

The subject of absorption spectrum applied to mineralogy has been investigated by several workers. Wherry[1] gives an up to date account which is generally accessible. Speaking generally, it may be said that absorption in narrow bands or lines is shown by certain of the rare-earth metals and by uranium, absorption in broader bands by chromium, cobalt, copper, iron, manganese, vanadium, and occasionally others.

A possibility in mineralogical spectroscopy which has probably already been suggested or applied by other investigators, although the present writer has not found reference to it in print, lies in the analysis of absorption spectra of solutions prepared from minerals. In this type of work, and in all studies of absorption spectra for that matter, the spectrophotometer as now designed for biological and biochemical investigations should be found useful. The spectrophotometer not only breaks light into its component parts, but also measures the quantity of light of any particular wave length. If a non-opaque body be placed in the light path of a spectrophotometer the kind and amount of light absorbed may be measured.

Atoms and molecules under proper conditions send out radiations

which are known as their emission spectra. The study of emission spectra
has become so important and the literature on it so voluminous that it
constitutes almost an independent science. All that physicists know of the
composition of celestial bodies, with the exception of the testimony of
meteorites, is gained from spectrum analysis of light emanating from celes-
tial bodies. T. G. Kennard[1] has written a rather popular, yet scientific
summary of the chemical aspects of spectral analysis and Fitch[2] has given
us a brief, concise statement of spectrum analysis in mineralogy. The latter
paper contains a bibliography on mineralogical spectroscopy.

Spectrum analysis in its mineralogical aspects is most conveniently
discussed as to methods of producing the emission, in other words the method
of excitation, and the instruments for observing the radiations produced.
The commonest means of excitation, heating in a high-temperature flame, is
familiar to all who have manipulated the blowpipe. The ordinary gas flame
does not give a sufficiently high heat for most observations. Any of the
flames fed with pure oxygen, such as the oxy-coal gas flame, the oxy-hydrogen
flame, and the oxy-acetylene flame are suitable. The electric arc is the
best and probably the most convenient method of excitation. Excitation by
the condensed spark is not generally employed in mineralogical spectroscopy,
except for the detection of some elements whose arc spectrum is not well
marked. The characteristics of the radiation emitted by an atom by the var-
ious methods of excitation is in general not identical, some lines being

[1]Kennard, T.G.
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[2]Fitch, A.A.
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visible, for example in the spark spectrum which are not visible or are weak in the arc spectrum.

Two types of instruments are employed for observing emission spectra. The first is a direct-vision spectrometer, or spectroscope. A monochromator may also be used for the same purpose. The other type of instrument is a spectrograph, on which is photographed the spectrum of the subject. A prism, rather than a grating, is used to disperse the light because only one spectrum is produced by a prism, hence the intensity of the light is greater and no overlapping takes place. Quartz, which is transparent to ultra-violet rays, is utilized almost exclusively in the prisms of spectrographs because many of the elements have their major lines in the ultra-violet region. Most of the spectrographs in use in chemical and mineralogical laboratories cover the range between 2000° and 10,000°. The ordinary photographic plates are sensitive to ultra-violet light down to about 2100°. The band between 8000° and 10,000° is not very broad as quartz has a small dispersion for light in this region. Visual observations are limited to the region between 4000° and 8000°. The exact limits depend on the individual. The medium quartz spectrograph as manufactured by Adam Hilger, Ltd., covers the range 2000° to 10,000° on a 4x10 inch plate. This suffices for most work. Where the dominant constituent is one of the following metals; chromium, cobalt, iron, molybdenum, nickel, titanium, tungsten, uranium, or zirconium, an instrument having a wider dispersion is needed. This larger instrument is preferable, but not essential for the analysis of minerals whose major constituent is one of the following; manganese, thorium, or vanadium. In the larger instrument the range 2000° to 10,000° is photographed on four 4x10 inch plates. An

instrument manufactured by Gaertner and in use in the chemical laboratory
at Pomona College photographs the range $2000^{\circ}$ to $8000^{\circ}$ in two parts, the
visible spectrum on a 4x10 inch plate and the ultra-violet spectrum on a
plate of the same size.

The writer has made qualitative use of arc spectral analysis on
minerals from the pegmatites of San Diego County. This method has yielded
many data discussed in the main body of this paper. It is the writer's
opinion that spectroscopic methods, both qualitative and quantitative, are
especially well adapted to the mineralogical investigations of the pegma-
tites.

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The principles underlying the staining of minerals are three:

(a) The mineral is a natural absorbent of certain dyes or can be made so by etching with certain acids.  In the case of silicates the action of the acid is usually to precipitate a layer of colloidal or gelatinous silica which has high absorptive powers for some dyes.

(b) The mineral has in it an element or elements which form colored compounds.  In dealing with silicates the element forming the colored compound must usually be rendered soluble by etching in a strong acid, such as hydrofluoric or hydrofluosilicic acid.

(c) The mineral exhibits the phenomenon of surface polarity, i.e. its surface has an electrical charge which renders it positive or negative.  Certain aniline dyes are also polar.  A negative dye will be retained by a positively polar mineral, and vice versa.  This fact is utilized in biology, but so far as the writer knows, has never been investigated in mineralogy.

Gabriel and Cox[1] evolved a method for separating certain rock minerals by rendering potassium in some of these minerals soluble and precipitating on the surface a yellow insoluble compound of potassium, potassium cobaltinitrite.  The reagent is sodium cobaltinitrite and there is some sodium in the precipitated potassium cobaltinitrite.

The writer has been interested in methods for staining and separa-

[1]Gabriel, A. and Cox, E. P.  A staining method for the quantitative determination of certain rock minerals.  Am. Mineralogist 14: 290-292  (1929)

ting the feldspar. The method of Gabriel and Cox was tested on numerous feldspar grains. The results may be stated, tentatively, as follows:

1. The method may be used successfully to separate potash from soda-lime feldspars.

2. The petrological problem of estimating the amount of potash in the more acid plagioclase feldspar and the amount of soda in potash feldspar may be attacked with hope of some success by staining methods.

Other conclusions, tentative in part, from the staining investigations carried on by the writer are

1. The separation by staining methods of the plagioclase feldspars into compositional varieties comparable with those disseminated optically, does not appear feasible.

2. Etching by liquid HF or liquid $H_2SiF_6$ has proved to be more uniform and more convenient than etching with gaseous HF.

3. The separation of potash and plagioclase feldspars by staining the etched surfaces with certain aniline dyes appears feasible.

4. Etching frequently brings out twinning and other structures in feldspar not readily visible megascopically.

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| STAINS | Etching & Staining | Orthoclase | Microcline (perthite) | Perthite | Microperthite |
|---|---|---|---|---|---|
| Sodium Cobaltinitrite | Etch: HF, 12 min. Stain: 10 min. Wash: water | Dist. yellow | Dist. yellow | Dist. yellow | Dist. yellow |
| " | Etch: HF, 12 min. Stain: 10 min. Wash: alcohol | Dist. yellow | Dist. yellow | Dist. yellow | Dist. yellow |
| " | No etch Stain: 10 min. Wash: water | No stain | No stain | No stain | No stain |
| Gentian violet | Etch: HF, 12 min. Stain: 10 min. Wash: water | Mod. violet | Dist. violet | Dist. violet | Mod. violet |
| " " | No etch Stain: 10 min. Wash: water | Mod. violet | Mod. violet | Dist. violet | Mod. violet |
| Malachite green | Etch: HF, 12 min. Stain: 10 min. Wash: water | Dist. green | Dist. green | Dist. green | Dist. green |
| " " | No etch Stain: 10 min. Wash: water | Mod.-weak green | Dist. green | | Dist.-Mod. green |
| Methylene blue | Etch: HF, 12 min. Stain: 10 min. Wash: water | Dist. blue | Dist. blue | Dist. blue | Mod. blue |
| Hematoxylene | Etch: HF, 12 min. Stain: 10 min. Wash: water | Weak tint | Weak tint | Weak tint | Weak tint |
| " | No etch Stain: 10 min. Wash: water | No stain | No stain | Weak tint | |
| Congo red | Etch: HF, 12 min. Stain: 10 min. Wash: water | No stain | Trace of pink | No stain | Brownish tint |
| Safraneen | Etch: HF, 12 min. Stain: 10 min. Wash: water | Faint pink | Light pink | Light red | Light pink (edges pink) |
| Eosin dye | Etch: HF, 12 min. Stain: 10 min. Wash: water | Pink | Light red | Light red | Pink |
| " " | Etch: HF gas 4min. Wash: dil.HCl. Stain: 10 min. | Med. pink | | | |
| " " | Etch: HF gas 4min. No wash Stain: 10 min. | No stain | | | |

Dist. = Distinctly          Mod. = Moderately

| Anorthoclase | Albite | Albiclase | Oligoclase | Labradorite | Anorthite |
|---|---|---|---|---|---|
| Dist. yellow | Slightly yellow | Dist. yellow | Mod. yellow | Mod. yellow | No stain |
| Dist. yellow | Slightly yellow | Dist. yellow | Mod. yellow | Weak yellow | No stain |
| No stain | No stain | No stain | No stain | No stain | No stain |
| Dist. violet | Mod. violet | Weak violet | Mod. violet | Mod. violet | Dist. violet |
| Mod. violet | Dist. violet | Weak violet | Weak violet | Mod. violet | Weak violet |
| Dist. green | Dist. green | Dist. green | Mod. green | Dist.-strong green | Dist. green |
| Weak green | Mod. green | Mod. green | Dist. green | Mod.-Dist. green | Mod. green |
| Strong blue | Dist. blue | Mod. blue | Dist. blue | Dist. blue | Dist. blue |
| Weak tint | Weak-Mod. brown | Weak-Mod. brown | Mod. brown | Dist. brown | Dist. brown |
| Brownish tint | Faint brownish tint | Brownish tint | Brownish tint | Feeble pink | Brownish tint |
| Light pink | Med. pink | Reddish pink | Bright pink | Light pink | Light pink |
| Pink | Pink | Med. red | Light red | Pink | Pink |