PETROLOGY AND STRUCTURE OF THE CRYSTAL LAKE AREA, LOS ANGELES COUNTY, CALIFORNIA

A Thesis

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TABLE OF CONTENTS

ILLUSTRATIONS

ABSTRACT

Crystal Lake is located near the head of the north fork of the San Gabriel River in the San Gabriel Mountains. Igneous and syntectic rocks are the dominant types in this locality. However, remnants and inclusions of the older metamorphic complex of meta-sediments and dike rocks, which is dominant both north and south of the area studied, form a large part of the exposures. The complex is intruded by a quartz diorite similar to the Wilson diorite described by Miller several miles to the southwest. The dioritic rock is in turn intruded and replaced by granitic material, the only intrusive evidence of which consists of a network of pegmatite and aplite dikes. Migmatization is indicated by gradations in structure and composition from the quartz diorite to the granite, porphyroblastic development in the intermediate rock, and replacement textures in the granite and intermediate rock.

Two parallel high-angle normal faults with displacements of 200 to 400 feet cross the area in a northeast-southwest direction. Associated with these major faults are innumerable minor faults and fractures with displacements from a fraction of an inch to a foot or more in magnitude.

The formation of Pine Flat Basin, the broad valley containing Crystal Lake, has been ascribed to glaciation, but the author believes that structural movements and stream erosion with accompanying landslides were the responsible factors. This explanation accounts for all of the physiographic features of the basin and is more compatible with the geographic location and climatic conditions.

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INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The present study was undertaken as an attempt to answer some of the questions arising in the minds of geologists and laymen who visit Crystal Lake Park. Particular attention was paid to those questions relating to the areal petrology and, in a general way, the origin of the broad valley in which Crystal Lake is located.

The complexity of the problems involved and the limited time available have greatly restricted the investigation.

FIELD WORK AND ACKNOWLEDGMENTS

The region was mapped by the author during the spring and fall of 1937. Altogether about thirty days were spent in the field. Contacts were traced where possible, and a generalized geologic map was prepared of the area on a scale of 1000 feet to the inch using an enlargement of the advance sheet of the Crystal Lake quadrangle, published by the United States Geological Survey, as a base. However, because of the complex nature of the rock relations, the need was felt for a more detailed map. A plane table survey was therefore made of a small part of the contact zone along the north ridge on a scale of 100 feet to the inch. Approximately 24 acres were covered by this survey. Specimens for microscopic study were collected from the detailed area, and the collecting points were located on the map to show, if possible, the nature of the gradation of the rock types.

The author is indebted to Russell Doolittle, Maurice Sklar, and Bruce Wilson of the graduate school for assistance in the field and to Dr. Ian Campbell of the Department of the Geological Sciences for many helpful suggestions and criticisms.

PREVIOUS WORK

Until recent years the San Gabriel Range, and particularly the central part, has been neglected by geologists. The first to do any detailed work in the range was W. J. Miller of the University of California at Los Angeles. He has been interested in the San Gabriels since 1922 and has published several papers which deal particularly with the geomorphology and petrology of the western part of the range[1]. The only paper which mentions the Crystal Lake area is that by Miller on glaciation in Southern California[2]. He concludes that Crystal Lake is a moraine-dammed lake in a valley formed by a glacier of the Alpine type. The author disagrees with this conclusion and believes that the physiographic features which Miller attributes to glaciation can be better explained as effects of structural movements and stream erosion, a hypothesis which seems

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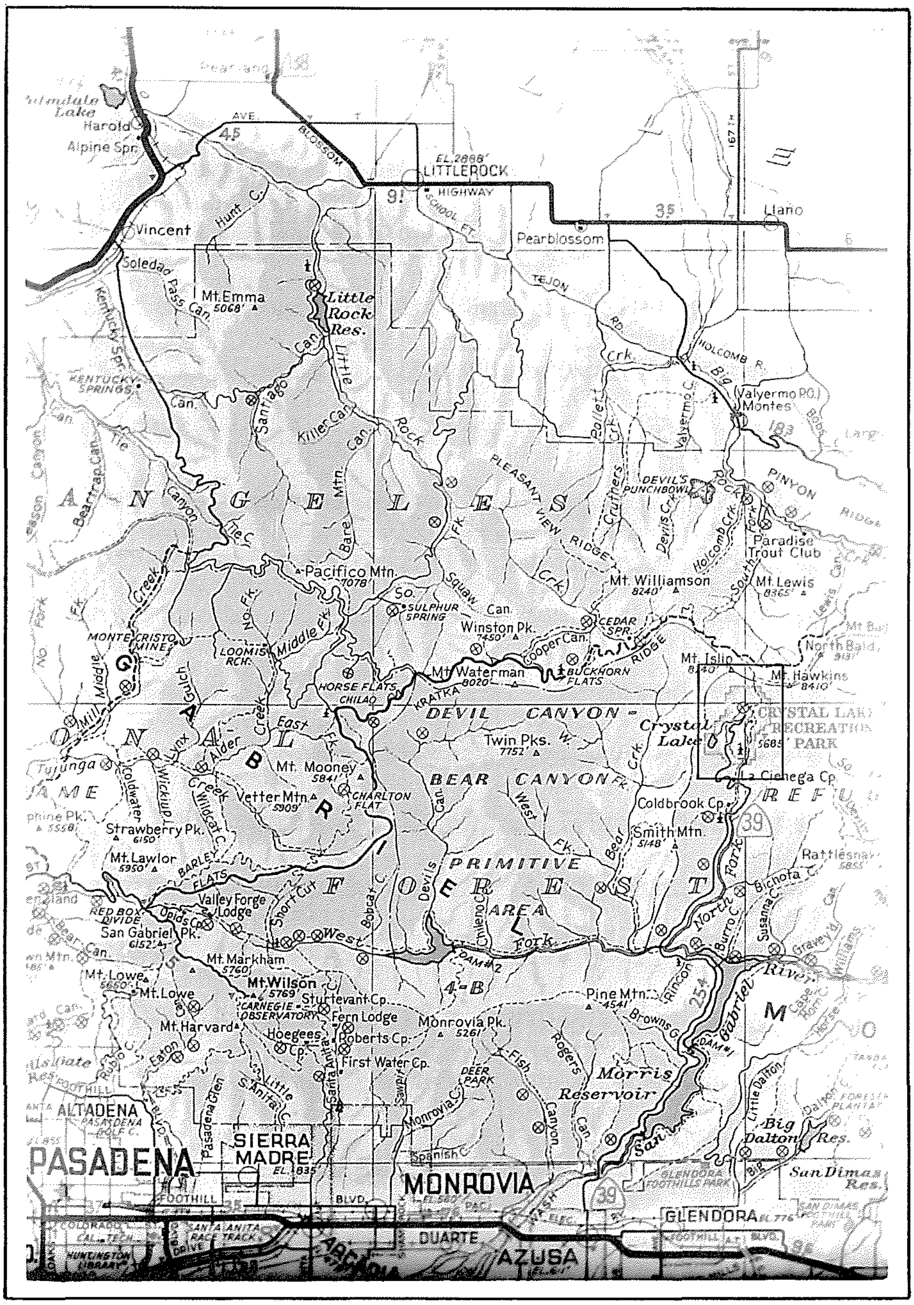
[1]Miller, W. J., Geomorphology of the Southwestern San Gabriel Mountains of California: Univ. of Calif. Pubs. in Geol. Sci., vol. 17, pp. 193-240, 1928.
Miller, W. J., Geology of the Western San Gabriel Mountains of California: Univ. of Calif. at Los Angeles Pubs. in Math. and Phys. Sci., vol. 1, pp. 1-114, 1934.

[2]Miller, W. J., Glaciation in the San Gabriel Mountains, California: Jour. Geol., vol. 34, pp. 74-82, 1926.

PLATE I INDEX MAP SHOWING LOCATION OF CRYSTAL LAKE AREA



Photographic copy of part of Southern California Auto Club map No. 1546

Scale in Miles

0 1 2 3 4 5

N

more compatible with the geographic location and climatic conditions.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

Crystal Lake is located near the head of the north fork of the San Gabriel River in the San Gabriel Mountains, Los Angeles County, California. The broad valley in which the lake is located has been set aside as a Los Angeles County recreational camp, and the excellent camping facilities in the park are of considerable help to anyone working in the area.

The area is easily accessible. A paved road which follows the San Gabriel Canyon from Azusa, a town on U. S. highway 66 and 25 miles south of Crystal Lake, terminates in the park campgrounds. Trails to Mount Islip and Mount Jackson begin at the north end of the campgrounds, and a Forest Service fire road has been recently completed along the north and east bounding ridges.

TOPOGRAPHY AND DRAINAGE

Pine Flat Basin, the valley containing Crystal Lake, is unusually broad and flat for its location. Because of its strong resemblance in outline to a glacial cirque and its proximity to the drainage divide, anyone accustomed to glacial topography might assume that the valley had been occupied by a glacier as did Miller.

The basin floor is about two and a half miles long and three-quarters of a mile wide and varies in elevation from 4000 to 6000 feet above sea level. A precipitous mountain face, 1500 to 2000 feet high, bounds the basin on the west, north, and east. In the following discussion this will be referred to as the west, north, and east bounding ridges. The west ridge varies in elevation from 5500 feet above sea level to 8250 feet on Mount Islip; the north ridge varies from 7560 to 8430 feet; and the east ridge from 7500 to 8500.

The basin floor consists of three relatively flat benches, the lower and middle of which are bounded on the north by steep scarps 200 to 400 feet high. The scarps are very irregular in outline, and the flatness of the middle bench is interrupted by small hills and depressions. The larger of the depressions in the southwest corner of the middle bench is occupied by Crystal Lake, a natural lake one-fourth mile long and 100 feet deep. The lake is bounded on the west and north by the west bounding ridge and on the east and south by a low ridge of unconsolidated material. The lake is fed from the northeast by a small stream originating in springs near the foot of Mount Islip and has no visible outlet.

The region as a whole is drained by small intermittent streams originating in springs at the base and on the slopes of the bounding ridges. These small streams form the headwaters of the north fork of the San Gabriel River.

CLIMATE AND VEGETATION

The climate is mild for a mountainous region. The rainfall averages about 27 inches annually. Most of the precipi-

PLATE II SCENIC VIEWS

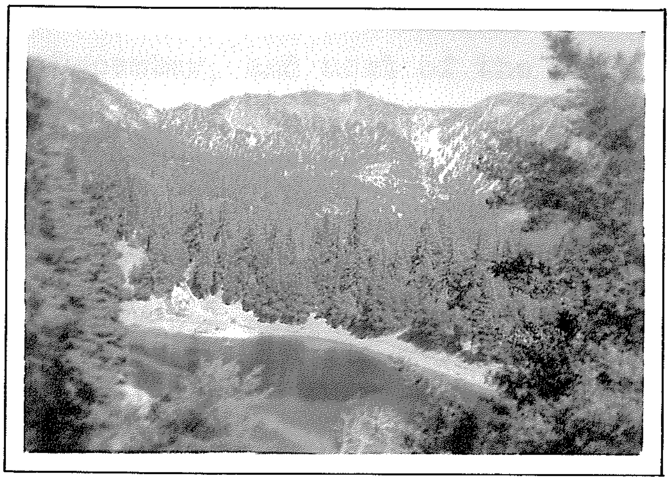


Figure 1. Looking northeast from ridge southwest of Crystal Lake

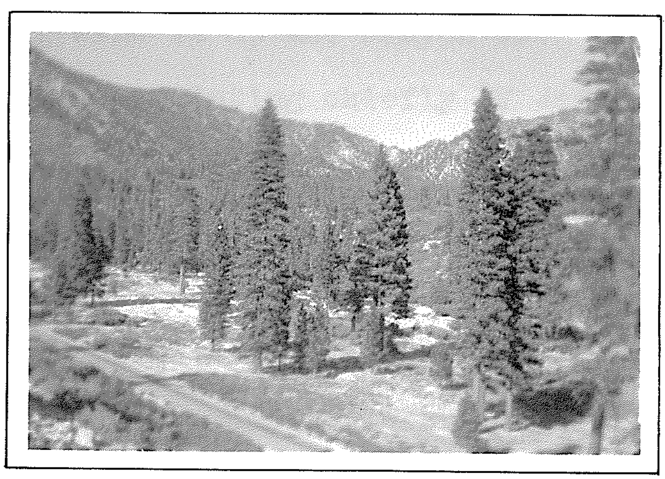


Figure 2. Looking north from ridge west of Crystal Lake guard station

tation comes as torrential rains in the early spring, but the winter snowfall is also a large factor. It averages about two feet and seldom exceeds four or five. The first snowfall usually occurs late in December, and most of the snow south of the divide melts during the month of March, but it remains much later on the north side. The author visited the area early in April, 1937 and found only isolated drifts south of the divide, but the slope on the north side was almost completely snow covered. The lookout's cabin on Mount Islip, which is in a small depression just north of the summit, was completely buried at that time, but the base of the tower about 50 feet to the south was clear of snow. Thus it is apparent that the snow accumulation is much greater north of the divide and that it remains during a larger portion of the year. The temperature range is from about 20° to 100° Fahrenheit and the prevailing wind is up the canyon from the south.

An evergreen forest, consisting chiefly of Jeffery pine, fir, and cedar, covers most of the region. The trees range up to three feet in diameter and some attain great height. (Plate II, fig. 2). Large trees are absent on the steep alluvial scarps. They are covered by a dense impenetrable growth of buckthorn, manzanita, and scrub oak. Mountain mahogany is common on the high rocky ridges. The soil is too rocky for grass except near the springs and small streams.

PETROLOGY

GENERAL STATEMENT

Igneous and syntectic rocks are the dominant types in this locality. However, remnants and inclusions of the older metamorphic complex of meta-sediments and dike rocks, which is dominant both north and south of the area studied, form a large part of the exposures. The complex is intruded by a quartz diorite similar to the Wilson diorite described by Miller[1] several miles to the southwest. The dioritic rock is in turn intruded and replaced by granitic material, the only intrusive evidence of which consists of a network of pegmatite and aplite dikes. The granitic dike rocks and the replacement rock resulting from the syntectic action of the granitic material are here termed the "Crystal Lake granite".

The San Gabriel complex, which is the name given by Miller to the metamorphic complex south and southwest of the Crystal Lake area, is assigned by him to the Pre-Cambrian although the age is not definitely known[2]. However, the lithologic similarity of these rocks to the known Pre-Cambrian in eastern California and the relative freshness of the later intrusives seem sufficiently convincing. The Wilson diorite and the Lowe granodiorite of which the Crystal Lake granite is probably a granitic phase are correlated by Miller with other California intrusives

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[1]Miller, W. J., Geology of the western San Gabriel Mountains of California: Univ. of Calif. at Los Angeles Pubs. in Math. and Phys. Sci., vol. 1, p. 30, 1934.

[2]Idem., pp. 49-56, 63-64.

on the basis of lithologic similarity and are believed to be late Jurassic or very early Cretaceous in age.

PETROGRAPHY

San Gabriel Complex

In the Crystal Lake area the complex consists of highly metamorphosed and migmatized argillaceous quartzites and basic dike rocks. The unmigmatized portions vary from light to dark gray and are fine grained and schistose. The migmatized portions are characterized by a mottled or banded white and gray color, variable structure and grain size, and the presence of metacrysts, veinlets, and irregular replacements of relatively fresh feldspars and quartz. All of the rocks composing the complex are highly fractured, and minor adjustments to strain are indicated by slickensided surfaces and small displacements of veinlets. The slickensides are all coated with a very fine grained reddish brown material which is probably a mixture of chlorite and iron oxides.

The rocks of the San Gabriel complex were not studied in detail under the microscope except in the particular cases where they occur as inclusions in the later quartz diorite. These inclusions are commonly lenticular in outline with the longer dimension parallel to the schistosity and vary from a few inches to a foot or more in length. The examples studied in thin sections were fine grained, medium gray, schistose meta-sediments consisting of about 60% quartz, 15% chlorite, 5% biotite, 5% magnetite, 5% introduced plagioclase, accessory apatite, zircon, tourmaline, and sillimanite, and minor amounts

PLATE III PTYGMATIC FOLDING

Figure 1. Ptygmatic folding and gneissic banding in the San Gabriel complex. Road cut north of Alexander Spring

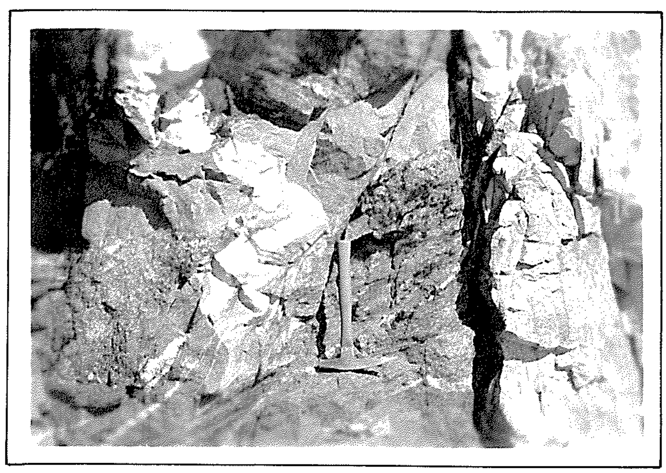

Figure 2. Ptygmatic folding in Wilson quartz diorite. Southeast corner of detailed map

of secondary sericite and limonite. The sillimanite is probably a product of the intense thermal metamorphism at the time of inclusion.

The dioritic material did not digest the inclusions to any appreciable extent. The contacts appear sharp both in the field and under the microscope. The only evidence of metasomatic action is the minor amount of introduced plagioclase in small metacrysts or porphyroblasts. Where the later granitic solutions came in contact with the inclusions, however, metasomatic action was intense. In one particular case in which an inclusion was cut by a small pegmatite dike large anhedral to subhedral crystals of oligoclase, orthoclase, and perthite were found several inches from the parent dike. These porphyroblasts are approximately parallel to the schistosity.

<u>Wilson Quartz Diorite</u>

Dioritic rocks outcrop on the summits and slopes of both the north and west bounding ridges, but the best exposures of relatively fresh and ungranitized quartz diorite were found on the south slope of the north bounding ridge east of the area covered by the detailed map. In general the composition and physical characters of this rock correspond closely with those of the Wilson diorite described by Miller in the vicinity of Mt. Wilson. The rock is extremely variable in structure, texture, and composition and is characterized by abundant inclusions, schlieren, segregations, and a more or less gneissic structure. (Plate IV). The color of the rock varies from light to dark gray, the darker phases being the more common,

PLATE IV PHASES OF THE WILSON QUARTZ DIORITE

Figure 1. Normal phase
natural size

Figure 2. Segregational phase
natural size

Figure 3. Hornblende phase
natural size

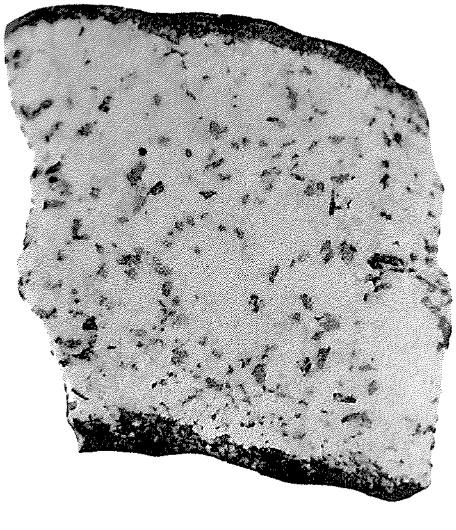

Figure 4. Feldspar phase
natural size

and it is medium to coarse grained.

The inclusions are commonly lens-shaped but some are very irregular and angular. They are all composed of fine grained meta-sediments as previously described. The schlieren are bands or stringers of dark minerals, sometimes spindle-shaped, and are parallel to the gneissic foliation of the rock. They are composed of platy hornblende and biotite and are segregations from the normal quartz diorite.

The average mineral composition of the normal medium grained phase as determined in thin section consists of 40% oligoclase-andesine, 15% quartz, 15% biotite, 15% hornblende, 3% orthoclase, 2% sphene, 1% magnetite, 5% secondary epidote, and accessory apatite, zircon, tourmaline, and rutile. This differs from Miller's type Wilson diorite in containing about 20% less plagioclase and more quartz and dark minerals. The most variable components are hornblende and biotite. The hornblende content ranges from 10% to 65% and the biotite from 0 to 20%. In some sections the biotite-hornblende ratio is 2 to 1; in others biotite is absent and hornblende may occupy two-thirds of the slide, in which case the rock resembles a hornblendite.

Strain is indicated in the thin sections by bent twinning and cleavage planes in some of the plagioclase grains and bent biotite plates as well as by the approximate alignment of the hornblende and biotite aggregates. Granulation has also occurred to a minor extent. The pleochroism of the biotite is usually dark brown to straw yellow and less commonly greenish brown to yellow. The hornblende commonly shows a pleochroism of green, bluish green, or greenish brown to greenish yellow.

Like the San Gabriel complex the Wilson quartz diorite is highly fractured and most of the fractures have slickensided surfaces coated with the same fine grained reddish brown material. The quartz diorite is also cut by innumerable pegmatite and aplite dikes some of which show ptygmatic folding. (Plate III, fig. 2).

Migmatite

The contact phase between the Wilson quartz diorite and the Crystal Lake granite, which was mapped as migmatite, is, as the name signifies, a mixed rock of syntectic or replacement origin[1]. It outcrops irregularly throughout the Crystal Lake area, but the largest bodies are on the summit and west slope of the east bounding ridge and on the east and southeast slopes of the west bounding ridge. At almost every exposure it was found to be gradational from dioritic rocks to granitic.

The typical migmatite found in the Crystal Lake area is a medium gray porphyroblastic rock. The porphyroblasts range up to one inch in length and are partially euhedral or rectangular in outline but more commonly irregular or lenticular. The

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[1]Sederholm defines migmatites as those rocks "originated by the mixture of older rocks and a later erupted granitic magma". Sederholm, J. J., On migmatites and associated Pre-Cambrian rocks of southwestern Finland: Part II: Comm. Geol. Finlande Bull. 77, 1926.

Barth later extended the term to include all syntectic rocks. Barth, T. F. W., Structural and petrological studies in Dutchess County, New York, Part II: Petrology and metamorphism of the Paleozoic rocks: Bull. Geol. Soc. Amer., vol. 47, pp. 775-850, 1936.

PLATE V MIGMATITE AND CRYSTAL LAKE GRANITE

Figure 1. Typical porphyroblastic migmatite natural size

Figure 2. Transitional phase between porphyroblastic type and banded type of migmatite natural size

Figure 3. Garnetiferous pegmatite cutting diorite natural size

Figure 4. Typical Crystal Lake replacement granite natural size

groundmass is medium grained and markedly gneissic, the banding or foliation being produced by orientation of the platy biotite and hornblende. The long axes of the porphyroblasts are usually parallel to the gneissic foliation, and the dark mineral bands commonly bend around them as in an augen gneiss. (Plate V, figs. 1 and 2).

Under the microscope the groundmass largely resembles the Wilson quartz diorite, but it appears to be more or less recrystallized with an increase in quartz and sodic and potassic feldspar. Myrmekite and pseudo-cataclastic textures are common in the more recrystallized portions, and hornblende, where present, is associated with and partially replaced by biotite. The normal biotite is straw yellow to brown in color, but the biotite formed by replacement of hornblende is greenish brown in color and appears to grade into the hornblende in an interfingering pattern. (Plate VI, fig. 2). The porphyroblasts are usually single crystals of oligoclase or orthoclase, the ratio of one to the other being subject to considerable variation. More commonly, however, the oligoclase porphyroblasts predominate. Replacement inclusions of quartz and albite are common in the oligoclase porphyroblasts. The quartz is in irregular stringers and blebs usually near the borders of the porphyroblasts and is usually continuous with secondary bodies of quartz in the surrounding matrix. The albite inclusions, however, are often near the centers of the porphyroblasts and usually have no direct connection with the albite in the surrounding matrix, indicating that these inclusions have grown

PLATE VI TEXTURES

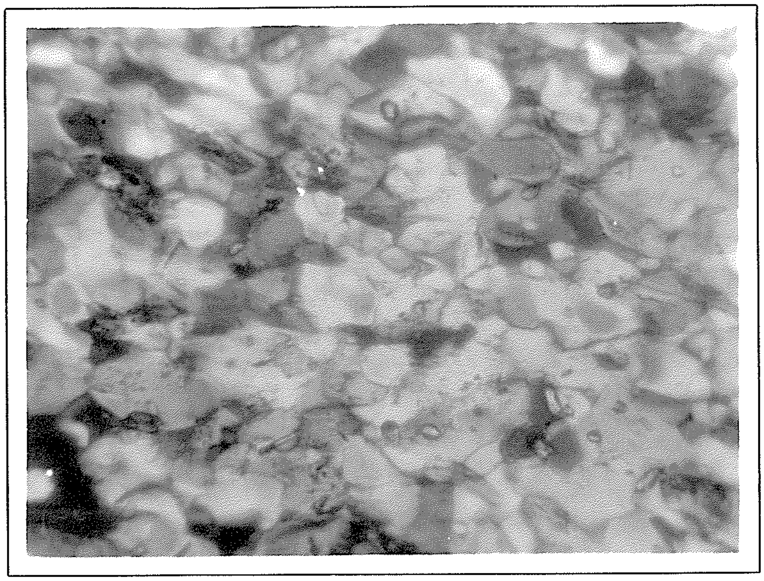

Figure 1. Meta-sedimentary texture of inclusion of San Gabriel complex in Wilson quartz diorite. Photomicrograph, crossed nicols, X 110
Section No. CL - 8

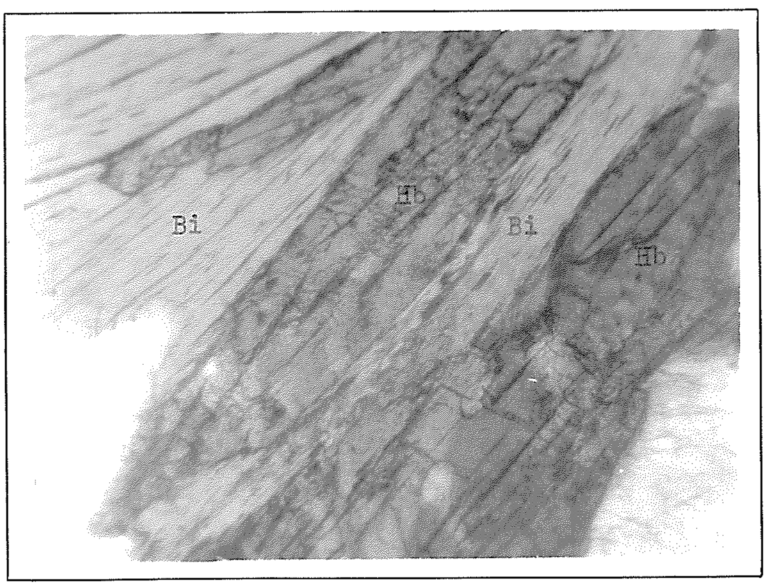

Figure 2. Biotite replacing hornblende in migmatite. Photomicrograph, plain light, X 110
Section No. CL - D5

within the porphyroblasts rather than being introduced from without. One or more of the borders of these inclusions is usually indistinct, indicating a gradation from the albite to the oligoclase. (Plate VII, fig. 2). Inclusions of primary minerals are rather rare and, where present, are scattered irregularly through the porphyroblast. Twinning is usually faint or absent in the oligoclase, and undulatory extinction is sometimes shown. It is light to dark gray under crossed nicols and usually partially sericitized. In contrast, the albite is always fresh and untwinned and is usually clear white to dark gray under crossed nicols and sometimes has a streaky appearance. Orthoclase is more difficult to distinguish. Large grains can usually be distinguished by their fresh uniformly light to dark gray color under crossed nicols and their distinct cleavage, but small grains can easily be confused with albite where the two minerals are not in mutual contact.

Crystal Lake Granite

Granitic rocks form the summit and upper slopes of the west bounding ridge throughout most of its length, and smaller, scattered bodies outcrop on and near the summits of the north and east bounding ridges. Much of the granite is pegmatitic or aplitic and it almost imperceptibly grades into the darker porphyroblastic rock of intermediate composition which has just been described.

The granite is normally light gray in color, medium grained, and slightly gneissic. (Plate V, fig. 4). The pegmatites are

PLATE VII REPLACEMENT TEXTURES

Figure 1. Veinlets of quartz and calcite in Crystal Lake granite. Dark part of veinlet is calcite. Photomicrograph, crossed nicols, X 110 Section No. CL - 13

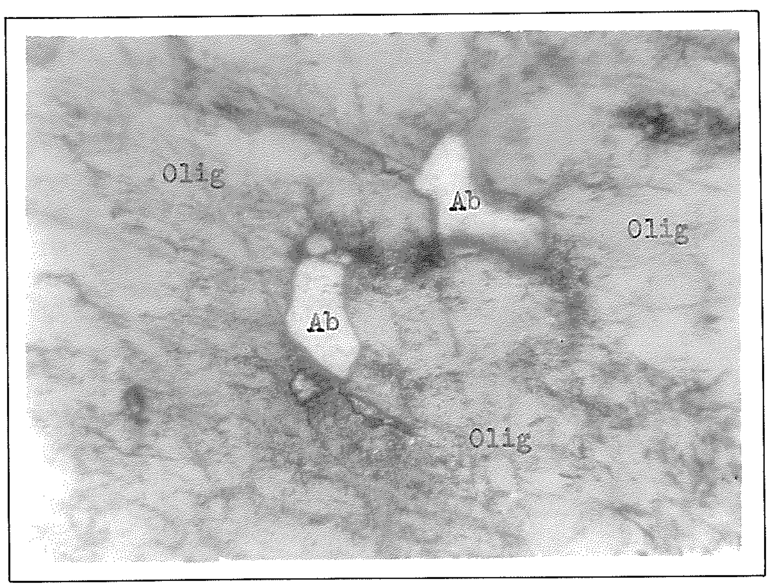

Figure 2. Replacement inclusions of albite in oligoclase porphyroblast. Photomicrograph, crossed nicols, X 110. Section No. CL - D6

white to pink in color, coarse grained, and graphic. Graphic granite is common in the pegmatitic areas, and small red garnets, either disseminated or in very fine grained bands, were found at some exposures. (Plate V, fig. 3). The aplites are white to light gray, fine grained, and equigranular. Small red garnets were found disseminated through a pure white, sugary type at one locality east of Big Cienega.

The average mineral composition of the normal light gray, medium grained phase, as determined in thin section, consists of 30% quartz, 30% orthoclase, 15% albite, 16% oligoclase, 6% biotite, and accessory hornblende, sphene, apatite, magnetite, muscovite, and zircon. Most of these constituents show considerable variation, and the accuracy of the determinations of albite, orthoclase, and untwinned oligoclase is doubtful in some cases because of their similarity in appearance. The pegmatitic and aplitic phases show even more variation because of contamination from the rocks which they intrude, but the uncontaminated portions of the dikes are dominantly microcline, perthite, and quartz. Garnet is also an almost universal constituent of the pegmatites and aplites and may range up to 3% of the rock.

Replacement or deuteric textures are dominant in all of the thin sections studied. The quartz and feldspars are all allotriomorphic and the grain size is quite variable. Pseudocataclastic textures are common and myrmekitic intergrowths of quartz and sodic plagioclase are universally present. (Plate VIII, fig. 2). Sutured grain boundaries and irregular

PLATE VIII REPLACEMENT TEXTURES

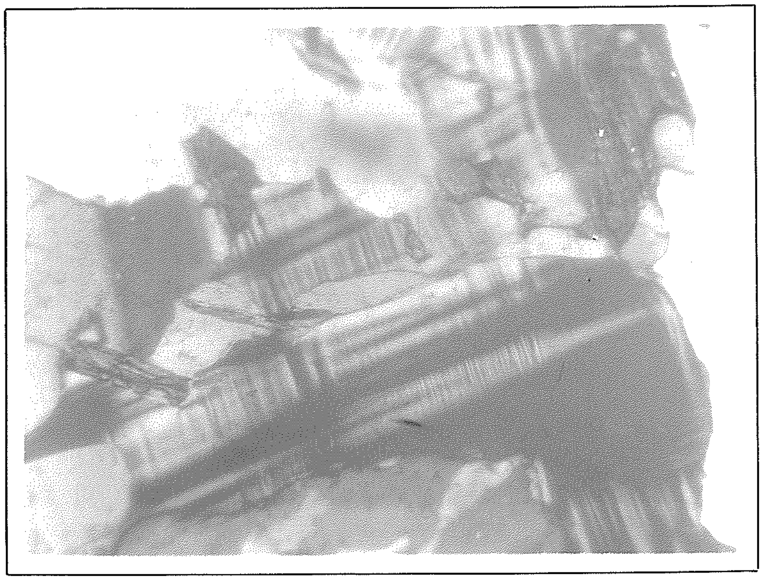

Figure 1. "Patch" perthites in Crystal Lake granite. Photomicrograph, crossed nicols, X 110 Section No. CL - Misc 1

Figure 2. Pseudo-cataclastic texture and myrmekite in Crystal Lake granite. Photomicrograph, crossed nicols, X 110. Section No. CL - Misc 3

stringers and veinlets are also universal features. Perthitic intergrowths of microcline and albite are common in the aplitic and pegmatitic phases. (Plate VIII, fig. 1). Replacement veins of quartz and calcite along parallel fractures were observed in one section. (Plate VII, fig. 1).

The biotite is straw yellow to greenish brown in color and both the scattered grains and the aggregates show approximate alignment. Most of the grains have irregular borders and appear to be corroded. Some have been reduced almost to relicts, and a few are partially replaced by muscovite.

Quaternary Alluvium

Pine Flat Basin is almost completely covered by unconsolidated material composed entirely of unassorted rock debris from the bounding ridges varying from fine sand and silt to large boulders twenty feet or more in diameter. The boulders and rock fragments are quite angular except where the material has been reworked along stream channels, and many of the fragments are less weathered than the outcrops on the ridges from which they were derived.

Talus accumulations, consisting of similar but finer material on the average than that covering the floor of the basin, cover the gentler slopes of the bounding ridges. This material shows definite stratification with alternating layers of fine and coarse material in a fresh road cut about half way up the west side of the east bounding ridge east of Alexander Spring. (Plate IX, fig. 2). This stratification probably indicates alternating periods of landsliding and normal disinte-

PLATE IX FIELD RELATIONS

Figure 1. Pegmatitic granite intruding migmatite. Canyon wall, southeast corner of detailed map

Figure 2. Stratification in a talus slope. Road cut southeast of Alexander Spring

gration which in turn indicates alternating periods of heavy and light rainfall.

PETROGENESIS

Examples of migmatized plutonics are peculiarly scarce in the literature, but migmatization of sediments and metamorphic rocks has been almost universally accepted as an important petrologic process. Some of the more significant works on this subject are listed below[1]. The nearest approach to the present problem is the work by S. R. Nockolds on contamination of granites in Great Britain. He sums up his view on the replacement of solid dioritic material by granitic solutions as follows:

> "Briefly then, we believe that such differentiation as can be shown to occur is of what may be termed contrasted type, leading to the separation, in intercrustal magma basins, of a basic and an acid magma of varying type. - - - - It is suggested that those intrusions

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[1]Adams, F. D., and Barlow, A. E., Geology of the Halliburton and Bancroft areas, Ontario: Can. Geol. Survey Mem. 6, 1910.
Fenner, C. N., The mode of formation of certain gneisses in the Highlands of New Jersey: Jour. Geol., vol. 22, pp. 594-612, 694, 702, 1914.
Sederholm, J. J., On migmatites and associated Pre-Cambrian rocks of southwestern Finland: Part I: Comm. Geol. Finlande Bull. 48, 1923.
Alling, H. L., The origin of foliation and the naming of syntectic rocks: Am. Jour. Sci., 5th ser., vol. 8, pp. 12-32, 1924.
Sederholm, J. J., On migmatites and associated Pre-Cambrian rocks of southwestern Finland: Part II: Comm. Geol. Finlande Bull. 77, 1926.
Stark, J. T., Migmatites of the Sawatch Range, Colorado: Jour. Geol., vol. 43, pp. 1-26, 1935.
Barth, T. F. W., Structural and petrological studies in Dutchess County, New York: Part II, Petrology and metamorphism of the Paleozoic rocks: Bull. Geol. Soc. Amer., vol. 47, pp. 775-850, 1936.
Anderson, G. H., Granitization, albitization, and related phenomena in the Northern Inyo Range of California-Nevada: Bull. Geol. Soc. Amer., vol. 48, pp. 1-74, 1937.

which show intermediate types are due to an intrusion of basic magma followed at a later date by one or more injections of acid magma, which, by reacting with solid basic rock in situ or at depth, produce the intermediate types."[1]

In an earlier paper[2] Nockolds expresses his belief that the replacement is effected by diffusion through a medium of low viscosity formed by the volatiles of the granitic magma.

A. Holmes[3] agrees with Nockolds' replacement theory, but believes that the solutions were derived from a separate granitic magma rather than as a product of contrasted differentiation.

The author was first attracted to the theory of replacement in situ or migmatization for the origin of the Crystal Lake granite and the intermediate porphyroblastic rock by the apparent gradations in texture and composition observed in the field and the replacement textures seen in a thin section of the typical granite. In an attempt to determine the nature of the gradations, if any, a detailed map (Plate XII) was prepared of a critical area containing good exposures of the supposed gradational types. Specimens for microscopic study were collected in this area, and the collecting localities were plotted on the map. Only a few of the 24 localities proved to be of

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[1]Nockolds, S. R., The production of normal rock types by contamination and their bearing on petrogenesis: Geol. Mag., vol. 71, pp. 31-39, 1934.

[2]Nockolds, S. R., Some theoretical aspects of contamination in acid magmas: Jour. Geol., vol. 41, pp. 561-589, 1933.

[3]Holmes, A., The idea of contrasted differentiation: Geol. Mag., vol. 73, pp. 228-238, 1936.

diagnostic value, however, because of the complications caused by (1) segregations and inclusions in the quartz diorite and (2) the later pegmatites and aplites which probably represent the residuals of the replacing solutions. Another complicating factor which has been almost invariably recognized in areas where replacement has been effective is the uneven distribution and concentration of the replacing solutions because of the irregular outlines of the magmatic body from which they emanate. This is well illustrated in the recent work of G. H. Anderson[1].

Of the 24 localities, numbers 1, 2, 3, and 5 along the top of the north ridge show the most complete gradational sequence both in the field and under the microscope. Number 5 is a dark gray, medium grained, granitoid rock; number 3 is lighter in color, fine to medium-coarse grained, and shows the beginning of porphyroblastic development; number 2 is lighter-colored than number 3, more variable in grain size, and definitely porphyroblastic; and number 1 is light gray, medium grained, and approximately equigranular.

The most noticeable compositional gradation from number 5 to number 1, which is apparent both megascopically and microscopically, is the reduction in dark minerals. Number 5 contains about 30% dark minerals, consisting of approximately equal quantities of biotite and hornblende; number 3 contains about 20%, of which three-fourths is biotite; and number 1

[1]Anderson, G. H., Granitization, albitization, and related phenomena in the Northern Inyo Range of California-Nevada: Bull. Geol. Soc. Amer., vol. 48, pp. 33-36, 1937.

contains only 5%, all of which is biotite. The complete disappearance of hornblende is probably due to replacement by biotite; evidence for this reaction is unmistakeable. (Plate VI, fig. 2). The reduction of the biotite cannot be accounted for as easily, but the corroded outlines of the remaining grains suggest reaction with the replacing solutions. Also much of the biotite might have been carried out into the cooler rocks and there deposited as segregations; this appears to have happened at certain other localities. Another noticeable gradation is in the quartz content. Number 5 and number 3 contain about 15% quartz, number 2 contains 20%, and number 1 about 35%.

The compositional gradations of the feldspars are not as distinct, largely because of the difficulties and uncertainties involved in the microscopic distinction of orthoclase, albite, and untwinned oligoclase. In most cases relative indices of refraction are the only definite discriminating characters and where the three are not in mutual contact this criterion fails. In cases of this sort a chemical analysis is the only accurate indication of the quantities of these minerals present. However, the microscopic determinations do indicate a reduction in lime from number 5 to number 1 and an increase in potash and soda. The plagioclase of number 5 has an extinction of about 12° on the albite twinning lamellae normal to (010) which indicates a composition intermediate between oligoclase and andesine whereas the plagioclase of number 3, number 2, and number 1 has an extinction of 3° to 10°, indicating a more sodic composition. Orthoclase also shows a definite increase from number 5 to number 1, although the gradation is somewhat irregular.

A second group of localities which shows a definite gradation, particularly in texture, includes numbers 19 to 23. These localities are located in the bottom of a narrow box canyon cut in solid rock in the southeast part of the detailed map area. Localities 19 to 22 are all mapped as migmatite because they are porphyroblastic and variable in structure, grain size, and composition. As in the previously described series the dark minerals decrease and quartz and potash feldspar increase in a fairly gradational sequence from 19 to 23, but the sequence is not as complete because it begins with an intermediate rather than a basic rock, and the granite end member, number 23, is aplitic in texture and composition.

In general, in the detailed map area, and at other exposures throughout the Crystal Lake area the gneissic foliation of the quartz diorite appears to persist through the intermediate rocks to the final granite. The foliation is not so marked in the granite though because of the reduction in dark minerals and the distortion produced by the growing of the porphyroblasts in the migmatite. The biotite contained in the aplites and pegmatites, however, has a random distribution with no apparent orientation. Thus it seems apparent that the gneissic foliation was not produced by post-intrusion regional metamorphism but was probably pre-granite and primary in the quartz diorite. A possible qualitative substantiation of this conclusion is the optical similarity of part of the biotite grains and aggregates of the granite to those of the quartz diorite together with the highly corroded appearance of the former, which suggest that the biotite of the granite was in large part derived from the quartz diorite without recrystallization.

The replacement textures observed under the microscope, such as myrmekite, perthite, allotriomorphic shapes, sutured boundaries, veinlets and stringers, and pseudo-cataclastic textures have been described and discussed both as evidences of migmatization[1] and of deuteric effects[2]. Both occurrences are now fairly well recognized; thus these textures are not in themselves sufficient evidence for either, but when combined with field evidence most workers agree that they may be of considerable importance.

In conclusion, the author is convinced that the normally appearing rock in the Crystal Lake area is a replacement granite formed in situ by granitic solutions penetrating the quartz diorite and that the intermediate porphyroblastic rock is an intermediate phase of the replacement process. Briefly the evidence for this conclusion is as follows:

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[1]Anderson, G. H., Granitization, albitization, and related phenomena in the Northern Inyo Range of California-Nevada: Bull. Geol. Soc. Amer., vol. 48, pp. 57-63, 1937.

[2]Gillson, J. L., Granodiorites in the Pend Oreille district of Northern Idaho: Jour. Geol., vol. 35, pp. 1-31, 1927.
Colony, R. J., Final consolidation phenomena in igneous rocks: Jour. Geol., vol. 31, pp. 170-175, 1923.

1. Gradations in texture and composition from the quartz diorite to the granite.

2. Persistence of primary gneissic foliation and probable preservation of original biotite from the quartz diorite to the granite.

3. Replacement textures in both the intermediate rock and the granite.

As regards the mechanics of the replacement the author is in agreement with the Nockolds theory, that is, the replacement was effected by diffusion through a medium of low viscosity formed by the volatiles of an underlying granitic magma. The minor amounts of hypogene calcite, tourmaline, and apatite in the granite suggest the presence of these volatiles. The calcite also partially accounts for the loss in lime in the plagioclase during the migmatization of the quartz diorite.

An intrusive granitic rock of sufficient size to have been the source of the replacing solutions is not exposed within the area studied, but the similarity of the pegmatites and aplites (which the author considers to be the residuals of the replacing solutions) to those related to the Lowe granodiorite in other parts of the range suggests the granodiorite as a possible source. Whether the granitic material differentiated from the dioritic in the same magma chamber or whether they represent separate magmas is a question which can not be decided in this discussion because of the small size of the area covered.

STRUCTURE

GENERAL STATEMENT

To the author's knowledge no major faults have been previously described in the Crystal Lake area. The central part of the San Gabriel Range has been considered to be a fairly rigid block bounded on the south by the San Gabriel fault, on the northwest by the Pacoima fault, and on the northeast by a fault south of, and parallel to, the San Andreas[1]. However, the present work has shown that vertical adjustments of 200 to 400 feet or more took place within the central block during Quaternary time. Associated with these major adjustments were innumerable minor displacements from a fraction of an inch to a foot or more in magnitude along joints and other minor fractures.

MAJOR FAULTS

Good evidence exists in the Crystal Lake area for two northeast-southwest trending faults of major magnitude for which the author proposes the names "Crystal Lake" and "Soldier Creek" since one underlies Crystal Lake and the other follows Soldier Creek Canyon for most of its length in the mapped area. The two faults are approximately parallel, both striking about N 45° E.

The most easily recognized evidences of recent movement

[1]Miller, W. J., Geomorphology of the Southwestern San Gabriel Mountains of California: Univ. of Calif. Pubs. in Geol. Sci., vol. 17, pp. 211-212, 1928.

along these faults are the partially dissected but distinct scarps which form the southern boundaries of the middle and upper benches. The upper scarp averages about 200 feet in height and the lower about 400 feet, and despite the re-entrants produced by recent stream dissection the fronts of these scarps appear quite straight when viewed from above.

At the northwestern edge of the middle bench two roughly lenticular depressions parallel the base of the upper scarp, the larger and more southerly one being occupied by Crystal Lake. Two hundred feet south of Crystal Lake a third depression parallels a bed rock spur, and southwest of this depression a saddle crosses the spur and connects with a straight canyon below, indicating that the fault probably continues beyond the mapped area.

North of Alexander Spring bed rock is exposed in the upper scarp and the scarp terminates in the re-entrant between the east and north bounding ridges. Here the only unmistakable fault planes and gouge were found. No major zone was found here, however, but rather several minor zones with small displacements all of which terminate under the landslide in the upper part of the canyon between the east and north ridges or under the talus slopes of the east ridge. (Plate XI).

The lower alluvial scarp is a continuation of the bed rock ridge which forms the north wall of Soldier Creek Canyon and terminates about half way up the east bounding ridge. The fault zone of the Soldier Creek fault is exposed from the mouth of the canyon to the new Forest Service fire road where it branches out into several minor faults all of which terminate before they reach the top of the ridge. The fault zone is characterized by extreme brecciation and the lack of gouge, indicating that the movement was not confined to a single plane but was distributed over a zone 100 feet or more wide.

The planes of both the Crystal Lake and Soldier Creek faults, where exposed, are nearly vertical with a slight southerly dip at most of the localities. This evidence together with the occurrence of the San Gabriel complex north of the fault in each case and the steep scarps indicate high-angle normal faulting. No evidence was found for strike-slip movement, but since most of the major faults of the range have strike-slip components, it is quite probable that such movement has occurred in this area. If so, it was not of sufficient extent to be reflected in the topography.

The total displacement in the Crystal Lake area can only be roughly estimated because of the absence of a datum plane of any sort, but the height of the scarps suggests that recent vertical movements have probably exceeded 400 feet on both faults.

MINOR FAULTS AND FRACTURES

In this area as elsewhere in the San Gabriel Mountains the rocks are all highly jointed and broken by minor faults and fractures. At several localities, particularly in the San Gabriel complex, the fractures are so numerous and closely spaced that the rocks have a brecciated appearance. Minor displacements are indicated on most of these fractures by

PLATE X MINOR FAULTING

Figure 1. Minor fault in migmatite east of Alexander Spring

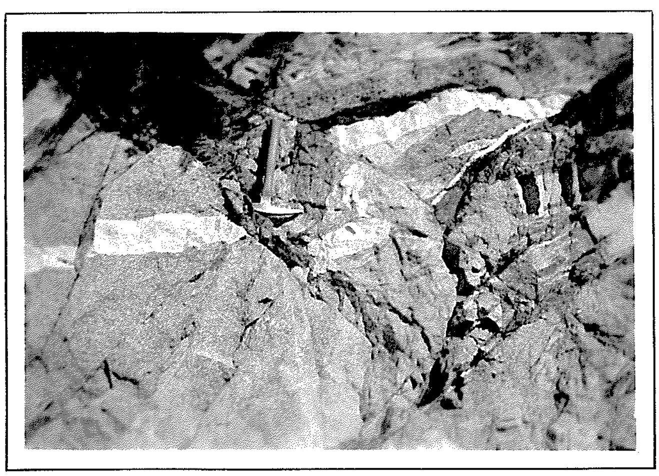

Figure 2. Pegmatite dike offset by minor faults in southeast corner of detailed map area

slickensided surfaces and offset dikes and contacts. (Plate X, fig. 2). The displacements vary from a fraction of an inch to a foot or more in magnitude and are very irregular in orientation. There is no regular pattern to suggest release of pressure in any particular direction.

The primary jointing is also very irregular and often indistinguishable from the later fractures produced by orogenic movements, and in some localities many of the minor fault displacements probably followed the joints. Because of these complications the primary joint systems can not be worked out with any assurance of accuracy.

The ptygmatic folding of the pegmatites and aplites in some localities indicates differential pressure during the period of igneous activity, and offset dikes indicate structural activity subsequent to their consolidation. Thus the complex network of minor faults and fractures was not formed during a single orogenic period but rather represents structural activity resulting in irregular stresses and release of pressure at least from late Mesozoic time to late Quaternary, the more recent activity being indicated by the alluvial scarps along the major faults.

GEOMORPHOLOGY

The origin of Pine Flat Basin is a problem that deserves more careful study than has been given it in the past. The author is convinced that its history is not a simple one and can not be attributed to a single geologic process although structurally controlled stream erosion was probably the dominant factor. As has been mentioned before, the basin strongly resembles a glacial cirque, and for that reason and because of the moraine-like alluvial ridges and terraces, Miller[1] inferred that the basin had been occupied by a glacier.

The only generally recognized glaciated area in California south of the Sierras is on the north side of San Gorgonio Mountain 60 miles east-southeast of Crystal Lake[2]. A comparison of the geographic features of the Crystal Lake area with those of the San Gorgonio area brings out two major differences. In the Crystal Lake area Miller states that the glacier extended from an elevation of approximately 8500 feet on Mount Hawkins to a point about three-fourths of a mile north-northeast of Coldbrook Camp where the elevation is only 4000 feet; in the San Gorgonio area on the other hand glacial evidence is recognized only above 8500 feet. A second and more fundamental difference is that the supposed Crystal Lake glaciated area is on the south side of the drainage divide whereas the San Gorgonio glaciated area is on the north side. In the Crystal Lake area the canyons north of the divide are narrow and V-shaped, showing no evidence of former glaciation; yet, as has been pointed out before, snow remains on that side over a much longer period of the year. Thus it is rather difficult to visualize a glacier of the size described by Miller in the

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[1] Miller, W. J., Glaciation in the San Gabriel Mountains, California: Jour. Geol., vol. 34, pp. 74-82, 1926.

[2] Fairbanks, H. W., and Carey, E. P., Gladiation in the San Bernardino Range, California: Science, new ser., vol. 31, pp. 32-33, 1910.

Crystal Lake area.

The step-like character of the basin floor formed by the benches and fault scarps has been previously discussed as evidence for normal step-faulting, but we must still account for the presence of the benches. The flatness of these surfaces and their general outlines suggest that they are old stream terraces which have been uplifted, step-faulted, and dissected. This explanation is in accord with many other examples of such uplifted terraces in the San Gabriel Range including some excellent examples in the San Gabriel Canyon south of the area studied[1]. In his discussion of glaciation Miller distinguishes the gravel benches and ridges of the Crystal Lake area from the stream terraces in the San Gabriel Canyon on the basis of their poor degree of sorting and states that the lower limit of the so-called morainal material is hard to determine because of the later reworking by streams. But why couldn't this poor sorting in the upper terraces be due to the short distance of transportation from their original source?

The moraine-like ridge which parallels the west bounding ridge and is separated from it by a narrow stream valley is a difficult feature to account for. A possible explanation is that it was part of a level terrace that was tilted slightly northwestward during the period of structural movement so that a stream channel could form at the junction between the tilted

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[1]Miller, W. J., Geomorphology of the Southwestern San Gabriel Mountains of California: Univ. of Calif. Pubs. in Geol. Sci., vol. 17, pp. 218-219, 1928.

terrace and the main ridge. The stream then cut down to form the present channel. The other irregularities in the basin are also believed to be results of the structural deformation and subsequent erosion, and, as has been stated before, Crystal Lake and the depressions to the south and northeast are probably sag ponds since they are along the line of the Crystal Lake fault.

The cirque-like outline of Pine Flat Basin is not an unusual feature in the San Gabriel Mountains or in other mountain ranges composed of highly fractured crystalline rocks where landsliding is an important factor of erosion. The master streams quite commonly fan-out into numerous small channels at their heads, and if the material between these small channels were largely removed by landsliding a cirque-like valley head would develop. This explanation is substantiated in the Crystal Lake area by fresh landslides of large size like the one in the canyon between the north and east bounding ridges.

In conclusion then, the physiographic features of the Crystal Lake area can all be explained by structural movements, stream erosion and deposition, landsliding, or combinations of these factors; explanations which are much more compatible with the geographic location and climatic conditions than is Miller's glacial hypothesis.

GEOLOGIC HISTORY

The major events in the history of the Crystal Lake area were as follows:

1. Deposition of arenaceous sediments and intrusion of

dike rocks composing the San Gabriel complex. Pre-Cambrian (?).

2. Structural deformations which metamorphosed the San Gabriel complex. Paleozoic and/or Mesozoic.

3. Intrusion of Wilson quartz diorite under stress producing primary foliation in the rock. Late Jurassic or early Cretaceous.

4. Replacement of quartz diorite by granitic solutions to form the Migmatite and the Crystal Lake granite. Late Jurassic or early Cretaceous.

5. Intrusion of pegmatites and aplites accompanied by differential pressure which produced ptygmatic folding in some of the dikes. Late Jurassic or early Cretaceous.

6. Structural movements which fractured the rocks, offset dikes, and made slickensided surfaces throughout the area. Tertiary.

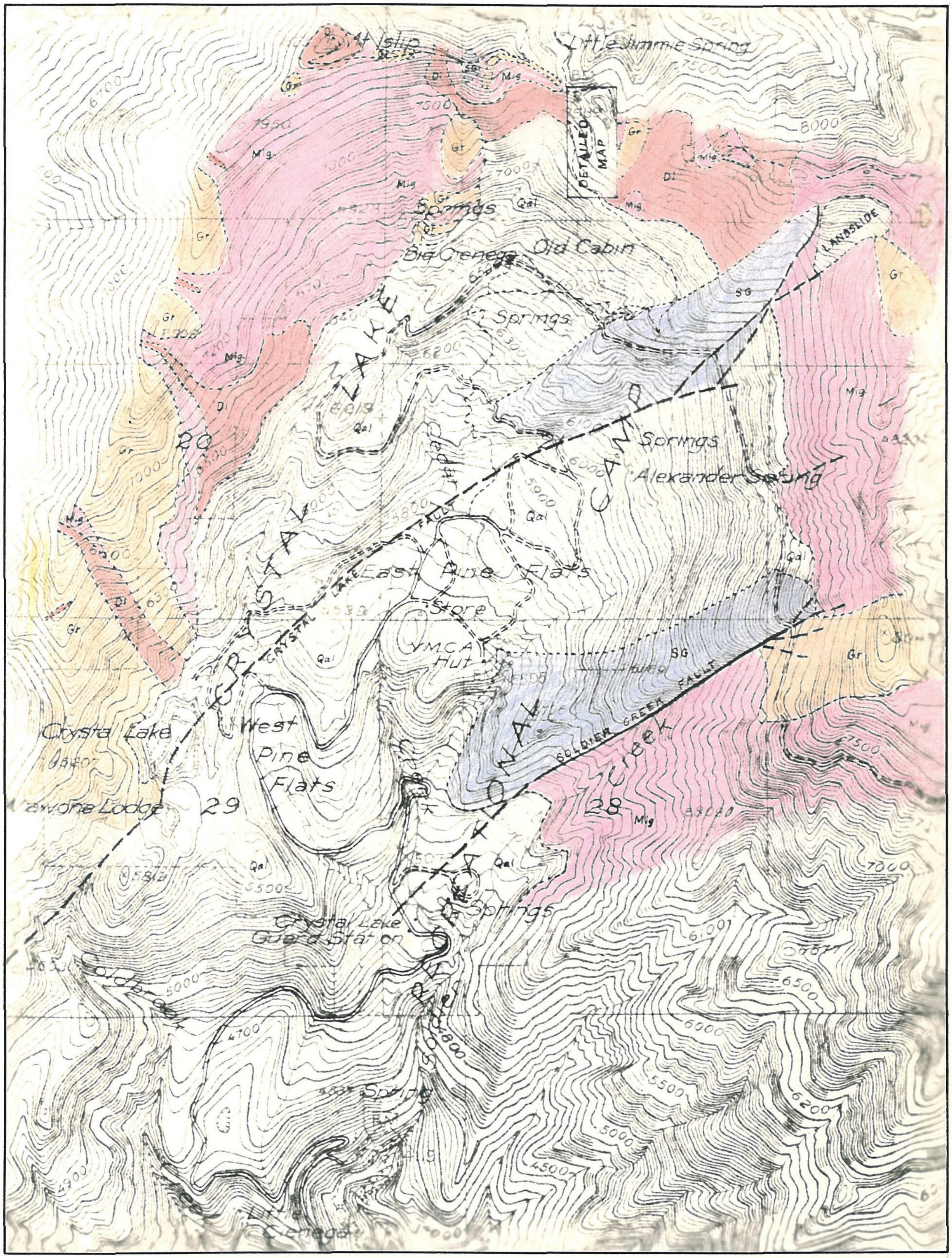
7. Uplift followed by erosion and deposition of stream terraces. Late Tertiary and/or early Quaternary.

8. Normal step-faulting. Late Quaternary.

9. Uplift followed by erosion which dissected the terraces and fault scarps. Late Quaternary to Recent.

The last two events were probably in part contemporaneous because the step-faulting was very likely a result of the uplift.

PLATE XI TOPOGRAPHIC AND GEOLOGIC MAP OF CRYSTAL LAKE AREA



Topography from U.S.G.S. advance sheet of Crystal Lake quadrangle.

Geology by J. C. Wells 1937

0 500 1000 2000 Ft.

Scale

Contour Interval 25 ft.
Datum mean sea level

LEGEND

- Quaternary alluvium
- Crystal Lake granite
- Migmatite
- Wilson quartz diorite
- San Gabriel complex

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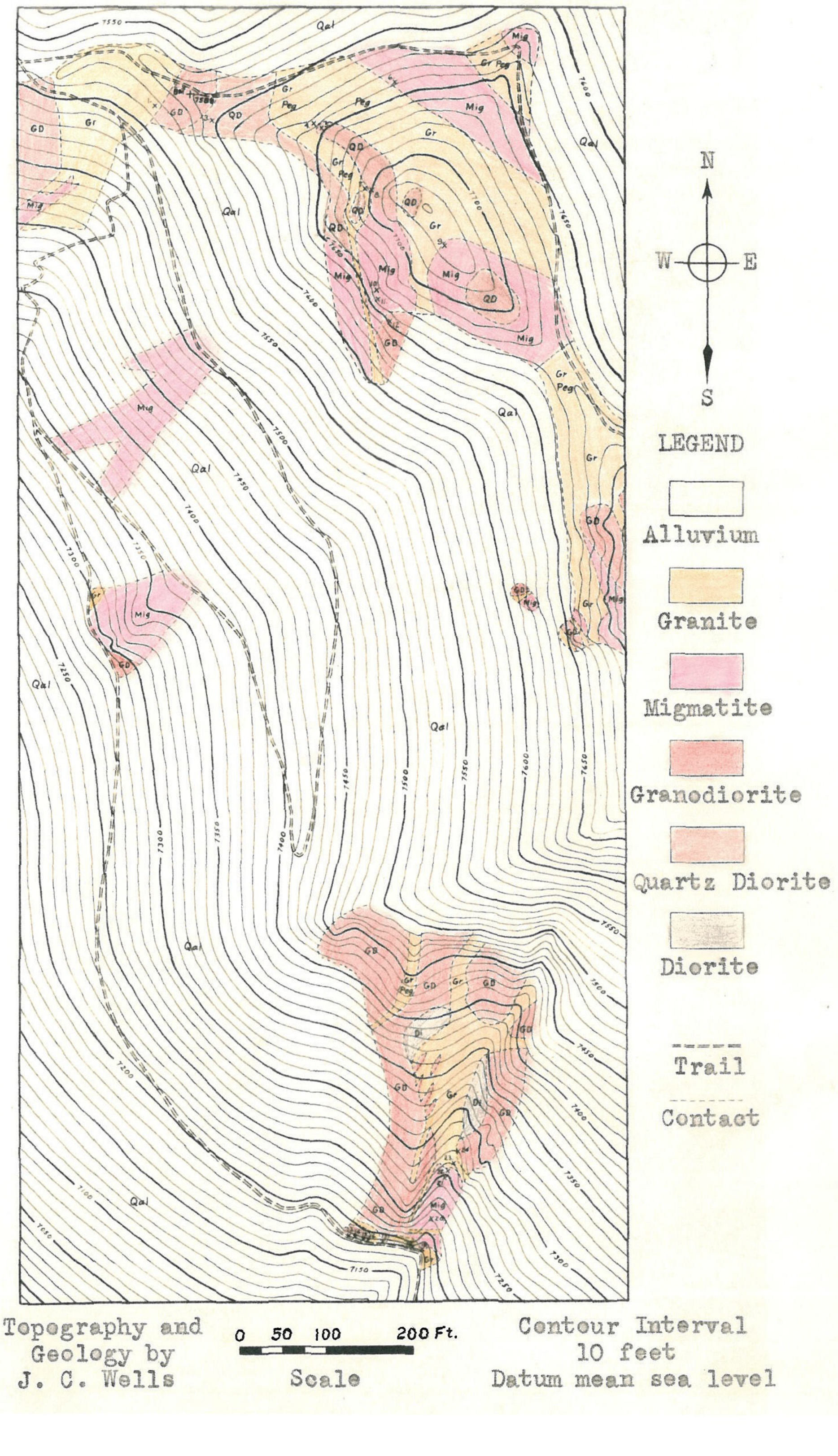
PLATE XII TOPOGRAPHIC AND GEOLOGIC MAP OF PART OF NORTH RIDGE



Topography and Geology by J. C. Wells

Contour Interval 10 feet
Datum mean sea level