Geology of the

LOCKWOOD VALLEY AREA

Kern and Ventura Counties, California

SPECIAL REPORT 81

California Division of Mines and Geology
Ferry Building, San Francisco, 1964

Cover mop is reproduced from AMS Series V502, NI 11-4, Los Angeles sheet,
scale 1 : 250,000.

Geology of the

LOCKWOOD VALLEY AREA

Kern and Ventura Counties, California

by

MAX F. CARMAN, JR.
University of Houston, Houston, Texas

SPECIAL REPORT 81

California Division of Mines and Geology
Ferry Building, San Francisco, 1964

STATE OF CALIFORNIA
Edmund G. Brown, *Governor*

THE RESOURCES AGENCY
Hugo Fisher, *Administrator*

DEPARTMENT OF CONSERVATION
DeWitt Nelson, *Director*

DIVISION OF MINES AND GEOLOGY
Ian Campbell, *State Geologist*

SPECIAL REPORT 81

Price $2.00

CONTENTS

CONTENTS—Continued

Illustrations

ABSTRACT

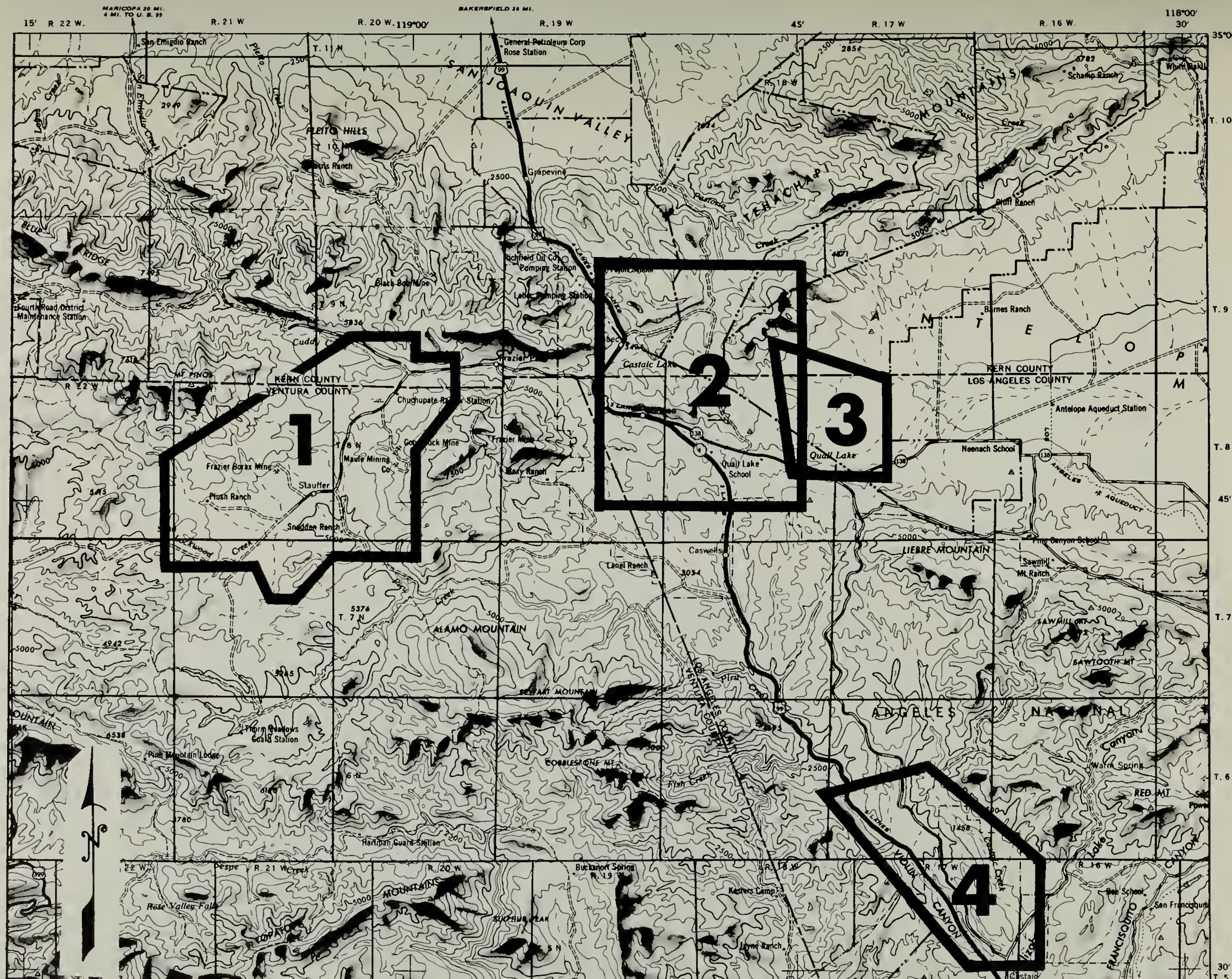
The Lockwood Valley area in the northeastern part of Ventura County, south of Mount Pinos, encompasses about sixty square miles.

The oldest rocks, now exposed as gneiss, schist, and hornfels, were derived from sediments which have been invaded by the Mount Pinos granite and other acidic intrusions of probable Jurassic age. Over 2000 feet of marine Eocene sandstone and shale lie unconformably on the crystalline rocks and are overlapped by 8500 feet of middle and late Tertiary continental sedimentary rocks. The continental rocks include the Plush Ranch and Caliente Formations, the Lockwood Clay, and the Quatal Formation. Coarse clastics comprise most of the section, but fine-grained lacustrine facies, basalt flows, and leucocratic tuff occur in subsidiary amounts. The Tertiary and older rocks are capped by Quaternary alluvial deposits of the Frazier Mountain formation, and later Terrace gravels.

The sedimentary rocks are mostly gently folded along northeasterly trends which reflect major movement of the crystalline blocks. The area is crossed by several faults of regional extent, including the San Andreas, Big Pine, and San Guillermo faults and the Frazier Mountain thrust.

Strong deformation, accompanying the deposition of post-Eocene beds, was manifested first by probable middle Tertiary block faulting. Strike-slip movement on the northwest-trending San Andreas and northeast-trending Big Pine faults occurred in late Tertiary and Quaternary times. At about the same time the Frazier Mountain thrust formed, perhaps in response to localization of regional north-south compression along an east-west-trending bend in the San Andreas fault, which borders the thrust on the north. Uplift of the region accompanied these movements and has continued into recent time, as shown by terrace relations.

The Lockwood Valley area has been the site of repeated diastrophism and deposition of continental sediments since middle Tertiary time. Part of these sediments are tentatively correlated with the Vasquez-Mint Canyon sequence forty miles to the southeast, and it is suggested they were once essentially contiguous deposits that have been separated by large lateral displacement on the intervening San Gabriel fault. This postulate is supported by the similarity of sedimentary sequences and crystalline rocks in the two regions, and by the age relations of the rocks.



The numbered areas on the map above are covered by Special Reports with large-scale maps, issued by the California Division of Mines and Geology. Area 1 is the region covered by this book (Special Report 81); area 2 is the Lebec quadrangle (Special Report 24); area 3 is part of the Quail quadrangle (Special Report 30); and area 4 is southern Ridge Basin (Special Report 26).

GEOLOGY OF THE LOCKWOOD VALLEY AREA KERN AND VENTURA COUNTIES, CALIFORNIA *

By MAX F. CARMAN, JR., Associote Professor
University of Houston
Houston, Texos

INTRODUCTION

This report is the result of a detailed geological study of the Lockwood Valley area, situated in the mountainous region just south of the San Joaquin Valley in southern California. The area is of structural interest in that it contains the intersection of the San Andreas and Big Pine faults. Exposed in the area is a distinctive group of sedimentary rocks, the age of which spans a considerable part of the Tertiary period, as well as crystalline rocks typical of a large area in the Transverse Ranges. The area lies near the juncture of the Coast Ranges, Transverse Ranges, and Sierra Nevada.

Location, Accessibility, and Culture. The area mapped covers about 60 square miles and is 43 miles south of Bakersfield. Lockwood Valley is 13 miles west of U.S. Highway 99, the arterial connection between the Los Angeles Basin and the Central Valley of California. Access to Lockwood Valley from this highway is by a paved county road, and most parts of the area may be reached by short branches of this road, or by ranch roads and U.S. Forest Service roads.

The nearest town, Frazier Park, lies 9 miles east of the valley. The town of Stauffer in Lockwood Valley (pl. 1) was a temporary site during the operation of colemanite mines three decades ago, but no longer exists. A little gold mining has recently been carried out on the western slope of Frazier Mountain, and clay deposits are being worked in the valley.

Topography. Lockwood Valley is an upland basin, lying at an average elevation of 5,200 feet, and surrounded by mountains which rise above 8,500 feet (fig. 1). The valley is transgressed by the Big Pine fault which marks the arbitrary boundary between the Coast and Transverse Ranges in this region. Low hills of varied shape and relief form finger ridges in the valley-floor; these generally trend toward the southeast corner of the valley, where it drains to the south. The north valley wall is the southern flank of Mount Pinos (8,831 ft.). The mass of Frazier Mountain (8,013 ft.) forms an eastern buttress, and a low divide at the west separates Lockwood Valley from the headwaters of the Cuyama River drainage. The southern boundary is a low ridge called Yellowjacket Ridge, and a table land which culminates westward in San Guillermo Mountain (6,569 ft.).

Relief is moderate throughout the area of the map, with the extremes of elevation being 4,800 feet at the southeast corner of Lockwood Valley and 7,500 feet on the flank of Mount Pinos. Within alluviated valleys the hills are seldom over 300 feet high, and slope steepness is a function of rock type. Sandstone and conglomerate of late Tertiary and Quaternary ages are widespread and form sharp hills (photo 17) although occasional clayey and shaly zones show gentle, rounded profiles. Many hills are formed from, or capped by, old alluvial fan and terrace deposits, with extensive flats standing 40 to 100 feet above the valley floor. Mountain flanks are cut chiefly in crystalline rocks showing a complex system of surfaces which give step-like stretches of subdued topography. However, relief is locally sharp on mountainsides where streams have incised ravines 100 to 300 feet deep. Mountain summits form broad, gently rolling uplands. Distinctive rift topography occurs along the San Andreas fault zone in the north of the area. Sag ponds, recent fault scarps cutting alluvial fans, and low elongate hills are here aligned along the fault trace.

On the western edge of the area, and in the upper Cuyama River drainage, relief is extreme and badland topography is conspicuous, with great vertical flutings suggestive of organ pipes. Cliffs of 500 to 700 feet are common, although local relief seldom exceeds 750 feet.

Drainage. The Lockwood Valley area encompasses the headwaters of three major drainage systems, all of which rise on Mount Pinos. Lockwood Creek drains its southern slopes, and flows southward through Lockwood Valley to join Piru Creek, which in turn reaches the Santa Clara River and finally the sea near Ventura. The headwaters of the Cuyama River flow from the western slopes of Mount Pinos and enter the sea at Santa Maria.

* Manuscript prepared as Ph.D. Thesis, University of California at Los Angeles; submitted for publication in June 1957.

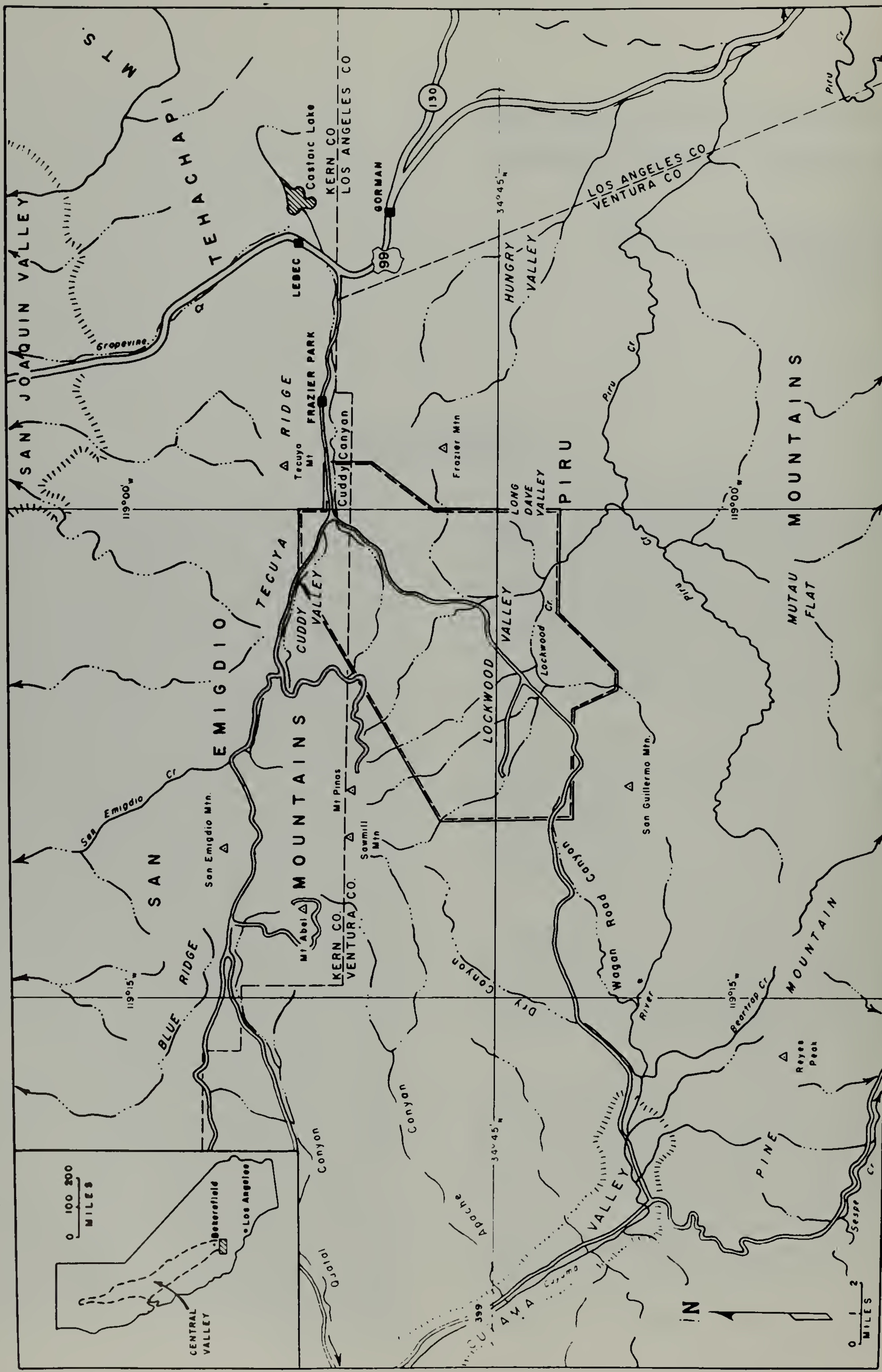


Figure 1. Index map showing location of Lockwood Valley and regional geographic features.

The northern and part of the eastern slopes shed water northward to the San Joaquin Valley. Eastern slopes also drain in part through Cuddy and Little Cuddy Valleys and along Cuddy Canyon (fig. 1) to reach Castaic Lake to the east.

The creeks of Lockwood Valley are dry during most of the summer months with the exception of Seymour Creek which often flows throughout the year. The middle and upper reaches of North Fork and Middle Fork of Lockwood Creek and Amargosa Creek (pl. 1) may carry water during most of the year where they flow on granitic rocks. However, most flow is subsurface in the lower portions of these streams, which are over a sedimentary cover; it returns to the surface only near the outlet to the valley, where crystalline basement rocks reappear. Potable water comes from shallow wells; although there are several good springs on the slopes of the mountains.

Climate and Vegetation. The climate is semiarid to subhumid, with rainfall occurring chiefly between the months of October and May. There are no permanent meteorological stations in or near the area. Those at Lebec, 15 miles to the east, and at Chuchupate Ranger Station, in Little Cuddy Valley, are fire-season stations for which are recorded only precipitation and humidity during the months of greatest fire hazard. Winter storms bring most of the precipitation. The lower areas are estimated to average 15 inches, much of which falls as snow; on higher ground precipitation undoubtedly is twice that much, and is mostly snow. Temperatures seldom exceed 90° F. in the valleys and do not often remain below freezing during the day in winter.

The vegetation shows marked zonation, reflecting the complex of climatic, drainage, and soil conditions. The alluviated valleys are mostly well drained and support a dense growth of sagebrush. Locally, as in Little Cuddy Valley, ponding causes grasslands which became marshy after a series of wet years. A pinyon-juniper woodland is characteristic of the low sandy hills in the valleys and of lower slopes of the mountains up to about 7,000 ft. The chief plant here is the single-leaf pinyon, which forms mostly a semi-woodland interspersed with sage and locally interrupted by manzanita in the western and lower portions. The woodland is quite dense at higher levels and farther east. Valleys in the conifer woodland region are generally lined with canyon liveoak. The Sierra-Cascade forest dominates higher slopes, consisting of stands of western yellow pine (*Pinus jeffreyi* and *P. ponderosa*) with scattered white fir (*Abies concolor*).

Previous Work. The most important piece of early work on the region was done by Gazin (1930a), whose study included almost all of the present area. However, he has published only an abstract of the geology (1931), together with a paper (1930b) on vertebrate remains collected from Apache and Quatal Canyons, between 10 and 15 miles west of Lockwood Valley (fig. 1). These mammalian assemblages were found in formations that crop out in Lockwood Valley and aid greatly in dating.

The earliest specific reference to the area is a report by Gale (1912) on the borate deposits of Lockwood Valley. He gave a detailed description of the rocks associated with the borates and made a map of about two square miles covering the region surrounding the Frazier and Russel mines (K.90, X.05 and K.00, X.80)*.

Further references to the geology of the region also appear in Foshag (1921), Buwalda, Gazin, and Sutherland (1930), and Hill and Dibblee (1953).

Field Work. Field work on which this report is based was done during the summers of 1949 and 1950, and in the spring of 1951. U.S. Forest Service aerial photographs on a scale of four inches to the mile (1:15,-840) were used in mapping. A base map for the geology was made from seven and one-half minute topographic sheets published by the Army Corps of Engineers (1944) on a scale of two inches to the mile (1:31,680). The map includes parts of five quadrangles: Cuddy Valley, Lockwood Valley, Frazier Mountain, Sawmill Mountain, and San Guillermo Mountain.

Acknowledgments. Aid was given the author in the field and in discussions with Professors John C. Crowell, Daniel I. Axelrod, Kenneth D. Watson, Cordell Durrell, and Edward L. Winterer, all of the University of California, Los Angeles, and by Drs. Kenneth J. Hsu, Donald V. Higgs, and Thane McCulloh. Dr. Mason L. Hill of Richfield Oil Corporation gave valuable advice on comparison of post-Eocene sediments with those in Cuyama Valley, and Dr. Donald E. Savage of the University of California gave further excellent help in dating post-Eocene formations. Thin sections were made by John de Grosse, and fossils were determined by Takeo Susuki and William T. Rothwell. Mrs: Lou Barrett, Geology Dept., Univ. of Houston, typed the manuscript. The Gene Reid Drilling Company of Bakersfield supplied a copy of the geological report on their operations in Lockwood Valley. Help was also given by Messrs. Baggett, Plush, and Snedden, whose hospitality and generosity in the use of private roads materially facilitated the work. To all of these people acknowledgement and thanks are given.

DESCRIPTIVE GEOLOGY

Lockwood Valley is part of a complex structural trough containing remnants of a diverse assemblage of rocks. Included among these are Eocene marine shale, sandstone, conglomerate, and limestone; a thick post-Eocene section of sedimentary breccia, conglomerate, arkosic sandstone, mudstone, shale, limestone, and volcanic rocks, most of which are continental (partly lacustrine); and widespread Quaternary boulder gravels in the form of terrace deposits and valley alluvium. Exposures of shale, sandstone, conglomerate, limestone, and tuffaceous sandstone of uncertain age and origin occur

* The geologic map (pl. 1) is marked with a grid system, the interval of which is 1,000 yards. Grid lines are numbered in Roman numerals from south to north and lettered in capital letters from east to west along the borders. Points under discussion are located on the map by means of this grid system and references to it appear in parentheses where appropriate. For example, the Frazier mine is located at K.90, X.05; that is, it lies 900 yards west of the north-south grid line K, or 0.90 parts of the way between lines K and L, and 50 yards north of east-west grid line X, or 0.05 parts of the way between lines X and XI. In more general locations one or both decimals are dropped, according to the size of the feature located: For example, J to M, VIII to XI means that the east-west limits of the area discussed lie between lines J and M, while its north-south limits are between lines VIII and XI.

in a fault wedge along the San Andreas fault, northeast of Lockwood Valley. The highlands around the trough are chiefly metamorphic and coarse granitic rocks of pre-Eocene age.

Relations between rock types and structure can be summarized as follows: A northern boundary for Tertiary beds is formed by the granitic complex of Mount Pinos, which seems to have been raised along the apparently normal Mount Pinos fault (pl. 4). To the east the predominantly gneissic mass of Frazier Mountain has overridden late Tertiary strata along the Frazier Mountain thrust, while along the southern border these sedimentary rocks lap onto gneissic and granitic basement. At the southwest Eocene rocks are in contact with late Tertiary beds along the San Guillermo fault, which appears to have steep-angle reverse movement. The Big Pine fault, which transects the area and extends many miles westward, probably has had considerable lateral movement. In Lockwood Valley it generally brings older Tertiary formations on the north against younger on the south, but in Little Cuddy Valley it bounds a wedge of basement rock (pl. 4). A small section of the San Andreas fault, at the northeast corner of the map, is bordered by a crystalline complex and the wedge of sedimentary rocks of uncertain age. Basement terranes on opposite sides of the San Andreas fault differ fundamentally and include distinctive rock suites.

Basement Complex

For this study the metamorphic rocks are separated from plutonic rocks and where possible field subdivisions have been made.

METAMORPHIC ROCKS

Northeast of San Andreas Fault

The area northeast of the fault contains metamorphic rocks intruded by quartz monzonite. Although they have not been distinguished on the map, several metamorphic types are represented. Calc-silicate hornfels and fine-grained feldspathic quartzite predominate, and biotitic quartzite, quartz-biotite schist, garnetiferous biotite gneiss, and quartzo-feldspathic gneiss are common. Mixed with these rocks, but with unknown relations, are zones of chlorite schist which enclose bands of marble as much as 20 feet thick. The marble is white and contains layers of graphite flakes. It grades along strike into grey, green, and pink banded lime silicate rocks. Most of the metamorphic rocks weather to white and buff angular fragments set in a sparse granulose soil. However, the biotite and chlorite schists break down to finer debris and give rise to dark brown and reddish-brown soil.

This assemblage has undergone high-grade contact metamorphism, and veins of quartz, pegmatite, aplite, and stringers of fine-grained biotite-quartz monzonite are abundant. A portion of a large mass of quartz monzonite is present in the northeast corner of the map (pl. 1). At one place (D.13, XVI.63) the monzonite can be seen to be intrusive into biotite schist, though generally the contact is not well exposed.

A thin section of lime silicate hornfels showed it to be a medium-to-fine-grained granoblastic assemblage of grossularite, diopside, and wollastonite with subsidiary quartz, calcite, and traces of plagioclase. Calcite and the quartz occur as medium-sized, subequant grains in contact with each other and closely intergrown with the other minerals. Calcite is also present as veinlets. The mineral assemblage indicates a high temperature of formation (pyroxene hornfels facies), but the occurrence of calcite, quartz, and wollastonite together also shows disequilibrium, possibly due to retrograde changes. The composition of these metamorphic rocks implies that they have been derived from dolomitic limestone, quartzite, feldspathic and argillaceous sandstone, and possibly basic igneous rocks. Such a group of sediments may have had a variety of origins, but the presence of large amounts of marble and calc-silicate hornfels, together with abundant fairly pure quartzite, suggest that the original rocks were marine.

The age of these rocks has not been established. They are certainly pre-Eocene, since the granitic bodies that have intruded them are overlapped by Eocene sediments a few miles north of Cuddy Valley. If the granitic rocks are correlative with intrusives of the Sierra Nevada, the metasediments are pre-Late Jurassic or older.

Southwest of San Andreas Fault

Frazier Mountain Rocks

For purposes of field mapping these rocks were divided into a light-colored group and a dark-colored group, although this division is somewhat arbitrary owing to intimate intermingling and transition. The rocks are crystalloblastic quartzo-feldspathic gneiss and schist with varying amounts of biotite. Their composition and fabric suggest their origin from normal clastic sediments by plutonic metamorphism involving anatexis, metasomatism, and possible injection by igneous fluids.

Differences in fabric and the proportions of the minerals are the principal bases for distinction of several groups of rocks, though gradations between types are common. The following is a summary of the metamorphic and related rock types present on Frazier Mountain:

A. Light-colored rocks
  1. Alaskite
     Coarse- to fine-grained, commonly aplitic, garnetiferous in places, potash feldspar predominant to absent, grades into 2 (below) through a garnetiferous quartz-potash feldspar gneiss.
  2. Light-colored biotite gneiss
     Garnetiferous in places, potash feldspar predominates over oligoclase, some phases with coarse potash feldspar augen similar to those in biotite augen gneiss. (C below).
  3. Quartzite
     Garnetiferous, locally quartzo-feldspathic and biotitic.
  4. Quartzo-feldspathic biotite schist (occurs within alaskite).
     Mostly garnetiferous, potash feldspar sparse to predominant, mostly with oligoclase and potash feldspar in equal amount, biotite-rich (over 10%).
  5. Pegmatite
     Mostly quartz and potash feldspar with some coarse muscovite.

B. Transition rocks
  1. Fine-grained quartzo-feldspathic biotite gneiss.
     Not garnetiferous, potash feldspar predominant to absent, with small augen of oligoclase.
  2. Migmatites
     Mixtures of all types, especially alaskite and the gneiss and schist listed above.

C. Dark-colored rocks
  1. Biotite augen gneiss
     Garnetiferous in places, mostly contains potash feldspar as large augen and oligoclase, less commonly with albite.

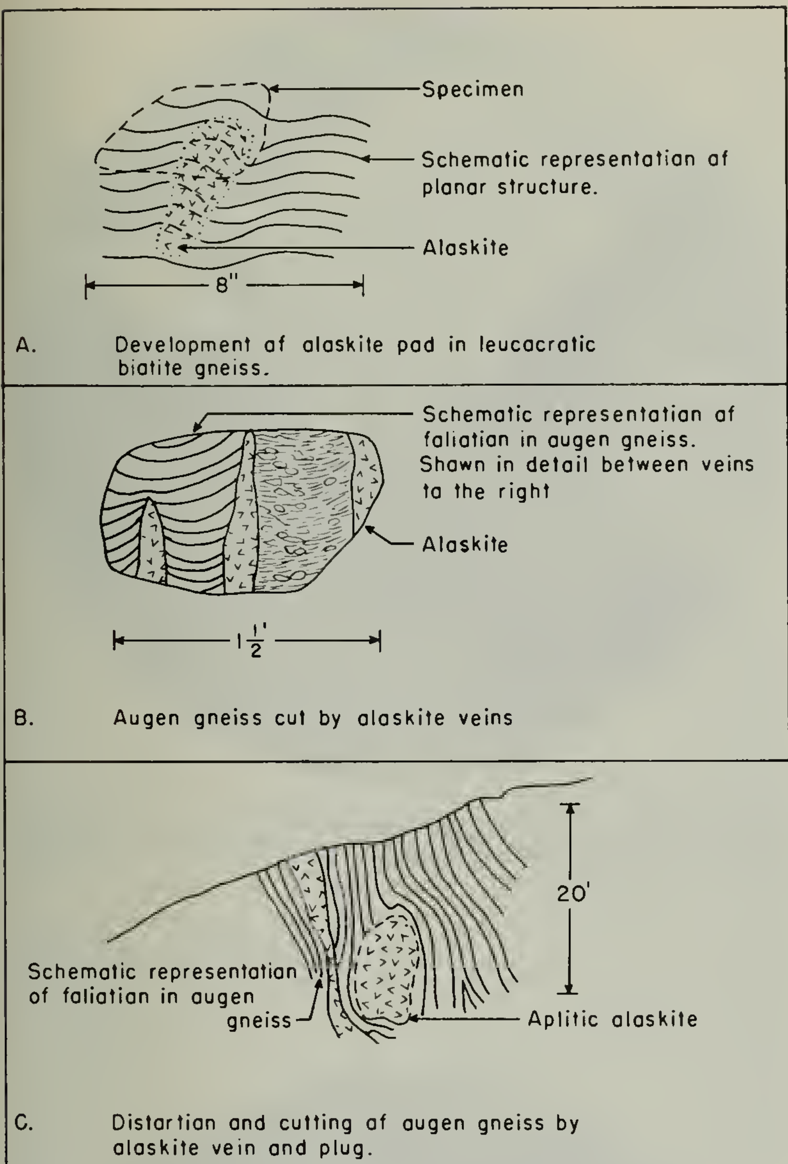


Figure 2. Distortion and cutting of augen gneiss by alaskite vein and plug.

Specimens from each unit near faults show cataclastic structure, in which the degree of deformation varies from a grinding-down of quartz only into bead-like stringers to a comminution and streaking out of all constituents. Widespread cataclasis is shown by strong undulatory extinction in nearly all quartz. Apparently cataclasis postdated formation of the fundamental metamorphic types and was not a factor in their origin. Crystalloblastic textures are evidenced by mutually interlocking grains and mutual enclosure of all mineral species. Poikiloblastic crystals and sutured boundaries are the rule, though locally cataclasis has obscured earlier textures and smoothed grain boundaries. Quartz generally shows replacing relations with consistent convex boundaries toward other minerals, especially toward plagioclase, which is often reduced to "interstitial-looking" grains due to a "cooky-bite" effect of the quartz. Potash feldspar commonly shows similar replacement of plagioclase. Myrmekite, common though not abundant, varies from albite-quartz to oligoclase-quartz inter-growths and is found between potash feldspar, plagioclase, or even quartz grains; but it usually occurs between potash feldspar and plagioclase, replacing the former.

The essential mineralogy of all members of the alaskite-augen gneiss series is similar. All are quartz-rich (30 to 60 percent), all carry at least traces of greenish-brown biotite, and most have the same feldspars in various proportions. Microcline is the chief potash feldspar, while subsidiary orthoclase or microcline microperthite is common. The plagioclase is consistently soda-rich oligoclase (An_{10-20}), but in a few rocks, especially augen gneiss, albite (An_{5-10}) also occurs. Minor and major sericitization and replacement by quartz are features common to plagioclase in all specimens studied; apparently plagioclase is in part older than the other constituents. Pale pink to brownish-red garnet appears in most units, either as scattered grains or concentrated layers. It is usually shattered and altered to biotite, chlorite, or sericite along cracks, and in some instances it is almost entirely replaced by sericite. Small rounded grains of zircon, irregular patches of sphene, subhedral apatite crystals, and iron oxide are accessory.

Alterations are chiefly sericitization with local epidotization and chloritization. Sericitization is most general, but it is especially concentrated in bands along the northwest side of Frazier Mountain, and is most intense in those specimens that show the most marked cataclasis. It has not been determined whether alteration and crushing are related to the same event, or whether the sericite is later and localized along zones of crushing. Epidote and chlorite are found largely in connection with hydrothermal alterations of augen gneiss in shear zones and where quartz veins cut the gneiss along the western flank of the mountain.

Light-Colored Rocks. Alaskite, a white to pale buff massive sparsely garnetiferous quartz-feldspar rock, occurs as irregular masses from a few inches to hundreds of feet across which have indistinct contacts, and as pods and stringers permeating and transecting all crystalline rock types. Oligoclase (about An_{15}) is the only feldspar in some rocks, whereas in others it is equal or subordinate to microcline.

The alaskite contains large and small patches of biotite schist, with which it has sharp boundaries. Specimens display all gradations between alaskite and leucocratic biotite gneiss; the transition occurs with an increase of biotite, the alignment of which gives the gneiss its structure. Patches of alaskite can be seen as if in the process of "forming" in gneiss. One case shows an alaskitic area containing traces of biotite layers developed along a flexure in the gneiss (fig. 2). A thin section across the boundary shows no difference in the chief constitutents of the two parts and reveals only garnet and a more completely permeating sericitization in the gneiss, where biotite is mostly altered. In other places, relics of light-colored gneiss with indistinct borders are surrounded by alaskite; yet, in many cases, veins of alaskite cut sharply across the foliation of the gneiss or appear as clearly defined sheets parallel to the foliation. The sheets often show pinch-and-swell structures, and foliation is dragged at the contact. Outcrops on the west side of Frazier Mountain show alaskite cutting dark-colored augen gneiss with sharp contacts and disrupting its planar structure (fig. 2). However, the composition of the alaskite is not noticeably different from the quartzo-feldspathic parts of these darker-colored rocks.

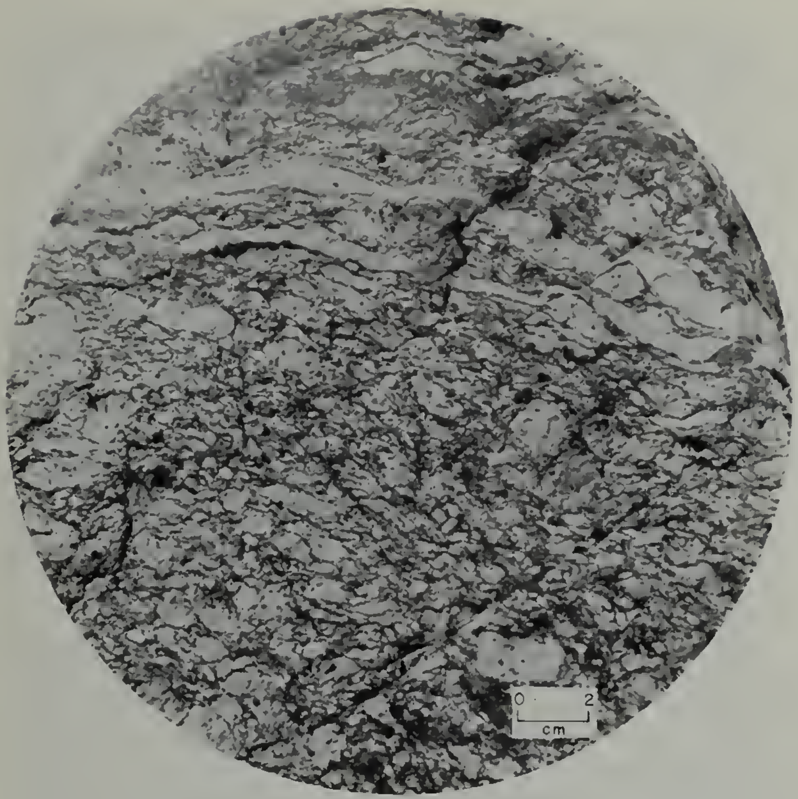


Photo 1. Biotite augen gneiss, coarse phase, showing large augen and quartzo-feldspathic (alaskitic) stringers.

Photo 2. Biotite augen gneiss, showing quartz (white) replacing sericitized plagioclase (black), with embayed relations showing "cooky-bite" effect. Crossed nicols.

Photo 3. Biotite augen gneiss, showing replacement of sericitized plagioclase (light-colored in center) by microcline (dark, with quadrille structure, surrounding plagioclase). In upper left quadrant microcline shows embayment relation toward plagioclase. Crossed nicols.

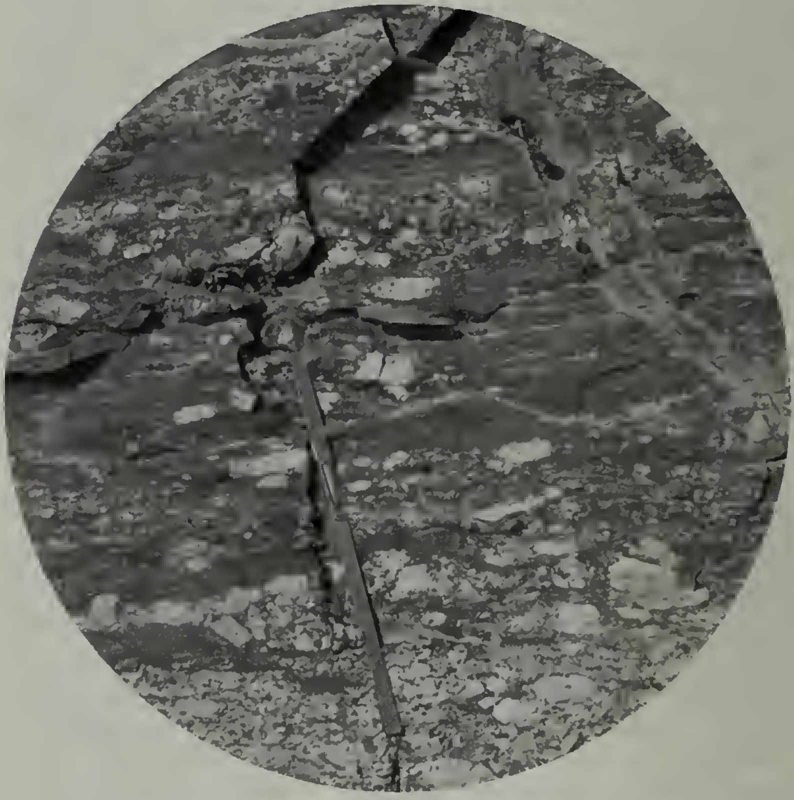


Photo 4. Fine-grained quartzo-feldspathic gneiss interlayered with biotite augen gneiss. Scale is 6 inches long. Locality G.3, V.O.

These phenomena are best explained by differential fusion or liquefaction of quartzo-feldspathic parts of a quartz-feldspar-rich rock, with liquid aggregating and locally injecting the surrounding rocks. However, crystalloblastic textures indicate much recrystallization in the solid state, and the replacement features mentioned above could be caused by melting or diffusion. Thus the relative importance of melting and solid-state growth is not known.

Leucocratic biotite gneiss, a medium-grained strongly crystalloblastic gneiss, is mostly buff or medium gray according to the amount of biotite present, but pale green sericite gives much of the rock a greenish cast. Oligoclase (about An_{15}) is subordinate where present and is generally replaced by predominating quartz and potash feldspar or minor amounts of micro-perthite. Biotite ranges from less than one to about five percent, averaging two or three percent; in many rocks it is largely replaced by sericite. Where oriented parallel to the plane of foliation, the biotite is commonly mostly altered, with only wisps remaining to show its former presence. The grains that trangress the foliation tend to be preserved, although some are severed by sericitic streaks.

This gneiss makes up more than three fourths of the light-colored rocks on the western half of Frazier Mountain, where it is partly in sharp contact and partly transitional with dark-colored augen gneiss. Hand specimens show the transition to be simply one of gradual increase in biotite content and grain size together with the enlargement of feldspars to form augen. In a few places, the light-colored gneiss is composed of coarse augen identical to those in the dark-colored biotite augen gneiss.

Brown to dark gray quartzite with greasy luster occurs in the light-colored gneiss and alaskite. It is a medium-grained, strongly crystalloblastic rock with faint banding due to layering of small percentages of biotite, oligoclase, and potash feldspar. Well-rounded zircons occur in some specimens.

The quartzite is at least several feet thick, and though no attempt was made to trace it, it is distinctive and persistent enough that detailed mapping might reveal some of the structures in the metamorphic mass. The banding reveals ubiquitous, tight, small-scale folds.

The greasy luster may have special significance, since both Read (1927) and Cheng (1944) have noted like occurrences in connection with similarly highly altered sediments in Scotland, though neither author has suggested any explanation.

A dark gray even- and fine-grained schist, found only within alaskite, occurs as isolated patches ranging from pods a few feet in diameter to bands about 100 feet wide and 250 feet long. It is composed of 50 percent or more quartz, 10 to 20 percent biotite, and varying amounts of feldspar, predominantly oligoclase (about An_{15}) or microcline.

Pegmatite veins containing books of muscovite and crystals of quartz and potash feldspar as large as two inches across occur in all of the metamorphic rocks on Frazier Mountain, but they are most common in the alaskite and light-colored gneiss. They are simple pegmatites, made up of the same minerals as the alaskite, and they intermingle transitionally with it. Alaskite stringers in the gneiss can be traced into pegmatitic patches that contain coarse crystals. Although their origin is uncertain, they probably are related to the alaskite of the metamorphic groups and/or the Mount Pinos granite.

Transition Rocks. In several places the contact between dark-colored augen gneiss and light-colored rocks is a band 10 to 30 feet wide of fine-grained dark grey thinly layered gneiss (e.g. E.56, IX.78 and E.20, IX.80). It is mineralogically similar to the biotite schist, but the biotite gneiss is not garnetiferous and usually contains only four or five percent biotite. Quartz composes over half the rock, and potash feldspar ranges from subordinate with respect to oligoclase to predominant. The plagioclase (about An_{15}) is present mainly as augen three to five millimeters long. Rounded rutile grains are a locally prominent accessory.

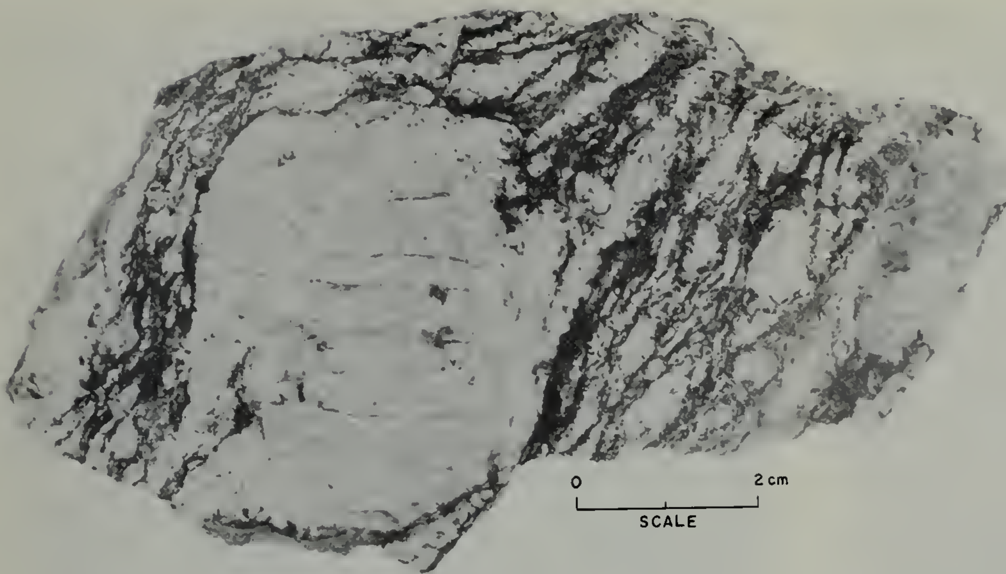
By increase in grain size, in biotite content, and the development of pinkish augen the rock passes transitionally into biotite augen gneiss, with which it is minutely interlayered. The contact with the light-colored rocks is more abrupt, although layers of the fine-grained gneiss up to two or three feet thick occur between light-colored layers. This may be due to injection by a mobile light-colored gneiss, or to original compositional variations of a sedimentary sequence. The rock is certainly transitional and has not been mapped separately.

The term migmatite is a catch-all used for gray banded rocks, mostly rather fine-grained, which are a mixture of the light-colored and dark-colored elements here described. Migmatites occur well within both light-colored and dark-colored units, but most are near the contacts and, according to whether they were light or dark, they have been mapped with either of the two groups.

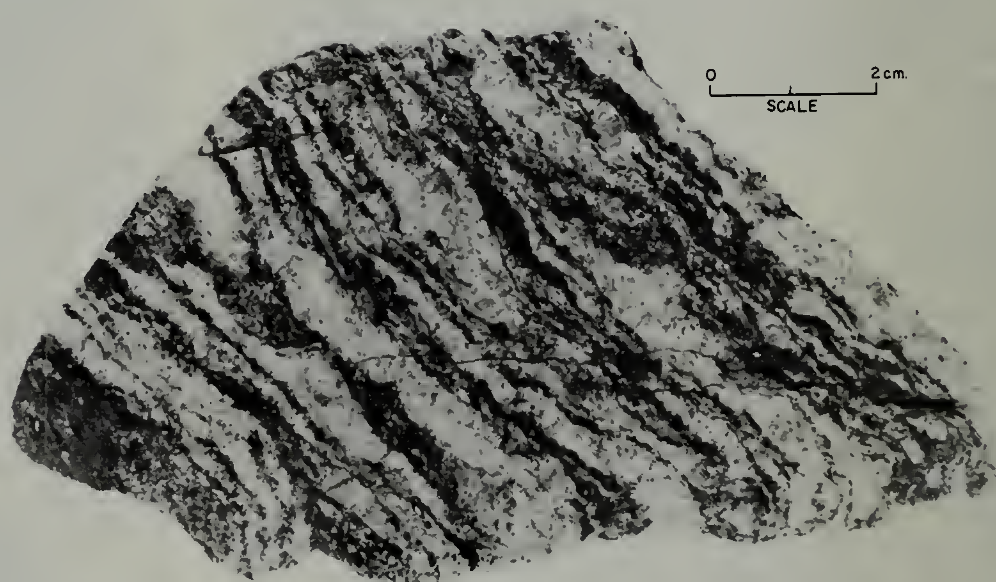
Dark-Colored Rocks. The southern half of the west side of Frazier Mountain consists chiefly of augen gneiss which contains feldspathic porphyroblasts and stringers in a schistose, biotite-rich, quartzo-feldspathic matrix. The rock is dark gray to almost black and contains from five to twenty-five percent of biotite mostly in mica-rich bands. Composition and structure are variable; but three types have been distinguished in thin section, although not separated in mapping.

In the most abundant variety black mica-rich bands are interlayered with coarse quartzo-feldspathic streaks, each layer ranging from a few millimeters to one or two centimeters in thickness. This rock contains the largest porphyroblasts, most of which are flesh-pink, composed of microcline or microperthite with inclusions of quartz, plagioclase, and biotite. Many porphyroblasts show carlsbad twinning. The streaks and smaller porphyroblasts contain both potash feldspar and plagioclase which ranges from oligoclase (about An_{15}), most common, to albite (An_{5-10}). Both plagioclases are sericitized, though the whole rock is not highly altered in this manner, and they both are replaced extensively by quartz and microcline. Garnet is rare in thin section.

A second variety of biotite augen gneiss is lighter gray, richer in quartz, and finer grained than the first except for occasional augen. Although the feldspar content of the two rocks is essentially the same, this more quartzose type is consistently garnetiferous and lacks the quartzo-feldspathic bands of the darker rock. This gneiss has five to ten percent biotite, and is only slightly more mica-rich than the darkest transitional quartzo-feld-



Phata 5 (left). Biotite augen gneiss, coarse phase, shawing develapment af large, nearly euhedral parphyrablast campased mastly of pink microcline. Biatite layers praject into parphyrablast, as well as curving araund it.



Phata 6 (right). Biatite augen gneiss, caarse phase, showing interlayering af quartza - feldspathic streaks and biotitic schistose layers.

Phato 7 (left). Biatite augen gneiss, fine-grained, quartzose phase, shawing banding (relic sedimentary feature?) and isalated, raunded "parphyrablasts" (relic pebbles?).

spathic biotite gneiss. The rocks are definitely gradational at one place at least (E.18, IX.83).

The third type of augen gneiss is distinctive from the other two only in that it contains no potash feldspar. It is composed chiefly of quartz, oligoclase (An_{10-15}), and biotite.

The augen common to these three varieties of gneiss deserve special mention. They vary in size and shape from tiny ovoid patches several millimeters long to ellipsoidal pods and well-shaped crystals as much as six centimeters long. The augen are commonly isolated in a fine dark matrix or are connected with quartzo-feldspathic stringers that permeate the rock. Biotite is concentrated in concordant rims about some augen where it almost surely has been pushed aside in the growth of the porphyroblasts. Biotite layers also project into many augen and are diverted and compressed about the ends of others. The evidence shows that most augen have formed by a combination of replacement processes and displacement of dark-colored layers as they grew, although in a few specimens rounded grains composed of aggregates of quartz and/or feldspar, outlined by biotite, have the appearance of granules in a gravel, and in some cases there is a suggestion that the augen represent pebbles in a metaconglomerate. The relations described above and shown in the figures convince the author that most of the augen are of metasomatic origin, a view most recently propounded by B. C. King (1950).

Gneisses of the Mount Pinos Area

Small areas of biotite augen gneiss and various light-colored gneisses like those of Frazier Mountain occur flanking Little Cuddy Creek (K.O. XIII.3; I.5, XIII.4). It is almost certain that they correlate with the rocks on Frazier Mountain in view of the similarity in types and the fact that augen gneiss is brought up along the Big Pine fault between Frazier Mountain and Mount Pinos. This conclusion is strengthened by a similarity between alaskite on the west end of Yellowjacket Ridge and the Mount Pinos Granite. Mount Pinos Granite definitely transects the metamorphic rocks, but it has a very complex and interlayered contact zone, the details of which are not clearly understood.

Origin of the Gneissic Rocks on Frazier Mountain and Mount Pinos

The occurrence of the quartzite, biotite schist, and garnet- and biotite-rich augen gneiss indicate that at least some of the gneissic rocks of Frazier Mountain were derived from sediments. The occurrence of rocks the composition and texture of which closely approximate those of igneous bodies, together with migmatites and coarsely porphyroblastic and layered gneisses, are signs of plutonic metamorphism.

A review of the literature concerning rocks similar to those under discussion reveals that the certain determination of their predecessors requires actually tracing them to their less altered equivalents in the field (Fenner, C. N., 1914; Goldschmidt, V. M., 1920; Sederholm, J. J., 1926; Read, H. H., 1927; Stark, J. T., 1935; Barth, T. F. W., 1936; Anderson, G. H., 1937; Turner, F. J., 1938; Cheng, Y., 1944). When this has been done there can be discussion of materials added to, or subtracted from the original rocks and processes by which changes have taken place. However, in the Lockwood Valley area the rocks cannot be traced into less metamorphosed equivalents, and contacts with plutonic masses are poorly exposed and have not been studied in detail. Of the papers cited above, the one in which the rocks described most closely resemble those on Frazier Mountain is that of Goldschmidt, who discusses the metamorphic terrain around Stavanger, Norway. The rocks discussed in most of these papers contain hornblende, which is notably lacking in the gneisses of Frazier Mountain; however, it is reported by Crowell (1947, p.16) and Schlee (1952, p.8) in associated rocks to the south. The gneisses around Stavanger are composed essentially of a light-colored trondhjemitic (that is, characterized by oligoclase) element together with mica-rich layers that contain potash-feldspar porphyroblasts. Several of the specimens from Frazier Mountain are devoid of potash feldspar, but can be called trondhjemitic; however, they are not connected with a dominantly trondhjemitic plutonic rock, but rather with granite and alaskite, the light-colored minerals of which reappear in the bulk of the gneisses. Goldschmidt's conclusion (1920, p.99) was that the augen gneisses of the Stavanger region were in large part "injection metamorphic derivatives of clay slates" rather than protoclastic intrusive rocks; being the result of intimate penetration of the slates by a trondhjemitic magma followed by potash metasomatism. Cheng (1944) agrees essentially, except that he believes the augen gneiss of the Bettyhill area, Scotland, is derived from semipelitic quartzo-feldspathic metasedimentary rocks by the action of potash-bearing fluids and envisions a very complex interplay of potash-bearing versus soda- and lime-bearing solutions.

The similarity between these established sequences in Norway and Scotland and the gneisses and allied rocks of Frazier Mountain gives grounds for the assumption that the predecessors of the Frazier Mtn. rocks were either pelitic or semipelitic sediments. The prominence of essentially quartzo-feldspathic gneiss also suggests that at least part of the rocks are derived from an arkosic psammitic sequence, although such light-colored phases might just as well be of igneous origin.

The following outline, based on the assumed presence of either pelitic sediments or semipelitic and partly arkosic psammitic sediments, gives two alternatives for the origin of the Frazier Mountain rock:

- A. Altered by igneous invasion
  - 1. Injection
  - 2. Metasomatism
- B. Anatexis
  - 1. Addition of at least SiO_2 and K_2O from some exterior source
    - a. Necessary for pelitic rocks
    - b. Possible, but not necessary for semipelitic and arkosic rocks
  - 2. Re-solution, partial melting, and metamorphic differentiation of light-colored phases already in the rock

On the assumption of alteration by igneous invasion only, the rocks have been thoroughly transfused and injected by magmatic material to give them their essentially homogenous light-colored mesostasis. Evidence for injection appears in the transcurrent relations shown by alaskite (fig. 2). Stringers from such cross-cutting veins extend parallel to the foliation of the rock and might be interpreted as lit-par-lit injection. However, the occurrence of porphyroblasts in those stringers and of identical isolated quartzo-feldspathic patches and porphyroblasts in the biotite augen gneiss attest to concomitant diffusion and metasomatism.

On the assumption of anatexis only, which involves re-solution, partial melting, and metamorphic differentiation of the light-colored phases already in the rocks, it is necessary that at least silica and potash be added to the pelitic rocks to account for the large amounts of essentially quartz-feldspar rocks. Such material would presumably come from an exterior source in which anatexis had also occurred and the light-colored phases were made mobile and driven out. Original semipelitic and arkosic rocks could contain sufficient quartzo-feldspathic material so that the only requirement is that they be made mobile, in order to transfuse the solid phases and aggregate the material into porphyroblasts, clots, stringers, and alaskitic masses.

Evidence for anatexis appears in the gradational relations between transecting veins and stringers of alaskite, and the layered gneisses and schist in which all light-colored parts have essentially the same composition and textures. An especially revealing case is that of the development of an alaskitic patch in a flexure in light-colored gneiss, as discussed in the description of alaskite (fig. 2).

Anatexis and igneous invasion have been discussed as separate processes for the sake of simplicity. However, the evidence cited above and the occurrence of granitic bodies in association with the gneissic rocks suggest that both processes have had a part in the origin of the gneissic rocks. Barth (1936, pp. 834-844) would call these syntectic rocks, and he points out the importance in their formation of such processes as: (a) "stewing in magmatic juices", including some injection, (b) anatexis, thought of as "selective re-solution" of certain constituents, and (c) metasomatism, considered to be a volume-for-volume or atom-for-atom replacement in the minerals. This is essentially a summing up of the concepts of Goldschmidt, Sederholm, and Eskola (1933).

On the assumption then, that the original sediments may have ranged from pelitic to arkosic-psammitic and quartzitic, the following is a statement of how the sediments may have developed to their present state:

The sediments were subjected to deep burial and deformation, and were dynamothermally metamorphosed to quartzite, granulite, mica-schist and garnetiferous mica-schist. Permeation of these rocks by magmatic silicate fluids, perhaps contemporaneous with the emplacement of the older Mount Pinos plutonic masses or perhaps much earlier, caused differential melting or re-solution of light-colored parts of schists and granulites. The fluid tended to accumulate into fairly large bodies in the more quartzo-feldspathic rocks, while in the more schistose rocks it formed stringers, layers, and clots. At a still-later stage the whole mass was permeated by silica- and potash-bearing solutions, perhaps related to the emplacement or formation of the Mount Pinos Granite. Large porphyroblasts formed in the dark-layered schistose rocks, while the light ones were generally more evenly pervaded, and replacement of plagioclase by quartz and potash-feldspar was extensive. Much later cataclasis was either coupled with, or prepared the way for, strong sericitization along crushed zones and less severe alteration throughout the rocks.

Age and Correlation

The gneisses of Frazier Mountain have not been dated. Like those northeast of the San Andreas, they are pre-Eocene and older than the plutonic masses, which may be correlative with Late Jurassic to Early Cretaceous Sierra Nevadan intrusives. In such a case, the sediments involved would be early Mesozoic or older, and great age seems more likely in view of the complex metamorphic history of the rocks.

Gneiss and alaskite extend eastward across Frazier Mountain, southward into the Piru Mountains, and continue some 20 miles southeastward along the west side of the San Gabriel fault. A similar, perhaps identical, complex is exposed in Mint Canyon, 35 miles to the southeast and east of the San Gabriel fault. These crystalline terranes are probably correlative.

PLUTONIC ROCKS

Northeast of the San Andreas Fault

A medium-gray biotite-quartz monzonite intrudes the metasediments north of the fault. The rock weathers to dark gray-brown granulose regolith, which is thick on flat ridgetops, but is rapidly removed from steeper slopes where reasonably fresh exposures occur.

The monzonite is a medium-grained, hypautomorphic granular rock composed of about 40 percent oligoclase, (An_{20}); 40 percent potash feldspar, a few grains of which show quadrille structure; 10 to 15 percent quartz; and about five percent fine-grained dark red-brown biotite gathered into clots and elongated patches three or four millimeters across. It contains accessory apatite, magnetite, zircon and sphene, mostly associated with biotite. The plagioclase is subhedral, but the rest of the minerals are complexly intergrown and show little development of crystal faces. The quartz has extreme undulatory extinction, and many of the grains display distinct mosaic texture. Oligoclase is partially decomposed to kaolinite and sericite, and biotite contains wisps of penninite, but the rock has undergone only slight alteration.

The rock is probably the same as the "finer-grained gray phase" of Crowell's quartz monzonite (1947, pp. 43-44), which is extensively exposed across the east end of Tecuya Ridge (fig. 1), and which Crowell tentatively relates to the Sierra Nevadan intrusives.

Southwest of the San Andreas Fault

Plutonic rocks form a complex mixture southwest of the fault, but only two phases are distinguishable in the mapped area. Predominating is a light-colored biotite granite, called the Mount Pinos Granite, which makes up most of the southeast slope of Mount Pinos, underlies the western part of Yellowjacket Ridge, and extends southward at least as far as Mutau Flat. The other rock, not separated from the granite in mapping, is a hornblende-biotite-quartz diorite, which makes up a large part of Mount Pinos and is intermixed with the granite along the north central border of the map (pl. 1).

Highlands of these rocks possess steep flanks, but within the highlands hills and ridges are rounded and the drainage patterns are coarse and simple compared to those in sedimentary terranes (pl. 1). Except where erosion is most active, weathering gives rise to even-grained arkosic gravel which, on gentle slopes, is several inches to a foot or more deep. Through this gravel protrude only isolated patches, monoliths, and boulder piles of bedrock.

Mount Pinos Granite

This unit is variable, ranging from alaskite, through biotite granite, to biotite-quartz diorite. Texturally and structurally it includes fine-grained aplitic, medium-and even-grained, coarsely porphyritic, and banded gneissic phases, the mutual relations of which have not been worked out.

The most abundant type is a pinkish-gray rock with mostly coarse hypautomorphic granular texture, the grain size of which ranges from two to seven millimeters, but with porphyritic parts containing potash feldspar crystals as much as two centimeters long. Euhedral to subhedral unzoned grains of plagioclase (An_{10-15}) are set in a matrix of coarse subhedral to anhedral microline microperthite, microcline, and quartz. Quartz also occurs as tiny grains in veinlets ramifying through the rock, along cracks, between grains, and bordering inclusions in many crystals. Dark greenish-brown biotite is the major characterizing accessory mineral, and small amounts of muscovite, sphene, magnetite, and allanite occur in most thin sections. Tabulation of the composition of a typical specimen of alaskitic biotite granite, estimated from thin section, gives:

Mineral	*Percent*	*Comments*
Microcline microperthite	45	Microcline:Albite-4:1 a trace of antiperthite
Microcline	5	
Plagioclase	15	An_{10-15}
Quartz	35	
Biotite	1	Dark greenish-brown
Muscovite	tr.	
Magnetite?	tr.	

In some specimens biotite increases to three or four percent, and in these sphene is common. Feldspars are dusted with clay minerals, biotite is slightly altered to penninite, and much of the sphene is largely altered to leucoxene. Quartz is characteristically smoky gray megascopically, and commonly shows extremely sutured boundaries and replacement relations with feldspars in thin section. Sparse myrmekitic intergrowths occur as tiny patches between feldspar grains. In gneissose phases, biotite grains display parallel alignment and are mostly concentrated in bands a few centimeters wide or in streaks composed of a few grains.

Four subvarieties of Mount Pinos Granite have been recognized, with virtually identical textural and structural relations to those described above, but which have consistent variations in compositions. The first variety is distinctive in that quartz predominates slightly over either of the feldspars and there is little perthite, the potash feldspar being almost entirely microcline. A second variety is the dominantly alaskitic rock which makes up the west end of Yellowjacket Ridge. It is quartz-rich, has a microcline-perthite to soda-rich oligoclase ratio of two to one, and contains traces of biotite and clear microcline. The other two varieties occur on the eastern slope of Mount Pinos. One is a biotite granite with about five percent greenish-brown biotite, a mixture of microcline and microcline-perthite, and more calcic oligoclase (An_{25-30}) than is common in the normal granite. The other is a trondhjemite in which subhedral calcic oligoclase (about An_{30}) composes 60 to 65 percent of the rock. In this rock, quartz amounts to only 20 or 25 percent, and potash feldspar is about 10 percent and definitely interstitial. The rock is relatively biotite rich (5 percent) in the dark greenish-brown variety typical of these rocks.

Irregular patches of hornblende gabbro occur at one locality in the Mount Pinos Granite (I.50, XIII.77). Its relation to the granite is not known, although it is intimately interlaced by alaskite stringers, and in some places the hornblende crystals are set in a matrix of alaskite. These features suggest digestion of gabbro by lighter-colored material.

Relations between Mount Pinos Granite and the metamorphic rocks that border Little Cuddy Creek are not clear. The granite has a notable aplitic border where the contact is seen (L.00, XIII.10 to J.82, XIII.35; and I.80, XIII.28 to I.46, XIII.50). Along this contact an alaskitic phase is mingled with very biotite-rich layers in migmatite. Patches of mixed-rock and of augen gneiss lie in the granite, but no sharp cross-cutting boundaries were observed.

The alaskite of the Frazier Mountain rocks and that of the Mount Pinos Granite are mineralogically similar. However, slight textural differences, presence of garnet in the Frazier Mountain rock, and spatial separation in the area mapped preclude anything more than the speculation that they have had the same origin.

Hornblende-Biotite-Quartz Diorite

Hornblende-biotite-quartz diorite makes up much of Mount Pinos north of the mapped area and is cut by granite on the southeastern slopes of the mountain.

Near the top of Mount Pinos the quartz diorite is a dark gray, crudely foliated, very coarse-grained, hypautomorphic granular rock, composed of about 60 percent andesine (An_{40-50}), 20 percent quartz, five percent interstitial orthoclase, seven percent dark greenish-brown biotite, and seven percent hornblende. The hornblende is poikilitic, pleochroic dark green to brownish-green, and is platy and somewhat stubby in habit. Apatite and sphene make up the accessory minerals and a little pale green biotite replaces hornblende. Light-colored bands and fine- to medium-grained bands give the rock a gneissic aspect in many places. In such places the hornblende is concentrated in bands and elongate clusters about an inch thick and several inches long.

On the eastern slopes of the mountain the rock is dark gray, fine- to medium-grained, and displays faint planar structure caused by alignment of biotite and hornblende. Quartz and feldspar occur as roughly equant and discrete grains set in a matrix of tiny crystals of the same materials along with numerous patches of myrmekite. This intergrowth of albite and quartz occurs between, and in, all of the light-colored elements of the rock. Biotite and hornblende occur as irregular grains having an interstitial appearance relative to quartz and feldspar. The total textural microstructural aspect is crystalloblastic, but compositionally the rock is quartz diorite (see table, p. 20).

The correlation of this rock with the other quartz diorite near the top of Mount Pinos is not certain, and insufficient work has been done to ascertain its relation to the granite. It may be more closely related to a mass of banded-diorite rocks just beyond the boundary of the map.

Composition of hornblende-biotite-quartz diorite

Minerals	*Percent*	*Comments*
Quartz	30–35	Strong undulatory extinction and sutured boundaries.
Plagioclase	35–40	An_{30-35}
K-Feldspar	12–17	Mostly orthoclase
Myrmekite	1–2	Intergranular and replacing light-colored minerals.
Biotite	5	Dark greenish-brown, interstitial and intergrown into light-colored minerals.
Hornblende	5	Pleochroism: X = yellow, Y = dark olive-green, Z = dark blue-green. Same textural relations as biotite.
Sphene	1–2	
Magnetite	1–2	
Epidote	trace	

Although petrogenesis has not been discussed, the above descriptions serve to distinguish the plutonic rocks and to show that the history is not one of simple intrusion of a granitic magma. The rocks probably represent a typical plutonic association, some rocks of which are intrusive and some of which may be metamorphic in origin.

There is no clue as to the age of the rocks, except that the whole assemblage is pre-Eocene.

HYPABYSSAL ROCKS

Here are grouped three rock types of the basement complex which do not fit temporally or lithologically with any of the other groups.

Lamprophyres

The lamprophyres are dark fine-grained rocks, mostly green, which are found in the augen gneiss of Frazier Mountain. At the Baggett mine a lamprophyre definitely transgresses gneiss (fig. 3), but at most outcrops relations are obscured by poor exposures.

One dike, on the hill due east of the Jewel mine, (D.15, X.45), is a kersantite, composed of 95 percent subhedral labradorite crystals (about An_{55}) and about five percent of evenly scattered dark greenish-brown biotite flakes. Sphene which is present as irregular grains and aggregates, calcite, iron oxide, and epidote are very minor constituents. Another rock, found in several areas low on the western slope of Frazier Mountain, may be either lamprophyre or amphibolite. The rock consists of small euhedral brownish-green hornblende crystals set in a matrix of labradorite (about An_{50}) granules. It shows a faint planar structure due to parallel alignment of the two or three percent of biotite it contains.

The age of these rocks is unknown, but some are younger than the augen gneiss and may be complimentary intrusives associated with the plutonic rocks of Mount Pinos. Those having amphibolitic qualities may represent altered basic rocks (tuffs or flows) associated with the parent rocks of the gneiss.

Diabase

Diabase, found at two localities, (D.32, VI.78 and D.30, X.08), is medium-grained with labradorite laths (An_{55-60}) predominating over interstitial ferro-magnesian grains. The rock is highly altered with plagioclase laced by epidote veinlets, and mafic minerals completely converted to fibrous blue-green hornblende. The age of the diabase is unknown since it occurs only in the basement complex and seems to be transgressive. It might be related to the basalt flows of the Plush Ranch Formation, but the state of alteration suggests that it is older.

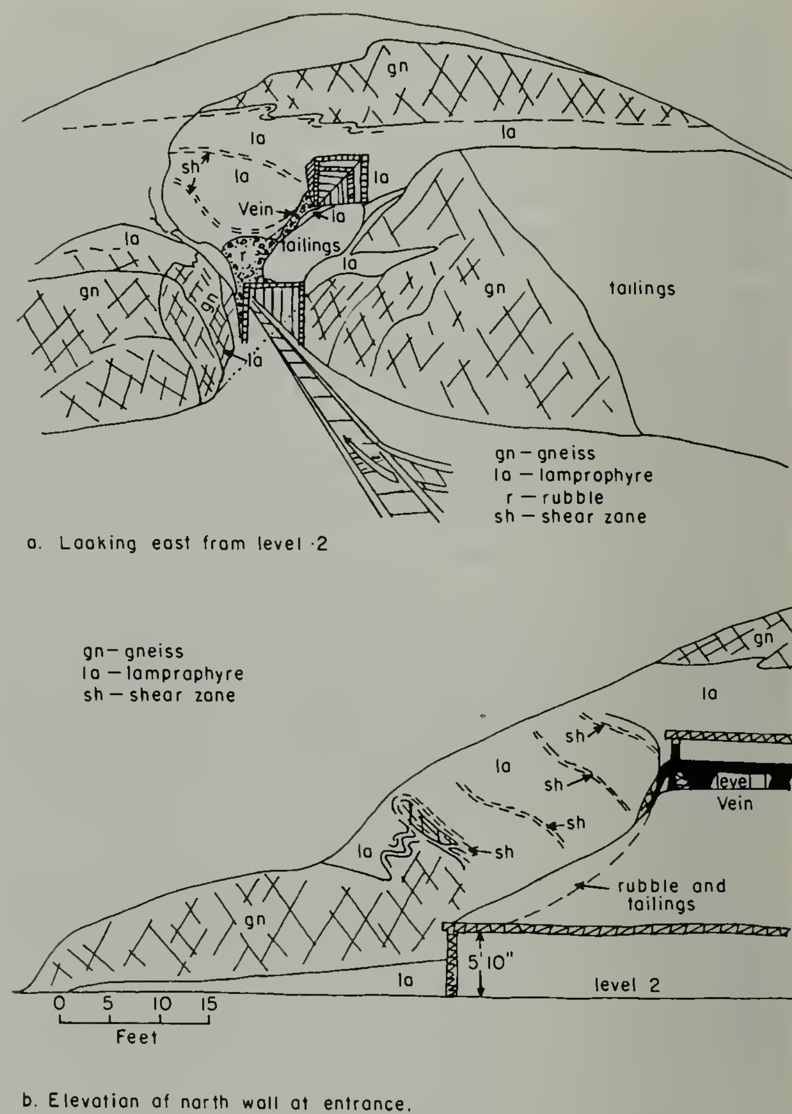


Figure 3. Baggett mine, Frazier Mountain.

Quartz Veins

Quartz veins, composed of chalk-white to grey, locally gossan-rich, massive quartz, are found mostly in shear zones and are most abundant where lamprophyric rocks occur. The mafic rocks associated with the veins are characteristically hydrothermally altered; for example, lamprophyre is changed to chlorite schist. The age of these veins cannot be determined with the evidence at hand. They may slightly postdate the activity which gave rise to the various plutonic and lamprophyric rocks, or they may be much younger.

Sedimentary and Associated Volcanic Rocks

Sedimentary units of the Lockwood Valley region range in age from early Eocene to Recent, although for the most part fossils are lacking and the rocks are poorly dated. Eocene beds are rather homogeneous throughout the area, displaying characters typical of beds of similar age widely distributed to the southwest. In Lockwood

Valley these rocks have not been designated as a formation because they occur only as partial sections in fault contact with other rocks. Future work to the southwest should establish satisfactory formations with which the Lockwood Valley rocks can be correlated. In the post-Eocene group of Tertiary rocks four formations are distinguishable. Although there are striking lateral variations in color and lithology, these are not so extreme as to preclude recognition of distinct horizons, and correlation of units exposed across a distance of some twenty miles is possible.

Quaternary rocks are divided into two units, each with distinctive lithology and subdivided geomorphically by successive terrace surfaces.

TERTIARY ROCKS

Eocene Rocks

Exposures on the South Flank of Mount Pinos. Marine Eocene sediments are exposed in a narrow east-trending fault wedge which crosses the North and Middle Forks of Lockwood Creek and Amargosa (Bitter) Creek, and which is cut out in Big Spring Valley (pl. 1). The fault wedge underlies the northern portion of a broad, gently south-sloping tread that descends from the Mount Pinos fault toward Lockwood Valley. The surface of this step is nearly flat, covered by terrace deposits, and cut on a thick sequence of Tertiary sedimentary rocks. The creeks mentioned above, in the process of dissecting the tread, are entrenched about 250 feet, giving fine exposures of underlying rocks. Here are seen at least 2,200 feet of steeply dipping marine shale, limestone, and sandstone (pl. 2, sec. 1). Sheer barren walls of shale, the dominant rock-type, are deeply etched into sharp ridges with crests that plunge abruptly into valleys; whereas sandstone beds stand out in resistant ledges or form the backbones of prominent ridges.

A small patch of shale, about 100 feet thick and north of the Mount Pinos fault (S.37, IX.65), may be the basal part of the Eocene section resting unconformably on granite. The contact with granite is not well exposed; nevertheless, the map pattern shows that it dips relatively gently to the south (pl. 2, sec. 1). Because shale south of the Mount Pinos fault dips steeply and is approximately parallel to the fault, it is not likely that the contact in question is a segment of the Mount Pinos fault.

Over 90 percent of the Eocene rocks consist of dark gray, calcareous, moderately fissile shale. Locally shale grades into limestone, massive mudstone, or sandstone layers that range from several inches to two feet in thickness. Colors include black, light gray, light brown, and tan, but weathering spreads an even buff hue over most of these rocks. The shale is ramified by fractures that are limonitized in some horizons and filled with gypsum in others.

Coarser phases show a range from sandy siltstone to small-pebble conglomerate in scattered beds and lenses which make up about five percent of the Mount Pinos Eocene rocks. Fine-grained, massive to moderately laminated sandstone beds are distributed evenly through the shale and are invariably buff or very light brown, weathering cream or pale yellow. The coarsest elements are limited to a few horizons near the base and the top of the exposed section. These rocks are poorly bedded, show almost no sorting, and range in color from dark brown, through medium brown, to light gray. They weather to dark brown and locally yellow. In composition the fine and coarse phases are similar, being feldspathic sandstone and arkose, and containing a small percentage of chlorite, muscovite, biotite, iron ore, and miscellaneous detrital fragments. In line with the arkosic composition, the grains are mostly angular to subangular with only a slight tendency for rounding in the finer beds. Thin sections show that about 25 percent of the grains are feldspar, with plagioclase and microcline predominant, and with orthoclase and perthite common. Most of these grains are rather fresh, though perhaps 20 percent show considerable sericitization, saussuritization, and/or kaolinization. These are all well-indurated rocks, cemented chiefly by calcite, with limonite occasionally abundant in yellower phases, especially in the pebble conglomerate. Conglomeratic layers contain about five percent of clasts, which range from granules to pebbles one and a half inches in diameter. Most common are subangular pebbles of fine- to medium-grained light-colored granitic rock and granules of red-brown chert. With these rocks are slabby, well-rounded fragments of gray mudstone, yellowish-cream siltstone, and yellow to brown silty limestone, which have a lithology similar to the more shaly portions of the unit. The clasts are mostly scattered evenly through the conglomerate, though pebble-rich lenses occur.

The limestones are dense, black, weather to pale buff or cream, and occur in massive beds ranging from a few inches to a foot thick. The pure limestones compose only a few percent of the total section; however, much of the calcareous shale grades into limestone in layers too thin to be noticed. Some shale beds contain numerous rounded nodules of dark gray limestone, which range in size from one half inch to four inches, and which have wood fragments in their cores.

Exposures South of San Guillermo Fault. In the southwest corner of the map, Eocene beds are in contact with younger Tertiary rocks along the San Guillermo fault. These beds differ from those just discussed only in being a little more sandy and in presenting more brightly colored weathered surfaces, with orange, yellow, and brown being prominent. Fossils were not found in them.

Exposures on San Guillermo Creek. A small patch of conglomerate and shale in the extreme southern part of the map is also designated as Eocene. This section is faulted against granitic rocks on the northeast and is overlapped unconformably on the northwest by late Tertiary beds. These Eocene rocks are also much like those in North Fork but some cobble conglomerate is present. The conglomerate has a medium- to fine-grained, feldspathic sandy matrix and contains very well-rounded clasts of pebble and small cobble size. All clasts are surfically stained deep rust-brown which is typical of Eocene conglomerates widely exposed south of the mapped area. The cobbles are composed chiefly of pink, purple, and green volcanic rocks that show a variety of textures and structures: some are aphanitic; some porphyritic; and some are flow-banded. Their composition ranges from rhyolite to andesite. Subordinate to volcanics are gray-brown quartzite and various granitics. The shale differs from that on Mount Pinos in displaying brighter weathered colors and also in containing some olive-green layers.

Age and Correlation. A few fossil remains, mostly fragments of thick-shelled mollusks, are found in the coarsest beds occurring on Mount Pinos. Here the presence of *Turritella andersoni* (Loc. 1, S.30, IX.41) suggests an early Eocene age ("Capay" Stage). The section on San Guillermo Creek is undated, whereas the beds in the southwest corner were dated broadly as Cretaceous and Eocene by Gazin (1930a, p. 8). However, similar rocks 10 miles to the south at Mutau Flat include the "Domengine," "Capay," and "Meganos" Stages (Schlee, 1952), indicating an age that ranges from middle Eocene to late Paleocene. It is probable that the rocks considered by Gazin to be of possible Cretaceous age would now be placed in the Paleocene. Gazin's report of *Turritella uvasana* from Beartrap Creek, 7 miles southwest of San Guillermo Mountain, suggests that little-known Eocene rocks extending south and southwest from the San Guillermo fault include beds as young as "Tejon" Stage *, or younger. Gazin (1930, p. 9) reports at least 15,000 feet of sediments just south of the San Guillermo fault, and Schlee (1952, p. 44) 10,000 feet in the Mutau Flat region.

Schlee, (1952, p. 48) has mapped the base of this marine sequence, in which early Eocene (Meganos) rocks rest conformably on a thin basal sandstone which in turn lies on granitic basement. There is some confusion in his dating in this area, for he reports *Turritella andersoni* (Capay) and *Turritella maganosensis* (Meganos) from the same locality (Schlee, 1952, pp. 71-72, pl. 18 and pl. 19, sec.cc'). Nevertheless, it is clear that the base of his section is near early Eocene age. By analogy, it is possible that the North Fork rocks of the "Capay" Stage are near the base of the section.

Origin. The lithology of the coarser layers of these rocks indicates a probable neritic environment, whereas the shale and limestone point to at least quiet, if not deep, water. Presumably deposition of the coarser phases in deep water would be accomplished by turbidity currents or submarine slumping (Ericson, et al.; 1952; Kuenen, 1950, pp. 240 and 360). Either process should leave evidence, such as graded bedding in the case of turbidity currents, and slump structures in that of slumping. Inasmuch as none of these features was noted in the beds examined, a shallow-water, near-shore environment is considered more likely. Also, Schlee (1952, p. 70) presents a faunal assemblage, from beds of age similar to those discussed here, that suggests warm water, 100 fathoms or less deep.

The proximity of the Eocene shoreline to this area is uncertain, though Reed and Hollister (1936, fig. 11) show the region as lying in the path of transgressing lower Eocene seas, and near the border of the middle Eocene "lower Llajas" sea. Corey (1954, fig. 2) also shows the area near the edges of his Paleocene and Eocene seas. However, there is the possibility of large lateral movements on the San Andreas and San Gabriel faults (Hill and Dibblee, 1953; Crowell, 1952b), both of which separate the Mount Pinos rocks from littoral phases of Paleocene and Eocene beds. Thus, the position of Eocene shorelines relative to the Mount Pinos rocks cannot be ascertained until we have a more adequate picture of movements on these faults.

* However, Gazin does not state that the form is *Turritella uvasana* ss, which is the one marking the "Tejon" Stage.

Oligocene?-Miocene? Rocks

Plush Ranch Formation

Between the Big Pine fault and the band of Eocene rocks on North Fork, are at least 6,000 feet of rocks of extremely varied lithology. Here and in the creeks to the east the beds consist of apparently continental and broadly conformable conglomerate, fanglomerate, arkosic sandstone, shale, clay, and limestone with interbedded olivine basalt and light-colored tuff.

Gazin (1930a, unpublished) named the upper portion of this section the "North Fork Member" of his "Monterey Group" and designated the basalt as the base of the "Monterey Group". However, beds immediately above and below the basalt are not only identical and occur interbedded with basalt flows, but they pass conformably into overlying and underlying rocks (pl. 2, secs. 1, 2, 3). Thus there is lithologic, stratigraphic, and structural continuity between all beds included in the section. For these reasons this group of rocks is designated as the Plush Ranch Formation, with the type locality in North Fork of Lockwood Creek, north of Plush Ranch (T. 8 N., R. 21 W, Sec. 30 to T. 8 N., R. 22 W., Sec. 24, SW.¼, Mt. Pinos Quadrangle, 1903).

Although the Plush Ranch Formation is in fault contact with Eocene or older rocks everywhere within the area mapped, the presence of Eocene sandstone cobbles (table 1) indicates unconformability with Eocene beds and partial derivation by erosion from those beds. Further, a breccia phase in the lowest part of the section (table 1) shows that some layers also formed from locally exposed crystalline basement rocks.

The formation is divided into six lithologically distinct sedimentary members, broadly superimposed in the vertical stratigraphic sense, but displaying marked interfingering between different members. Member four-a, for example, is stratigraphically equivalent to members two, three, and probably part of member four.

For the sake of brevity detailed lithology of the members of this formation is summarized in tabular form (table 1). The arrangement is by rock types from coarse to fine and bears no necessary relation to stratigraphic position within a member. The columnar section shows the general distribution of rock types within each unit (pl. 5). In the description of rocks of this and following formations, the terminology for stratification and cross-stratification proposed by McKee and Weir (1953) has been used. The reader is especially referred to table 2 of that publication.

Distribution and Topographic Expression. The Plush Ranch Formation extends beyond the area to the west (T.00, VI.20 to VIII.43), whereas eastward it is cut out between the Big Spring, Big Pine, and Mount Pinos faults just north of Cuddy Ranch (pl. 4). The formation is in a fault wedge south of the San Andreas fault at the easternmost extremity of the map. The formation is always in fault contact with basement rocks and younger Tertiary beds within the mapped area; however, west of the area, in Dry Canyon, it is unconformable with overlying Caliente beds (Adams, 1956).

Table 1. Rock description, Plush Ranch Formation.

Member	Rock type	Colors	Composition	1. Degree of induration 2. Bonding agent	Textures	Bedding and structures	Remarks
Five	Feldspathic biotitic sandstone	Gray (see member 4 feldspathic sandstone)	See member 4 feldspathic sandstone. Slightly more biotitic than member 4 (3-5% biotite).	Hard (see member 4)	See member 4 feldspathic sandstone	See member 4 feldspathic sandstone	
	Arkose	Yellow, orange (see member 4 arkose)	See member 4 arkose	Soft (see member 4 arkose)	See member 4 arkose	See member 4 arkose	1. Contains brown and greenish-gray shaly horizons; at one locality passes upward into thin-bedded limestone and is lithologically like member 4, but stratigraphically well above it (Q.35, VIII.25). 2. Arkose and shale particularly developed on hills north and northwest of Plush Ranch (Q.00, VII.95 and R.00, VII.90). Pinch out westward across North Fork.
	Breccia	Medium to light gray, locally gray-green, brown, and nearly black.	1. Clasts and matrix of same derivation. 2. Clasts are of 2 types: a. Medium-grained, light colored biotite quartz monzonite. b. Black augen gneiss, Frazier Mtn. types. 3. Clasts are mixed in various proportions in different beds, with black zones almost entirely of augen gneiss interbedded with layers dominantly of quartz monzonite. Most frequent are mixtures in which monzonite predominates. 4. Matrix can be termed a feldspathic graywacke.	1. Hard 2. Argillaceous, micaceous, and locally calcareous.	Almost no sorting within separate breccia layers. Mostly angular clasts, a few subrounded, pebble to boulder size (2-3 feet in diameter). Many beds contain 80-90% fragments over pebble-size.	Massive beds and lenses few inches to 100 or more feet thick, with interlayered sandy streaks.	1. Compositional, textural, and strucural features all attest to fanglomeratic origin. Probably mostly mud flows. 2. Local dark red-brown shale streaks suggest ponding on a large, complex, alluvial fan.
Four	Tuff and basalt						Described in text.
	Gypsum	White to pale cream			Fine-grained and dense to coarsely fibrous	Thin-bedded in shale and limestone	Most abundant near eastern margin of area in Cuddy Canyon (B.50, XV.30).
	Limestone	Pale buff, locally black to blue-gray and pale greenish-gray to white.	Calcite, partially argillaceous and silty.	Hard	Mostly fine-grained and dense.	Thin-bedded slabby, locally travertinous, contains limestone breccia layers.	Contains the borates, colemanite and howlite.

Table 1. Rock description, Plush Ranch Formation—Continued.

Member	Rock type	Colors	Composition	1. Degree of induration 2. Bonding agent	Textures	Bedding and structures	Remarks
Four (cont.)	Shale	Dark greenish brown, green, and gray.	Clay, locally silty, calcareous, and gypsiferous.	Moderately indurated to hard.		Thin-bedded, fissile, locally contains limestone nodules, and small limestone and gypsum lenses. Minor contortions locally abundant, possibly due to expansion of anhydrite on hydration to gypsum.	1. Grades transitionally into mudstones, siltstones, limestones, and layers of gypsum. 2. Sections devoid of sandstone are seldom over a few feet and never more than a few tens of feet thick. 3. Limy nodules contain fish, insect, and plant remains suggesting fresh water. Ostracods also suggest fresh water environment.
	Feldspathic sandstone	Light to medium gray, greenish gray or brown where associated with basalt or limestone. Weathers gray, brown, and light yellow.	Quartz, various feldspars, fresh biotite (2-3%).	1. Hard. 2. Calcareous and argillaceous.	Fine- to coarse-grained, moderately well-sorted, mostly angular to subangular, locally subrounded grains.	Well-bedded from laminated to thin-bedded, slabby. Structures include cross-stratification, ripple marks, graded beds, slump structures and intraformational folding, scour and fill (esp. R.30, VIII .13).	1. Similar to hard slabby sandstone near bottom of member 3. 2. Occurs throughout the member and interbedded with basalt. 3. Passes transitionally upward and laterally into member 5 on North Fork (R.90, VII.76 and R.30, VIII.00).
	Arkose	Buff, light yellow, light gray. Weather yellow and orange. Medium to dark brown where interbedded with basalt.	Quartz, various feldspars, mostly nonmicaceous though biotite is prominent very locally (1-2%).	1. Moderately indurated to soft. 2. Argillaceous and calcareous.	Medium- to coarse-grained, poorly to well-sorted, angular to subangular grains.	Mostly massive, locally thin-bedded.	1. Mostly associated with basalt, especially on Middle Fork near Big Pine fault. 2. Differences from feldspathic sandstone of this member suggest separate sources for arkose and sandstone, though some mixing of materials is shown by transitional rocks.
	Conglomerate	Medium to dark gray.	Matrix composed of quartz, various feldspars, biotite grains. Pebbles and cobbles are dark metavolcanics, nondescript metamorphics, and granitics. None can be readily related to known local basement rocks, nor are they like the clasts from other members.	1. Hard. 2. Argillaceous and micaceous and locally calcareous cements.	Pebbles and cobbles mostly subrounded, poorly sorted.	Conglomerate in layers and lenses from few inches to ten feet thick; interbedded with coarse massive arkosic sandstone rich in dark metavolcanic (?) fragments.	Found only south of Big Pine fault near eastern margin of area (B.90, XV.04) where conglomeratic zone 50 feet thick forms vertical hogback.
	Breccia	See member 5.	See member 5.	See member 5.	See member 5.	See member 5.	Localized lenses of breccia up to a foot thick, and identical to that of member 5, occur in the sandy phases of member 4 where it interfingers with member 5 (pl. 2, secs. 1, 2, and 3).

Table 1. Rock description, Plush Ranch Formation—Continued.

Member	Rock type	Colors	Composition	1. Degree of induration 2. Bonding agent	Textures	Bedding and structures	Remarks
Four-a	Limestone and marl	See member 2.		Limestone hard, marl soft.		See member 2.	1. Limestones are more abundant and marl is more widely distributed through this member than in members 2 and 3.
	Clay, shale, and silt	See member 3.	See member 3.	Poorly indurated.		See member 3.	Concentrated in middle of member.
	Arkosic sandstone	See member 3. Light brown and buff dominate.	See member 3.	1. Hard. 2. Calcareous showing luster mottling, locally siliceous.	See member 3. Some coarse-grained layers.	See member 3.	See member 3, notes 1, 2, 3.
Three	Limestone	Tan, weathers white or locally brown		Hard.		Thin-bedded, slabby, layers a few feet thick.	1. Occurs just above and below the lower breccia zone. 2. Some slabs contain tubular calcareous remains, charophytes (?) and ostracods.
	Clay, marl, shale, and fine siltstone	Gray, gray-green, tan.	Quartz, clay, calcite.	Poorly indurated.		Thin-bedded, intercalated with arkose and some sandstone.	1. Mostly in middle portion of member. 2. Gypsum veinlets ramify portions of section with these layers.
	Arkose	Light gray to buff, yellow and cream to orange and reddish-orange in upper half.	Quartz, various feldspars, traces of micas.	1. Moderately well to poorly indurated. 2. Calcareous and argillaceous.	Silty to coarse-grained, poorly to well-sorted.	Laminated to thick-bedded. Current bedding, cross stratification, flow casts, graded bedding, cut and fill, and current lineation.	1. Occurs throughout the member. 2. Similar to arkose of member 2, though less feldspathic.
	Arkosic sandstone	Pale brown, light gray, greenish gray.	Quartz, various feldspars, biotite and muscovite (1 to 2%), chlorite.	1. Hard. 2. Calcareous.	Fine- to medium-sized, mostly subangular to subrounded grains. Sorting mostly good.	Thin-bedded to laminated, slabby.	1. Notably micaceous. 2. Shows more erosive working than most rocks of Lockwood Valley area. 3. Concentrated in lower third of the member.
	Breccia	Upper zone mostly light gray; lower zone mostly red, locally gray or orange.	Upper zone: Blocks and fragments of Mt. Pinos granite, and dark grey to black augen gneiss of Frazier Mtn. types. Granite predominates. Lower zone: Blocks and fragments of Mt. Pinos Granite.	1. Well-indurated. 2. Argillaceous and micaceous.	Unsorted to poorly sorted, fine to extremely coarse-grained, angular fragments.	Massive to faintly bedded in crudely lenticular fashion.	1. Mudflow. 2. Granite blocks as large as 40 feet across are present.

Table 1. Rock description, Plush Ranch Formation—Continued.

Member	Rock type	Colors	Composition	1. Degree of induration 2. Bonding agent	Textures	Bedding and structures	Remarks
Two	Limestone	Gray to buff.			Very fine-grained.	Platy, thinly bedded, but not laminated.	1. On Middle Fork and Amargosa Creek over half of the member is composed of interbedded shale and limestone. Not seen on North Fork, but may be faulted out. 2. Limestone identical to that of member 4.
	Shale	Gray to brown.		Moderately to poorly indurated.		Thin beds and shaly partings.	
	Sandstone	Tan.	Mostly quartz.	1. Well-indurated. 2. Calcareous.	Fine- to medium-grained, moderately well-sorted.	Well-stratified, thin bedded in lenticular layers up to several inches thick, slabby.	
	Arkose	Pale buff to white; all weather nearly white.	Quartz and various feldspars with biotite, chlorite, and dark green amphibole common accessories. Tiny limonite-rich shale particles also present.	1. Friable. 2. Calcareous and argillaceous.	Fine- to coarse-grained, poorly sorted, subangular to subrounded grains.	Beds generally about 3 feet thick; partly massive, partly stratified in thin layers.	More rounded grains and absence of gray metamorphic granules mark chief differences from arkose of member 1.
One	Limestone	Light gray.				One massive bed, 2 feet thick.	Low in section at two localities (L.27, XII.80; N.05, XI .05).
	Clay	Red-brown, gray.				Lenticular layers mostly a few inches thick. Internally massive.	
	Shale	Gray, dark gray-green, tan.		Moderately to poorly indurated.		Thinly bedded to laminated with siltstone intercalations. In zones from few inches to several feet thick.	Very similar to shales of member 4.
	Feldspathic sandstone	White, cream.	Quartz, feldspar, minor accessory biotite, and granules of granitic and dark gray fine-grained metamorphic (?) types.	1. Hard to friable. 2. Mostly calcareous and argillaceous.	Fine- to medium-grained, angular to subangular, poorly sorted.	Mostly massive to poorly bedded, some cross-bedding, graded bedding, and scour and fill.	
	Conglomerate	Gray, buff, white, rust-red, maroon	Polymictic conglomerate with clasts set in arkosic and feldspathic sandstone matrix like that described above. Clasts of 3 main types: (a) Granite, light gray fine- to coarse-grained acidic types, including Mt. Pinos Granite. (b) Metamorphic-migmatite, dark and light gray banded quartzo-feldspathic gneiss, augen gneiss (rare), biotite schist, gray quartzite, hornfels. (c) Sedimentary, one occurrence of hard brown Eocene sandstone cobbles on west edge of area.	1. Very hard to friable. 2. Calcareous cement with locally abundant limonite and hematite.	Mostly poorly sorted, locally well-sorted (e.g. pebble beds), mostly rounded to well rounded clasts; sizes over 8 inches rare, 3 to 5 inches most common.	Poorly bedded to massive, units few inches to tens of feet thick, mostly lenticular.	1. No noticeable vertical change in composition of clasts, but individual beds may differ. 2. Breccia phase, 30-feet thick, occurs at base of section west of Seymour Peak (L.50, XII .74). Rock is hard, deep red to maroon conglomerate with angular clasts packed thickly in coarse beds and with layers and lenses of poorly bedded sandstone.

The lower members, which dip steeply and strike east-northeast, form a part of the tread on the south flank of Mount Pinos. Most of the rocks are soft and exposure is obscured by detritus on the canyon slopes of deeply incised streams; although well-indurated conglomeratic beds do form ridges and bluffs. The upper parts of the section are exposed in the line of hills which form the northern wall of Lockwood Valley. The hills are chiefly underlain by basalt, but west of Middle Fork nearly horizontal coarse fanglomerates predominate and form striking buttresses along the canyons.

Member One. Member one, the lowest member of the Plush Ranch Formation, is exposed south of the Mount Pinos Eocene section, from the western edge of the area to Little Cuddy Creek (T.00, VIII.30 to I.20, XII.95). It is about 2,300 feet thick north of Big Spring Valley, but since its base is faulted out against older rocks its actual thickness is unknown. The unit is typified by gray pebble and cobble conglomerate, with well-rounded clasts set in a coarse arkosic matrix, but it contains beds and lenses of several other sedimentary types.

Highly colored beds low in the section grade upward into drab beds. In the eastern part the color change is from deep rust-red and maroon in lower beds, through medium-gray in the middle, to light gray and cream in upper portions. In North and Middle Forks, and Amargosa Creek, however, the lowest beds consist of interbanded variegated layers, grading upward through drab gray beds into white beds at the top. In the lowest part of the member conglomerate persists across the area and the changes are chiefly in color, as noted above, and hardness (well indurated in the east, poorly indurated in the west). The middle portion of the member displays a marked difference from east to west. In the east all of the beds are well-indurated bluff-forming pebble conglomerate, but a transition occurs across the north side of Big Spring Valley and in Amargosa Creek conglomeratic layers are replaced by softer sandy beds. Farther west, in North and Middle Forks, these sandy beds contain shaly zones, clay layers, and occasional conglomeratic lenses. The upper part is moderately indurated white to cream arkose with lenses of pebble and cobble conglomerate which erodes in distinctive smooth curves giving broad humps and hammock-shaped recesses.

Member Two. Member two is distinguished between North Fork and the northwest corner of Big Spring Valley. Its thickness, ranging from 275 to 375 feet, is more uniform than that of most members in the formation. However, its lithology changes rapidly laterally. The lithology of the lower portion of member four-a, which underlies Seymour Peak (pl. 1), is like that of the eastern part of member two and apparently is its equivalent; but, for reasons given in the description of member four-a, member two is not separated from the Seymour Peak section. Member two is mostly soft and the unit is characterized by smooth debris-covered slopes, although there are some well-indurated layers which form rounded ledges. Good exposures occur along some streams, and locally badland fluting develops in which exposures are fair. The bulk of the member is a soft pale buff to white arkose on North Fork and its tributaries, whereas on Amargosa Creek grey shale, and platy gray limestone are typical. Slabby sandstone layers are scattered through the unit and become more common eastward.

Conformity between members two and three is well displayed on Amargosa Creek, where the contact is arbitrarily drawn between light buff arkosic strata containing interbedded grey shale and limestone (member two) and more grey arkosic sandstone which has interbedded clay layers (member three). To the west this contact is faulted and member three is separated from the light arkose by a zone of gouge, caliche, and contorted beds.

Member Three. Member three consists of about 1,400 feet of interbedded arkosic sandstone, shale, clay, and sedimentary breccia. The distribution of the member is similar to that of member two, except that it cannot be distinguished east of Amargosa Creek. It is hidden under Big Spring Valley, where a transition occurs in which differences with the underlying member become blurred (cf. member four-a). Exposures are poor in much of the member; however, the sedimentary breccia zones are resistant, and nearly vertical beds form prominent hogbacks with cliffed sides and good exposures.

At the base of the unit occur drab, light gray and greenish-gray, micaceous, arkosic sandstone and shale. The color gradually changes to brighter hues passing upward through the section, and the upper half is characterized by arkose that ranges from yellow to orange; however, on Amargosa Creek a reddish-orange color extends to the base of the section. Current bedding, cross-stratification, flow-casts, graded bedding, cut-and-fill, and current lineation are common near the top of the member, which features allowed determination of tops of beds and direction of current flow during deposition. When the beds are rotated to horizontal, indications are that the source area lay to the north.

Two prominent sedimentary breccia zones of mudflow origin are exposed chiefly between North and Middle Forks (Q.5, VIII.9; Q.5, IX.1). They are in the upper third of the member and are separated by about 250 feet of soft sandstone, shale, and clay. At the east and west ends both units pinch out, reappearing laterally in short thick lenses at slightly different horizons (S.2, VIII.2 and O to P, IX.3 to X.0). Thus the units are referred to as occurring in zones. Both zones have similar lithology, and the rocks are composed mostly of unsorted to very crudely sorted angular fragments of Mount Pinos Granite, ranging in size from fractions of an inch to forty feet in diameter, set in a matrix of granules and sand made up of material of the same composition. One outcrop on North Fork (R.80, VIII.40) would appear to be a highly sheared exposure of bedrock granite; but it is interbedded with normal sediments, and eastward in the unit sedimentary origin is evidenced by crude bedding and coarse gravel lenses. The lower of the two units is more coarse, poorly bedded, and oligomictic than the upper one, which contains more gravel lenses and definite layers of clasts a foot or two thick. Layering is particularly noticeable near Middle Fork where bands composed predominantly of dark augen gneiss are scattered throughout the upper zone. The gravel lenses are a few feet long and a few inches thick, and are generally shadowy and irregular in the coarser fabric of the clasts.

A branch of Middle Fork is cut between walls of steeply dipping breccia which rise 50 to 80 feet above

Photo 8. Basalt of Plush Ranch member four showing labradorite with strong oscillatory zoning and well-developed {hol} pinacoids. Section of grain cut parallel to side pinacoid. Crossed nicols.

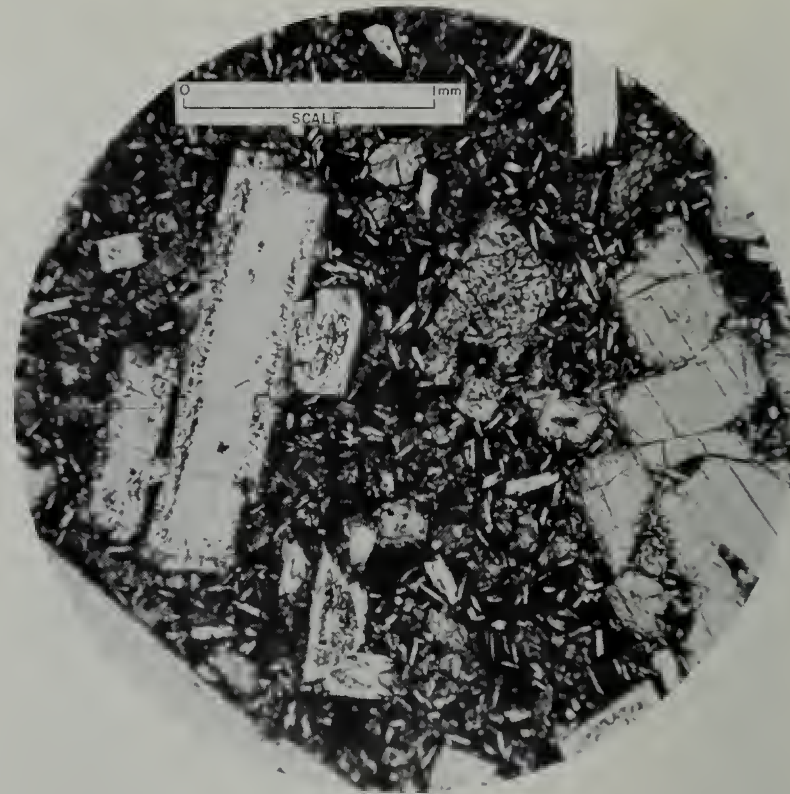


Photo 9. Basalt, Plush Ranch member four, showing vermicular tubules of glass in labradorite (left) and augite and hypersthene (right).

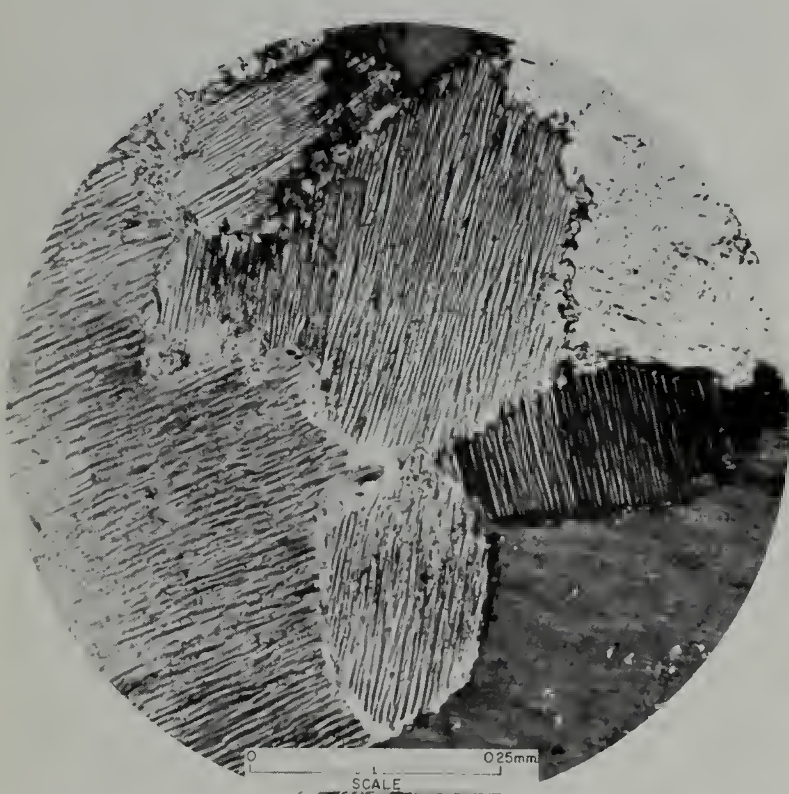


Photo 10. Perthite in clast from Plush Ranch member five, eastern margin of area. Crossed nicols.

Photo 11. Perthite (lower half) and plagioclase (upper half, about An_{30}) in clast from Plush Ranch member five on eastern margin of area. Crossed nicols.

the creek (P.20, IX.38). The breccia on either side is at least 100 feet thick, whereas in the stream bed there is good exposure of moderately indurated orange arkose with bedding parallel to that of the breccia. The exposure is continuous across the extent of the breccia, and the arkose passes into identical layers of arkose which overlie and underlie breccia. A similar situation exists for a number of lenses of breccia at both extremities of the main layers. The lenses are very short and thick, as though they were either deposited in narrow channels cut deeply into the arkose or had once stood out as high narrow ridges on a surface underlain by dissected breccia. These breccias are almost certainly flood deposits, chiefly of mudflow type, which came from nearby.

Member Four-a. A section of arkosic sandstone, shale, clay, and limestone measuring at least 2750 feet in thickness underlies Seymour Peak. It is in the same stratigraphic position as members two and three, and the lithology of the beds corresponds chiefly to fine-grained rocks in those members; however, the units of members 2 and 3 separated in the west cannot be distinguished here. Instead, the section is more even-colored and drab, has a more uniform distribution of rock types, and the white arkose of member two as well as the breccias and yellow and orange upper arkose of member three do not occur. The only distinctive mappable elements are a zone of shaly and limy beds just below the middle of the section (K.72, XII.00), and a thin band (K.20, XI.94) of fine- to coarse-grained arkosic sandstone of characteristic grey and greenish-grey colors which stands out from the more brown-tinged layers. The distribution of these units reveals the general trend of otherwise monotonous and locally slumped beds. The upper several hundred feet of member four-a are browner and the sandstones are more fine-grained than the lower parts. The uppermost portions are composed of thinly bedded and interlayered limestone, shale, and hard brown sandstone. These beds are similar to those associated with the basalt in member four, and it is clear in the field that they represent a transition into higher deposits although the actual transition is not seen because of faulting (K.20, XI.80).

In summary, member four-a appears to be the eastern equivalent of members two, three, and part of four. However, the upper and lower limits are obscured by faulting, and one might argue, for example, that member two is entirely faulted out between Amargosa Creek and Seymour Peak. That this is not the case is indicated by the gradual change in lithology of member two from Middle Fork to the north side of Big Spring Valley. In this transition, there appear platy sandstone, shale, and limestone identical to those found in lower member four-a, and there soft light-colored arkose disappears.

This part of the Plush Ranch Formation thickens eastward, and a minimum of 2,750 feet in the east are opposed to only 1,900 feet in the west, with the latter figure including about 450 feet of lower member four that lies beneath the basalt.

Member Four. Member four, the most widely exposed unit of the Plush Ranch Formation, extends from the western edge of the area (T.00, VII.80) into Little Cuddy Valley west of Cuddy Ranch (E.63, XIV.30) and lies just north of the Big Pine fault over most of this extent. The member also occurs south of the Big Pine fault at the eastern extreme of the map (B.0, XV.0). The unit consists of interbedded platy limestone, gypsum, gypsiferous shale, and hard slabby feldspathic sandstone which is typified by dark shades of brown, brownish-green, and gray; together with light-colored tuffaceous sandstone, light-colored vitric tuff, and somewhat variable olivine basalt. Local accumulations of borates, mostly colemanite, are found in the limy and shaly portions. The maximum thickness of member 4 is more than 1250 feet, exposed just north of Plush Ranch. The basalt is 650 feet thick in this region, though it thins to 300 feet farther west. However, the absolute thickness of the member, and variations thereof, cannot be determined because of faulting and the fact that over much of its outcrop the unit is roughly flat-lying, allowing only incomplete sections to be seen. There is also much small-scale but intense deformation which largely precludes tracing or close correlation of horizons within the member.

Sandstone, shale, and limestone are intermixed through much of the section, and in some places they grade laterally into each other very rapidly. Futhermore, these rocks interfinger with much coarser clastic units assigned to member five. Exposures in the valley walls of Middle Fork and Amargosa Creeks reveal these relations quite clearly. Basalt lies on nearly 100 feet of limestone, shale, and laminated sandstone on Middle Fork, three-quarters of a mile north of the Big Pine fault (0.80, IX.00). These sedimentary rocks lie directly on breccia of member five. As the sedimentary rocks are traced along the northeast valley wall toward the Big Pine fault, they gradually become more sandy until finally, just north of the fault, basalt rests on 100 feet of coarse massive sandstone which is in turn underlain by member five. The sandstone contains lenses and thin layers of sedimentary breccia typical of the subjacent unit. On the southwest side of the creek a similar situation occurs, except that the transition from finely laminated rocks to massive sandstone is completed further upstream. Furthermore, the sandstone either pinches out or is transgressed by basalt (0.80, VIII.28) which lies directly upon member five near the Big Pine fault (0.90, VIII.10). Less than a mile to the northeast, such transitions are not found. Instead, basalt rests on nearly 200 feet of interbedded thin sandstone, shale, and limestone throughout its exposure on Amargosa Creek (N.60, VII, 90). Farther east and west from these creeks the lithology is more constant with sandy phases predominant in the west and the finer more limy phases prevalent in the east (cf. fig. 4 and pl. 2, secs. 1, 2, and 3).

The shale of member four contains the only fossils found in the Plush Ranch Formation. One occurrence is in limestone nodules which are locally abundant in the shale and are apparently concentrated in the areas where borates are found (eg. K.90, IX.90). The nodules are rounded, mostly half an inch to 2 inches in diameter, laminated parallel to shale bedding, are colored dark blue-gray, and weather to lighter gray, blue-gray and buff. They have a petroliferous odor when broken, and many carry insects and other organic remains. Dr. Allison R. Palmer, of the U.S. National Museum, has examined some of the nodules, and the following is from a letter by him (June 3, 1954):

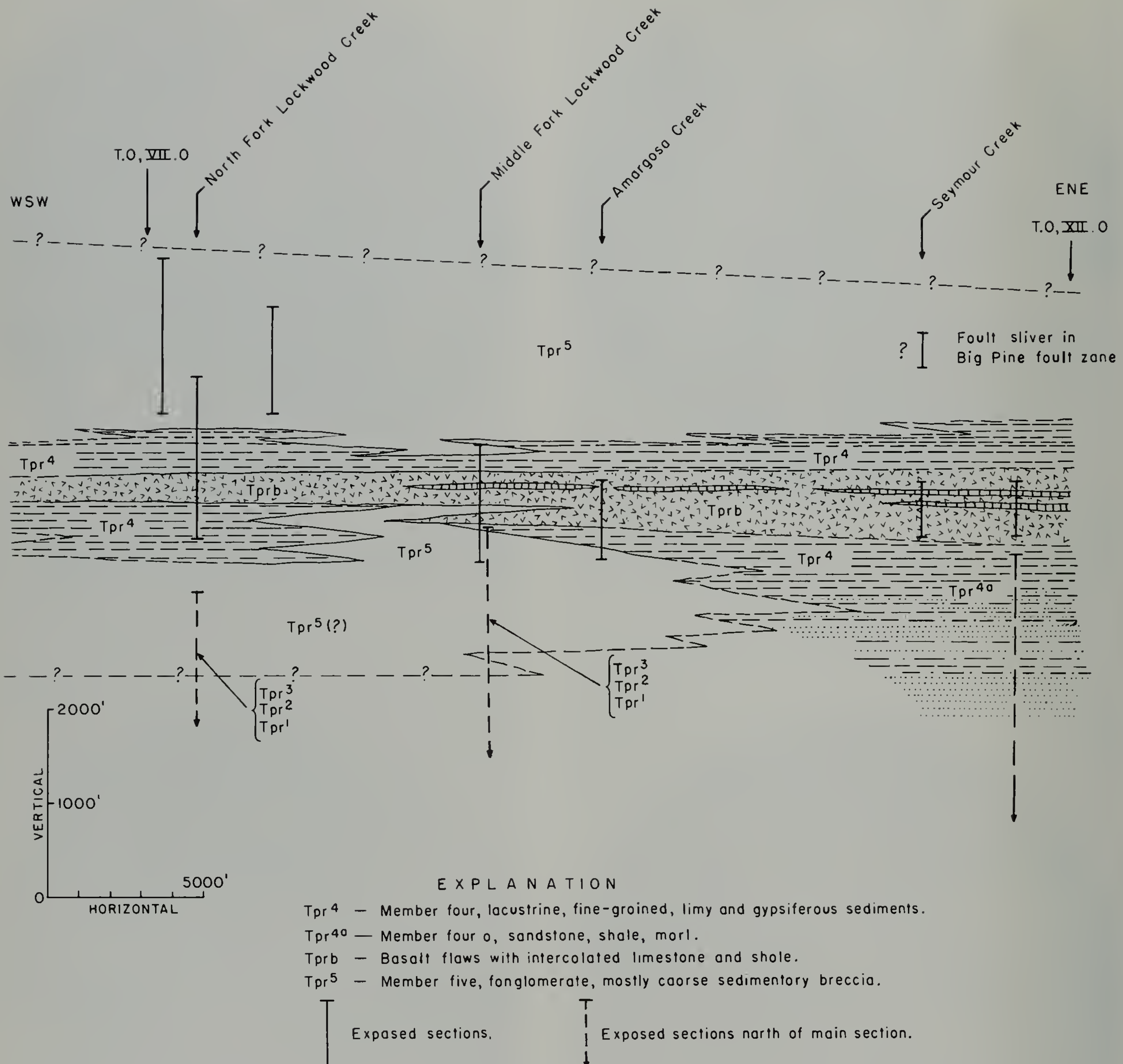


Figure 4. Schematic representation of the stratigraphic relations believed to exist between Plush Ranch members four, four-a, and five across the area in an east-west direction. Constructed from partial sections as indicated, it illustrates the deductions concerning interfingering between members in a general way, and also shows how successively lower rocks are exposed eastward by the broadly westward plunging structure north of the Big Pine fault.

"The Frazier Mountain nodules contain abundant coprolites made up largely of fish remains, but also carrying plant spores (pine). The presence of fish remains is strongly suggestive of a more or less permanent body of water. . . . The faunas of the deposits are characteristic of fresh-water rather than brackish, saline, or otherwise abnormal mineralized water."

The presence of these nodules was first noted by T. H. McCulloh who found similar nodules in Tertiary shales associated with borates and volcanics in the Calico Mountains, Mojave Desert. On North Fork (loc. 3, R.58, VIII.23) the very fine sandstone and shale beds are rich in ostracods. Some layers, one or two millimeters thick, are almost entirely composed of them. Mr. William T. Rothwell, of the Richfield Oil Co., examined samples of the material and says (letter of December 8, 1953):

"Your forms are not related to those of salt-water lagoon or open-sea environments with which I am familiar. Although poorly preserved, they seem similar to *Candona* or a related genus and suggest a fresh water environment. . . .

Your forms probably occupied an environment similar to that of the ostracods collected by Dr. J. C. Crowell in the Ridge Basin. . . ."

However, nothing can be told about the age of these forms.

Limestone beds are more abundant in this member than in any other rocks in the area. In association with gypsum and gysiferous shale, the limestone beds are commonly highly deformed and fractured and give characteristic exposures of thin slabs. Such exposures are common in the basalt, are traceable for several hundred yards, and reveal sedimentary layers therein. Porous travertine and local bands of sedimentary breccia in the limestone indicate a probable shallow lacustrine origin. The breccia is composed of small slabs of limestone and pellets of clay set in an even matrix of identical material. In addition, the breccia contains thin continuous "non-clastic" layers. The structure is apparently the result of wave action on a shallow lake bottom.

The rocks of member four display considerable reworking by lime-bearing solutions where they are associated with basalt. This is seen at the Russel mine (J.92, X.76), where gray clay and shale are intimately veined, and in part replaced, by calcite; and near the Frazier mine (M.35, IX.47), where bedded limestone in basalt is offset by fractures filled with massive fine-grained calcite. Further evidence is abundant in the form of veinlets of calcite transgressing various rocks, and small areas of breccia in the basalt composed of basaltic fragments in a calcareous matrix. Where the action of limy solutions has been most intense, there occur the borate minerals discussed in the section on economic geology.

Beds of tuff occur at Frazier mine (K.90, X.00) and three localities to the east and west: one is on the highest hill due south of Big Spring Valley (M.48, X.00); another is a tiny patch, indicated by float, about 200 feet stratigraphically above the basalt north of Plush Ranch (Q.48, VIII.38); the third is south of the Big Pine fault (B.05, XIV.63) where the tuff is in association with sedimentary rocks, also stratigraphically above the basalt.

In all localities the rock grades into sandstone. Although there is a color distinction north and south of the Big Pine fault, there is no lithologic difference between the tuffaceous rocks. Those of the more westerly exposures, north of the fault, are pale with yellow hues, ranging in color from nearly white and yellow to pale greenish-yellow and greenish-gray. In the east, south of the fault, they are mostly bright blue-green and green, but some are also greenish-gray. Where the rocks are most pure they are very fine-grained and well-bedded, though massive layers do occur. Fracturing and jointing cause the tuff to weather into distinctive angular chips, but less shattered specimens display conchoidal fracture.

Biotite is the only megascopically visible constituent, other than sand, and appears as minute flecks throughout the rock. Microscopic examination shows that all specimens but one contain angular fragments, but which fragments, if any, belong to the original ash fall cannot be determined with certainty. The fragments have a wide range of composition: quartz, plagioclase (An_{25-27} and An_{33}), orthoclase, microcline, perthite, biotite, and minor amounts of epidote, garnet, and zircon. The biotite, appearing in the purest tuff, is probably at least in part an original constituent. Thin sections also reveal the rock to have been highly vitric with angular shards set in a glassy groundmass. Both matrix and shards are almost completely altered to a zeolite, probably clinoptilolite, which occurs in sheaf-like bundles, radiating groups, and as prismatic or lath-shaped crystals projecting into cavities. It also occurs either as a replacement or alteration of some of the feldspar grains. The mineral has very low birefringence and an average refractive index between 1.481 and 1.486. Measured x-ray data for clinoptilolite could not be located in the literature, but the x-ray spectrometer shows a close comparison with the pattern for heulandite, with a few lines slightly displaced and one major heulandite line missing. The specimens were also examined optically by Professor M. N. Bramlette, who noted their similarity in form and occurrence with zeolitic alterations in other California Miocene pyroclastics. He and Dr. E. Posnjak found that vitric tuffs of this age are commonly altered to clinoptilolite (Bramlette and Posnjak, 1933). The authors show x-ray powder photographs of clinoptilolite and heulandite which are very similar, and they expressed the view that the two minerals probably belong to a solid solution series.

The likelihood is good that the unaltered rock was an alkalic tuff. This is suggested by the light color, and by the fact that if the mineral to which it has altered is truly clinoptilolite the chemical composition of the rock is "close to that of an alkalic volcanic glass" (Bramlette and Posnjak, 1933, p. 171).

The tuff is water-laid, as evidenced by gradation into thinly bedded sandstones interlayered with shale and limestone. The occurrence in much of the tuff of a wide variety of clastic grains, all of which are distinctive of the sandstone, indicates that the rock is in part reworked or contaminated.

Wherever member four is exposed it contains layers of basalt. These extend from the eastern edge of the area westward for five miles beyond its limits (Adams, 1956). The basalt is associated with a limy portion of the member, as is shown by the predominance of limy bands over other types between volcanic layers. In the west the flows are confined to a single horizon in the middle of the formation (T.O, VII.9 to P.3, VIII.9), but east of North Fork their position is not so certain (pl. 2, secs. 1,2,3,4) and there is more mixing of volcanic and sedimentary beds. This rock is essentially a hypersthene-augite-olivine basalt. In detail it is structurally and texturally complex, but its gross lithology is constant within the limits of the name given above. The rock is mostly black or very dark red-brown, and it weathers to deep red-brown and greenish-brown.

Vesicular phases are common, weather gray-green, and appear as broad continuous bands several feet thick or as discontinuous irregular streaks in more dense rocks. No consistent association along contacts with sedimentary rocks was noted, and indeed, in as many places as not, dense porphyritic rock occurs at such contacts. Vesicular phases commonly are amygdaloidal, with calcite, zeolites, and serpentine filling the cavities. In several places the rock is truly scoriaceous. Flow banding was detected at a few localities as shown by parallel arrangement of tabular feldspar phenocrysts. Zones of fragmented rock, possibly a flow breccia, are seen just west of the Frazier mine (L.43, IX.64). Wherever these zones are developed on a scale sufficient to indicate the attitude of the basalt, the zones display good accordance with associated sediments. Near Middle Fork (P.40, VIII.92), an outcrop of the basalt reveals very fine-

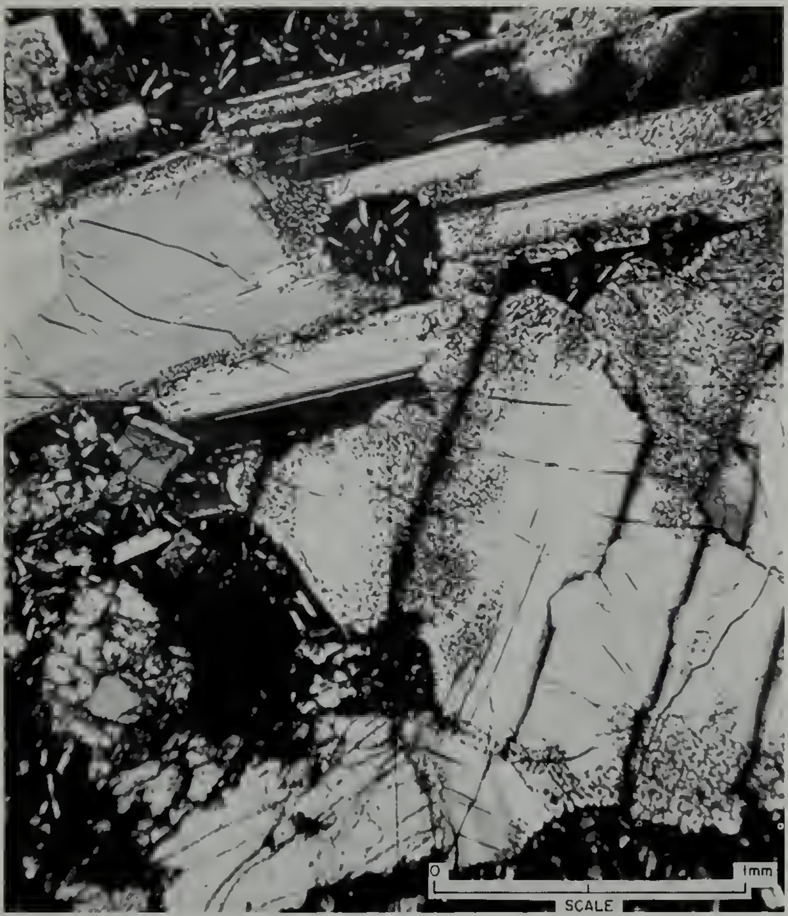


Photo 12. Basalt of Plush Ranch member four, showing corrosion effects in labradorite. Vermicular tubules project inward from edges. Crossed nicols.

grained patches bounded by glassy selvedges which, though not having the form of distinct "pillows", do indicate rapid localized chilling and suggest extrusion into water.

The map shows the irregular and discontinuous nature of sedimentary beds in the basalt. Some beds bifurcate around basalt layers, as seen west of the Frazier mine (L.38, IX.54; L.03, IX.95). At a number of places highly contorted limestone and shale beds are cut by fingers of basalt (J.80, X.87). It is thus evident that the flows plowed into partially consolidated strata, distorting, cutting, and probably locally pushing under soft beds. Sediments, mostly calcareous and argillaceous, were also deposited in depressions on the volcanic surface, and in places overlapped the edges of flows to unite with beds under them. These features, together with the basalt fabric and the fossils in the shale, indicate deposition in a lake.

The upper contact of the basalt is seen in the eastern and western portions of the area (B.05, XIV.66 and Q.50, VII.50). By the irregular contact, and by sediments striking into what were apparently low basalt banks, an erosional top is indicated. In the easternmost exposures a breccia, overlying the basalt with local unconformity and possibly correlative with Plush Ranch member five, contains small angular blocks of basalt, shown by thin section to be identical with that of member four.

Texturally, the basalt ranges from vitrophyric to microcrystalline and to holocrystalline porphyritic, with subsidiary textures such as seriate and subophitic occurring locally. The groundmass of the holocrystalline porphyritic variety is usually intergranular or pilotaxitic. The chief mineral, forming over 60 percent of the rock, is labradorite, which occurs in well-formed laths that range in composition from about An_{60} in small groundmass grains to about An_{69} in larger strongly zoned phenocrysts. The coarse crystals occasionally show oscillatory zoning. Olivine (about Fa_{23}, $-2V$ near 85°), present in many specimens in amounts up to 10 percent, appears as large and small euhedral and subhedral grains. The smaller ones are included in all other minerals. Most olivine has been altered to deep yellow serpentine. Augite and hypersthene appear as phenocrysts or in the groundmass of most specimens. In rocks with intergranular texture, the augite and hypersthene comprise over 30 percent of the composition and appear solely in the groundmass. The ratio of augite to hypersthene is about two to one in all but one specimen, in which hypersthene predominates slightly. The phenocrysts all seem to be normal augite ($-2V = 45°$-$50°$), but in the matrix pigeonite ($-2V = 10°$-$20°$) and augite ($-2V$ near 45°) are both present.

There is an unusual feature in most specimens studied. It consists of worm-like tubules, chiefly in plagioclase but also common in augite and hypersthene. These tubules generally form lace-like rims around the borders of grains, extending in from the edges, but some appear as central cores. They are mostly opaque, though a few have clear isotropic central zones. The tubules might be interpreted as glass included in host crystals (Stevenson, 1947, p. 550, footnote 9), except for the fact that they occur in all types of phenocrysts which must have crystallized over a relatively long period of cooling. A more probable explanation is that they represent incipient remelting of the grains upon extrusion, oxidation, and consequent increase in temperature in the basalt (Stevenson, 1947, p. 550).

Conformable relations between members three and four can be observed in a transition that occurs through about 100 feet of section, as seen about one mile north of the Big Pine fault on Middle Fork and Amargosa Creeks (O.99, IX.12 and N.77, IX.70). To the east, just

Photo 13. Detail of Plush Ranch member five breccia layer. Most fragments are slightly water-worn. Augen gneiss and quartz monzonite clasts are about equal in number. Locality R.4, VII.2.

south of Seymour Peak, the transition between member four and member four-a seems even more gradual, as mentioned in discussing member four-a; but here faulting obscures relations between beds that are certainly in member four and those below it. In rocks immediately adjacent to the Big Pine fault on the north, member four is conformable on breccias of member five (eg. O.40, VIII.60 and N.28, VIII.93). The upper contact is unfaulted northwest of Plush Ranch (Q.80, VIII.20). There, steeply dipping fine sediments of member four pass gradationally into the overlying beds of member five; member four is thus bounded above and below by member five (fig. 4). The upper contact is transitional through 300 or 400 feet of section, with rocks typical of each member interbedded in thin layers. Therefore, the contact is arbitrarily taken at the point where coarse beds typical of member five become dominant.

Member five lies some 500 feet stratigraphically above the basalt of member four on North Fork; a little farther east it is interbedded with the volcanics (P.65, VII.75); on Middle Fork member 5 lies under the basalt and a thin layer of the sedimentary rocks of member four (O.40, VIII.60); and on Amargosa Creek, it appears beneath at least 150 feet of the fourth member (N.28, VIII.93). Thus members 4 and 5 interfinger through a large section, and member five rapidly transgresses stratigraphically upward west-southwest of its exposure on Amargosa Creek (fig. 4). Furthermore, in the north-south extent if member five continued northward at a persistent stratigraphic position on Middle Fork and Amargosa Creek, it should reappear under the basalt near the present contact of members three and four on these creeks. Since it does not reappear, it must finger out in the northerly direction (pl. 2, secs. 1, 2, 3).

Member Five. Member five is best exposed on North Fork, just north of the Big Pine fault. There, about 1200 feet of fanglomerate composed of sedimentary breccia and massive sandstone dips gently to the west, forming

Photo 15. Exposure of Plush Ranch member five in North Fork, showing breccia-like nature of coarse layers, size of clasts, and type of bedding. Locality R.4, VII.3.

the lower portion of a sequence of coarse clastics which is exposed north of the Big Pine fault between North Fork and Dry Creek six miles to the west. Near Dry Creek these Plush Ranch beds are unconformable under the Caliente Formation, which covers them west of Dry Creek (Adams, 1956).

As mentioned before, member five interfingers with member four northward and northeastward from its exposure on North Fork. It is last seen in normal stratigraphic position on Amargosa Creek (N.28, VIII.93); however limited exposures occur as fault slivers northeastward along the Big Pine fault zone (K.00, X.38, and J.38, X.75). Recent mapping west of Lockwood Valley shows that this fanglomerate retains its thickness westward and that it fingers out within 1½ miles northward

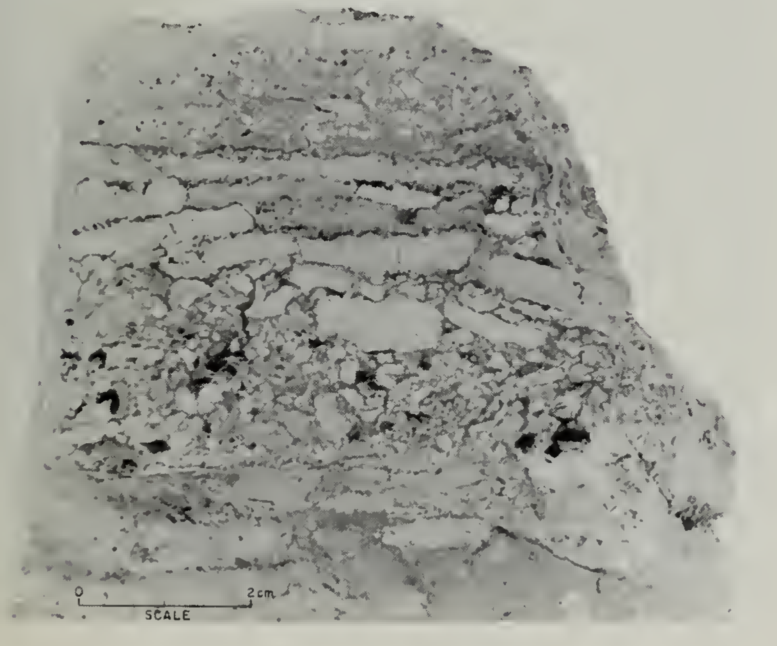


Photo 14. Limestone breccia from Plush Ranch member four, showing clay pellets (dark rounded and irregular patches in lower part) and limestone slabs.

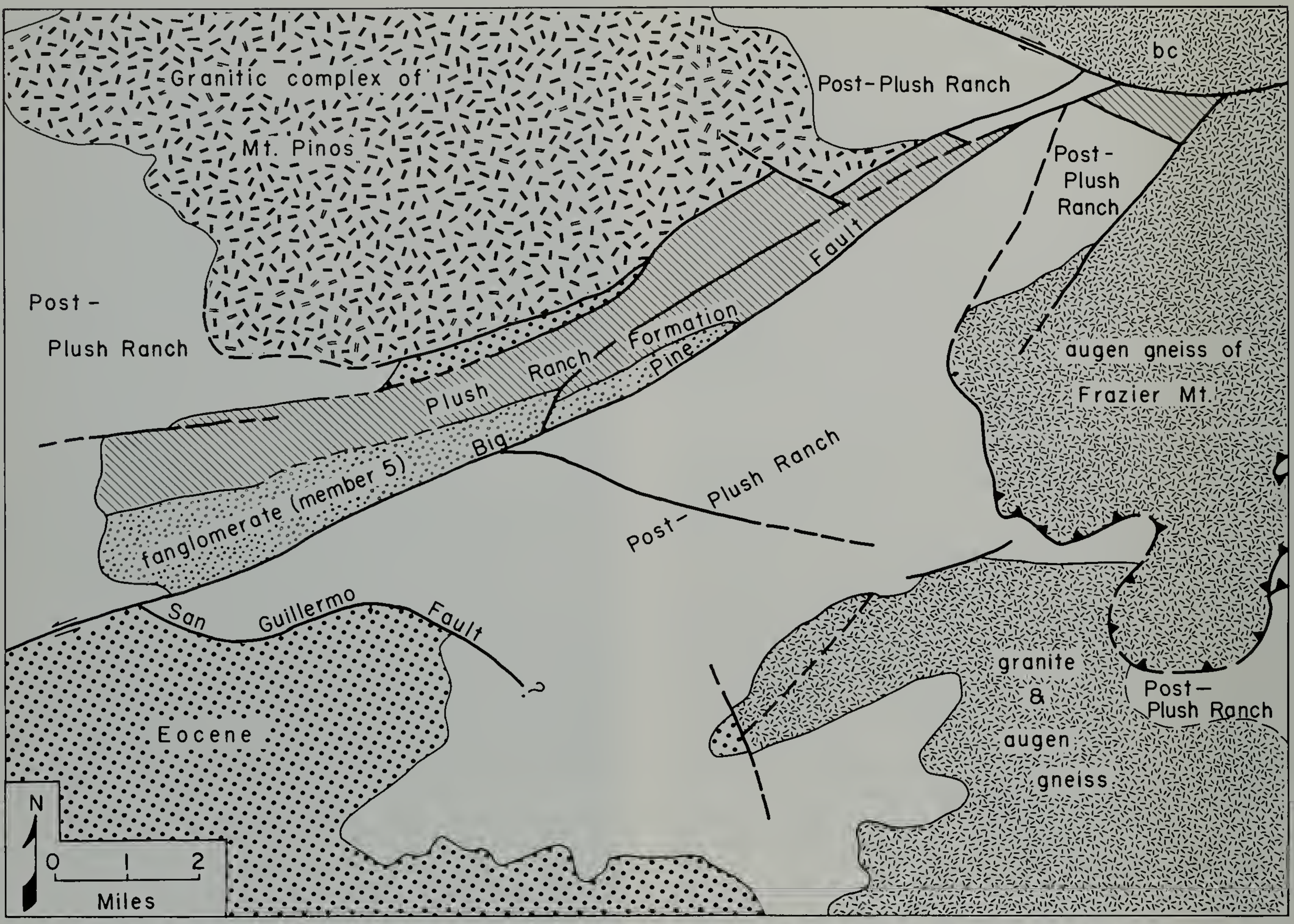


Figure 5. Map of Lockwood Valley and area west to Dry Canyon, showing the extent of Plush Ranch member five (labeled "fanglomerate").

from the Big Pine fault over its whole extent (Adams, 1956). The unit is thus a thick (1200 feet plus), long (at least seven miles east-west), and narrow deposit (not over two miles north-south), presently localized along the Big Pine fault (fig. 5). Apparently it was derived from a fault scarp to the south, either from the Big Pine fault, or a fault not much farther south. The origin of this unit has important bearing on movements on the Big Pine fault, and the matter is further discussed in the section dealing with that fault.

The detailed lithology of member five north of the Big Pine fault is given in table 1. Member five is mostly well indurated and its massiveness and hardness, together with vertical jointing, lead to development of cliffed buttresses that form nearly vertical, stepped valley walls, in which exposures are excellent and details of structure and lithology are easily studied. In eastern exposures, south of the Big Pine fault, the Plush Ranch Formation includes a gray-green to brownish-green section containing layers of breccia and hard, slabby, brown sandstone, of the type common in member four (C.10, XIV.90). Though completely bounded by faults, the section is assigned to member five because of its coarseness and gross structural similarity to member five farther west. The breccia beds in this eastern exposure are five to fifteen feet thick and contain angular fragments of the augen gneiss of Frazier Mountain, light-colored gneiss, and alaskite, of which all emphasize local derivation. The clasts are poorly sorted but lie within a relatively restricted size-range; none is over a foot across. At one locality above the basalt, mapped together with member four because of scale and structural complexity (A.85, XIV.62), some beds contain more thoroughly rounded clasts of the same lithologic types, basalt from member four, and two distinctive metamorphic rocks. One of these unusual rocks has all the megascopic features of noritic rocks associated with anorthosite of the San Gabriel Mountains (Higgs, 1954). Thin sections show the same mineral assemblage (with one major exception) and identical textures and alteration features as do the noritic rocks. The exception is that, in the place of the coarse andesine crystals of the norites, the clasts contain coarse perthite grains and rare large crystals of plagioclase, apparently calcium-rich oligoclase, that appears to be replaced by perthite. The perthite is a distinctive variety in which potash and albitic feldspar are intimately intergrown in tubular or platy layers, each feldspar composing about 50 percent of each grain. Dr. Higgs examined the sections and confirmed the similarity to the San Gabriel rocks. However, he pointed out that, while he had seen precisely the same perthite in some of those rocks, it never exceeded 30 percent of the total feldspar content and was usually much less. Also of interest in this connection is the "hair perthite" described by Eskola from granulites of Lapland (Eskola, 1952, fig. 20 and p. 149). His photomicrographs show identical patterns with those of Plush Ranch rocks, and his description matches perfectly that given above for the perthite. In Eskola's account, such perthite is "one of the most specific characteristics" of his granulites. A further striking similarity in the same specimens is the undulose extinction and faint but definite development of the quadrille structure of microcline twinning in many potash feldspar grains. Eskola states, "The development of microcline from strain shadows seems to be specific for the granulite facies."

The second distinctive metamorphic rock is typified by an abundance of blue quartz set in a feldspathic matrix with abundant hornblende, chlorite, and ilmenite. Specimens range from leucocratic to mesocratic. This rock has recently been described by Oakeshott (1957) as a granulite gneiss. It is found in place on the northeast side of the San Gabriel fault in the western San Gabriel Mountains, about 50 miles south of Frazier Mountain. The gneiss has been intruded by rocks of the anorthosite-norite complex of the San Gabriel Mountains.

Neither of these unusual metamorphic rocks is known to exist in the basement complex west of the San Gabriel fault or north of the San Gabriel Mountains. Using arguments outlined for the source of anorthosite clasts in Caliente beds, it is concluded that the clasts found on Frazier Mountain had their source in the San Gabriel Mountains.

Age and Correlation of the Plush Ranch Formation. The formation contains no datable fossils. It is unconformable under Caliente beds known to be Barstovian and possibly Hemingfordian in age. The Plush Ranch section is deformed with, and faulted against, lower to middle Eocene rocks on North Fork. These facts allow a range in age from upper Eocene through lower Miocene (invertebrate marine time scale) for the Plush Ranch Formation.

A section of marine and continental sedimentary rocks that contains basic volcanics and somewhat resembles the Plush Ranch rocks occurs 20 miles north of Lockwood Valley on the north slopes of the San Emigdio Mountains. The beds were designated the "Vaqueros" Formation by Hoots (1930, pp. 259-63), but the lower portions of that formation have since been divided into the marine Pleito and continental Tecuya Formations. The "Vaqueros" beds are dated as early Miocene or "Oligo-Miocene" and the Pleito and Tecuya strata are Oligocene, ranging down to early Oligocene (Weaver, C. E., et al, 1944). Gazin (1930a, p. 11) correlated the basalt of Plush Ranch member four with the "Vaqueros" agglomerates to the north, and considered underlying strata to be Eocene or possibly Oligocene. However, difficulty in correlation is caused by the fact that the San Andreas fault, which may have had large lateral movement, intervenes between the "Vaqueros" exposures and the Plush Ranch Formation. Furthermore, comparison with Hoots' descriptions reveals that a vague similarity exists between the "Vaqueros" beds and Plush Ranch rocks below the basalt; but, the conglomerates of both these formations contain a very different assemblage of clasts and more detailed comparison would be necessary to establish correlation.

All beds in the Plush Ranch Formation are considered by M. L. Hill and T. W. Dibblee to be of Oligocene (Refugian) age, and to be at least in part equivalent to the Simmler Formation, distinguished by them in the southeastern Cuyama Valley (personal communication). This evaluation is based on a considerable amount of mapping in Cuyama Valley west and northwest of Lockwood Valley. The correlation rests mostly on lithologic and stratigraphic comparison of rocks on North Fork with those at the heads of Dry, Apache, and Quatal canyons and with those farther to the north, as well as with red beds on the west side of Cuyama Valley. It is noteworthy that the red eastern part of member one is reminiscent of Sespe beds that range in age from late Eocene to early Miocene.

A comparison can also be made with the Vasquez series exposed 45 miles southeast of Lockwood Valley in the Soledad basin, which contains coarse sedimentary breccia similar to that on North Fork. Clasts in the Vasquez rocks are composed mostly of (a) granite, megascopically identical to Mount Pinos Granite and that appearing in the breccias of Plush Ranch member three; (b) augen gneiss identical to that occurring in the breccias of members three and five, and exposed in place on Frazier Mountain and Mount Pinos; (c) migmatites of the types associated with gneiss in the crystalline rocks surrounding Lockwood Valley; and (d) a few volcanic cobbles of the types found in the Caliente Formation and immediately subjacent beds. Anorthosite clasts are also found in the Vasquez series and are known to occur in successively higher beds stratigraphically as the Vasquez rocks are traced northwestward away from the San Gabriel Mountains (Muehlberger, 1954; Jahns and Muehlberger, 1954). The sources of most of the clasts in the Vasquez series are local. For instance, the augen gneiss and migmatite occur in place in Mint Canyon on U.S. Highway 6, ten miles northeast of Newhall, and Muehlberger reports that the granite appears in several places in this general region. Anorthosite is found in the western San Gabriel Mountains, adjoining sections of Vasquez rocks on the south. At Lang the lower portion of the Vasquez series contains borate deposits associated with olivine basalt flows, agglomerate, and porphyritic andesite bodies, together with red, yellow, and white arkose and pebble conglomerate, leucocratic tuff, and shale. These rocks are at least in part lacustrine.

The similarities are remarkable and suggest correlation of the Vasquez series with the Plush Ranch Formation. However, certain dangers are recognized. The Vasquez beds of Lang lie 45 miles southeast of the easternmost exposure of comparable Plush Ranch rocks, and they are on the opposite side of the San Gabriel fault. Further, although there is a strong gross similarity between the two groups of rocks that seems greater than that between the Plush Ranch and the "Vaqueros" and associated rocks in the southern San Joaquin Valley, it is not yet known whether the Plush Ranch and Vasquez sections will match on more detailed comparison. One possibility mitigates the geographic and structural paradox mentioned above. Crowell (1952b, and 1954a) has presented a case for about 20 miles of right lateral movement on the San Gabriel fault since Late Miocene time. If this movement is reversed and the rocks returned to their "original" positions, present outcrops of the units

Figure 6. Regional geologic map of parts of Kern, Santa Barbara, Ventura, and Los Angeles Counties, California.

would be about ten miles apart (fig. 6). No other similar sequences are known to the author and he tentatively correlates the Plush Ranch and Vasquez sections, fully realizing the uncertainties involved in view of the present lack of knowledge concerning the northern and central Transverse Ranges. More definite correlations are not possible until more is known of the petrography of clasts and the basement complex, and of movements on the large faults in the region.

Origin of the Plush Ranch Formation. The Plush Ranch Formation represents a sequence of continental sediments deposited in lacustrine, terrestrial, and fluvial environments. The major facts may be summarized as follows: direct evidence of continental origin is found in member four, where fresh water ostracods, fish and insect remains, and limestone breccia and travertine in a dominantly shaly section reflect a quiet shallow water environment, best interpreted as lacustrine. Subaerial conditions during deposition are indicated by the shape of mudflows in member three, the surficial erosion of basalt flows of member four, the fanglomeratic nature of member five, and the repetition throughout the formation of multicolored lenticular and rapidly transitional units.

The conglomerate of member one, containing cobbles of Eocene sandstone, probably originated from Eocene beds that may have extended over Mount Pinos. The predominantly fine-grained member two and lower member three probably also represent Eocene detritus. A northern source for beds higher in the section is revealed in breccia and associated arkose in member three; and they indicate early post-Eocene exposure of the basement. The picture during the deposition of members four and five would be that of a lake into which large alluvial fans were being built from the south and southwest (pl. 2). The breccia-bearing fans, composed of basement types now exposed to the south, may reflect the existence of a sizeable fault scarp at, or south of, the Big Pine fault. The situation is similar to that existing 20 miles to the southeast in the Ridge basin in Pliocene time (Eaton, 1939, p. 532; Crowell, 1950, pp. 1638-39, and 1954 b; Axelrod, 1950, pp. 170-174). The breccias in member three suggest faulting to the north at about the same time or a little earlier than the faulting during deposition of members 4 and 5. If this is so, the Plush Ranch Formation is a remnant of the filling of a structural trough, the trend of which was roughly east-west.

Miocene and Pliocene Rocks

Lockwood Valley is underlain by relatively gently deformed continental pebble and cobble conglomerate, arkose, siltstone, and clay. Stratigraphic relations are complex in detail; interfingering, overlap, and unconformities are present on small and large scales. Nevertheless, the rocks can be divided into three formations (Caliente, Lockwood Clay, and Quatal) on lithologic and stratigraphic bases (pl. 5). The division is not perfect, since each formation contains units virtually indistinguishable from those in other formations. Furthermore, much mapping was done by recognition of distinctive residuum developed on various units. Widespread terrace cover, which is not greatly different from the residuum, obscures relations.

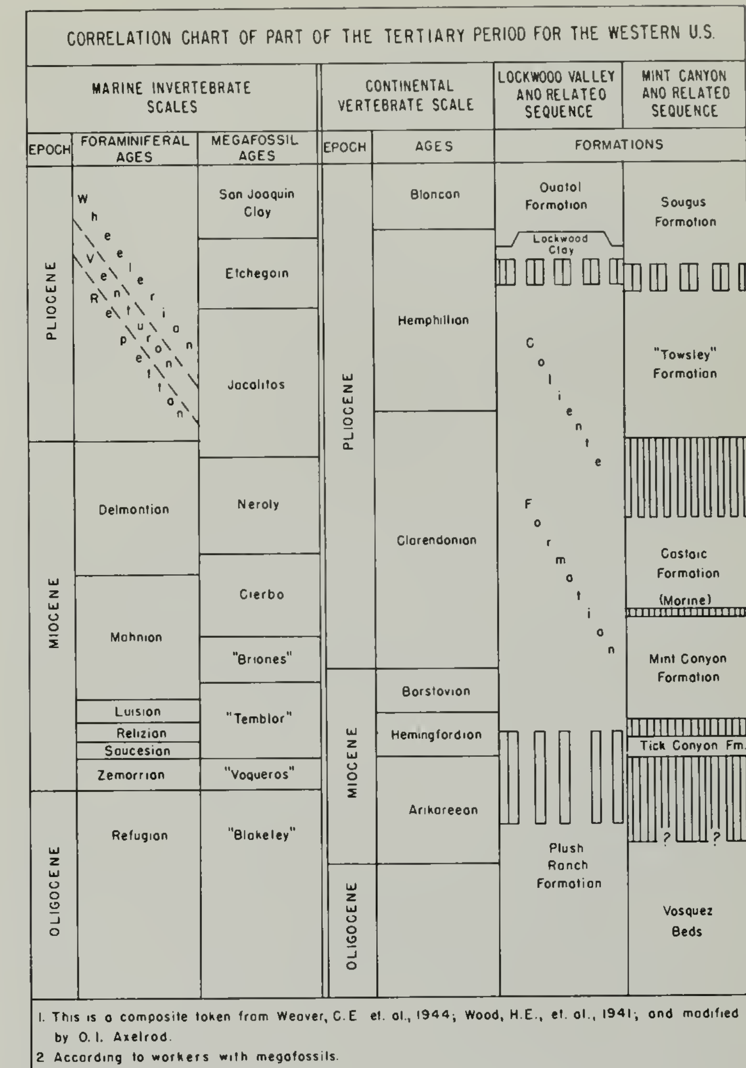


Figure 7. Correlation chart of part of the Tertiary period for the western United States.

The Caliente and Quatal Formations and their regional associates are of late Tertiary age, and some are dated on vertebrate evidence while others contain only invertibrate faunas. Thus, the disagreement between invertebrate and vertebrate paleontologists as to the position of the Miocene-Pliocene boundary would probably lead to confusion if we tried to apply the terms "Miocene" and "Pliocene" in discussing these rocks. Therefore, in this report late Tertiary rocks are discussed mainly in terms of Ages, the sequence of which is established and understood by most workers. "Miocene" is used in the sense of the invertebrate scale, unless otherwise stated (fig. 7).

Caliente Formation

The Caliente Formation was named by T. W. Dibblee, as referred to in a paper on vertebrate remains (Dibblee, in Stock, 1947; Schwade, 1954). It includes a group of rocks termed "Quatal sandstone" by Gazin (1930a, p. 18). The formation consists of interbedded conglomerate, arkose, siltstone, and clay, occurring in Quatal Canyon (fig. 1) and adjacent areas. It underlies a regionally persistent clay layer (Lockwood Clay), and contains vertebrate remains. The strata can be traced into Lockwood Valley with but one break, at the Big Pine fault. However, the lithology of the unit and sequence of overlying beds are so similar there is no question that the units are the same.

The Caliente Formation in Lockwood Valley underlies the Lockwood Clay and rests on basement where the base is exposed. The easternmost exposures are not in contact with the clay, but their lithology is distinctive of the Caliente Formation. Three members were mapped in Lockwood Valley. The lowest unit, member one, is mostly conglomeratic and contains member two, a lenticular lacustrine facies. The upper section, designated member three, is mostly arkose, with distinctive orange and red-brown clay and silty streaks. Westward in Dry Canyon, a thick basal unit appears which is not distinguished in Lockwood Valley. This unit is distinctly unconformable on Plush Ranch deposits (Adams, 1956).

Distribution, Thickness, and Topographic Expression. The Caliente Formation crops out in a band about a mile wide, just south of the Big Pine fault, from the western extremity of the area to the north-south portion of the county road; it also occurs on the north flank of Frazier Mountain, south and east of Chuchupate Ranger Station. It appears to underlie the central portion of Little Cuddy Valley in a long fault wedge (pl. 4), though exposures are poor and its presence is not certain. In the south a small patch is exposed east of Snedden Ranch (G.85, V.15). South of Chuchupate, member one rests depositionally on the gneisses of Frazier Mountain and is overlain unconformably by terrace deposits. In southern Lockwood Valley member three rests on basement east of Snedden Ranch, and interfingers upward into the Lockwood Clay. It is overlapped eastward by the clay, which rests on basement three-fourths of a mile east of Snedden Ranch (F.40, V.43). On the north side of Lockwood Valley, the Caliente Formation seems to be overlapped unconformably by more gently dipping Lockwood Clay on the south limb of the anticline east of Middle Fork (pl. 2, sec. 3, M.5, VII.0). At the western extremity of the area, the clay pinches out and the Caliente Formation is more or less conformable under the Quatal Formation (pl. 2, sec. 1). The base of the Caliente beds is not seen on the north side of Lockwood Valley.

The total thickness of the formation is not known in this area. The greatest measurable thickness, more than 2,000 feet, lies east of Chuchupate Ranger Station (pl. 2, sec. 7). In the anticline east of Middle Fork, 950 feet of Caliente beds are exposed and nearby well data indicate a possible thickness of 2,100 feet (Dutton #1; N.72, VII.21). Members one and three thin westward to 200 or 300 feet in Dry Canyon, but Adams' basal unit mentioned earlier is several hundred feet thick (Adams 1956), and the formation at least maintains its thickness into Quatal Canyon.

Most of the rocks of the Caliente Formation are moderately soft and give rise to low debris-strewn hills, the slopes of which are abrupt and scarred by bedrock outcrops at the heads of streams. Member two, however, contains mostly soft clay and silty layers which weather into rounded slopes on which no outcrops occur. Member one, which forms the bulk of the formation in Lockwood Valley, weathers into distinctive badland topography in which conglomerate lenses stand out in notable relief.

Lithology. The Caliente Formation consists of multicolored lenticular beds of poorly sorted pebble and cobble conglomerate which grade into coarse clay-rich arkose layers, and enclose sporadic silty bands, sandy clay layers, and light-colored tuffaceous beds. In general, the Caliente strata are more varicolored and pinkish in cast than other formations of the area. The coarse parts of member one are diverse shades of buff, pale brown, and light grey, all of which have the pinkish cast, but in strong light the tones become washed-out and pale pinkish-brown prevails. Silty and clayey bands are usually more strongly colored, red-brown, deep brown, and greenish grey predominating. The rocks weather to pale buff, grey, or white. Member two is typified by medium grey and pale green colors. The upper part of the formation contains white, cream, buff, and yellow-orange layers interspersed with numerous red-brown and orange streaks.

Bedding is usually poorly developed; although good bedding is seen in the finest phases, especially in member two and the uppermost layers in the formation. Lenticular conglomerate beds, averaging several inches in thickness and several feet in length, are scattered through most of the unit and locally aggregate into zones several feet thick and a hundred or more feet long. The percentage of the rock composed of conglomeratic layers ranges between two or three and 60 or 70, with 15 or 20 percent being most common. Channeling and scour-and-fill are common in the finer beds, but cross-stratification is rare. Member two contains beautifully preserved ripple-marked layers and numerous finely laminated beds. The overall aspect of the formation is that of very crude sorting of coarser parts, better than that of sedimentary breccias, but not as good as that of marine sandstone and conglomerate. The granule and coarse sand portions of most beds are virtually unsorted, and the sediment appears to have been deposited rapidly with only local and periodic washing and separation of particles.

The clasts are extremely variable in size, shape, and composition. Detailed pebble counts were made in members one and three of the Caliente Formation and members two, three, and four of the overlying Quatal Formation. The facts are summarized in table 2, and all of the details can be found in the author's dissertation (Carman, 1954, table 1). Localities for the counts were chosen on the basis of units already distinguished by mapping. Clasts counted ranged from granule-size to

Photo 16. Caliente member one, showing typical bedding and moderate badland fluting west of Seymour Creek in Lockwood Valley. Hammer (center) gives scale. Locality I.8, X.2.

Table 2. Summary of pebble-count data, Caliente and Quatal Formations.

Formation	Quatal						Caliente							
Member	2			3	4		3	1						
Sample number	21-147-7	21-145-14	21-147-13	27-11-32	20-127-1	20-168-1	21-147-26	21-147-25	20-128-20	20-165-2	20-168-20	26-64-19	21-152-14	27-11-30
Locality number	8	7	9	14	3	4	11	10	1	2	5	6	12	13
Percent volcanic clasts	38.0	39.7	0.7	7.6	60.8	54.3	17.4	55.7	48.8	22.9	65.7	47.5	68.3	70.9
Percent clasts definitely of local basement types	32.3	42.6	97.2	87.6	30.3	33.8	71.0	27.4	30.7	6.6	14.7	40.4	9.2	18.5
Ratio: Percent volcanic / Percent local basement	1.2	0.9	0.0	0.1	2.0	1.6	0.2	2.0	1.6	3.5	4.5	1.2	7.4	3.8
Percent anorthosite clasts	0.0	0.0	0.0	1.8	2.9	2.5	0.8	4.2	4.3	10.0	5.7	1.4	3.7	1.3
Total clasts in count	272	380	543	226	377	363	355	544	562	499	245	492	217	227

boulders 10 inches in diameter and were taken from rectangular areas about six feet long and four feet high. The pebbles and cobbles were examined megascopically and 29 rock types were distinguished, of which 26 appear in the Caliente beds. The rock types can be divided broadly into two groups: (a) volcanic, in which red, pink, purple, and white rocks ranging in composition from andesite to rhyolite predominate, and (b) basement rocks, composed mostly of plutonic igneous and high grade metamorphic rocks. Of the basement types, alaskite, light-colored gneiss, augen gneiss, migmatite, and biotite schist can be recognized as definitely local basement rocks. The fragments smaller than granule size are chiefly quartz and feldspar; however, the pinkish cast of the rocks comes from numerous minute red, pink, and purple volcanic particles in the sandy fractions. The cement for the most part is a mixture of calcite and clay. The latter composes a major proportion of the rock of member one, but is more restricted in members two and three.

Member One. This unit, forming 75 or 80 percent of the outcrop area of the Caliente Formation, appears along the Big Pine fault, reappears in the complex anticline on the western border of the area (S.00, V.00), and laps onto the crystalline complex on the north side of Frazier Mountain. It may lie unconformably below member three, but the contact is not well exposed. However, the fact that member three does not reappear at the proper stratigraphic level on the north limb of the anticline between Middle Fork and Amargosa Creeks indicates either unconformity or interfingering between members one and three (pl. 2, secs. 2 and 3). A paucity of volcanic cobbles in float near the Big Pine fault suggests that volcanic-poor member three may reappear very near the fault between those creeks *, but it is stratigraphically several hundred feet above its next exposure to the south. Better evidence for the uncomformity is found just west of Seymour Creek (I-J, IX-X), where the general trend of bedding in member one is north-south, reflecting gentle north-south-trending folds, whereas that of member three is consistently northeast-southwest.

The lithology of member one has been mostly covered in the general discussion of the formation. Most characteristic are well-rounded pink, red, and purple volcanic cobbles, and a small (one to ten percent) but persistent content of anorthosite clasts. The latter are megascopically identical with those of the San Gabriel Mountains, down to details of texture, shattering of grains, and white "crush" streaks through the rock. The anorthosite clasts range in size from granules to boulders two feet across, all of which are well-worn, and some are rather badly decomposed. The variability among the beds of this member is shown in part by the pebble counts. South of Chuchupate Ranger Station (C.72, XI.79), exposures contain an abnormal abundance of anorthosite and other unusual clasts such as alkali feldspar rocks and crystal fragments (table 2, sample number 20-165-2); exposures east of the station have a slightly lower volcanic to-"local" basement-type ratio than is normal (table 2, sample number 20-128-20). A pinkish-gray zone that crosses Seymour Creek in a large fault sliver (K.00, X.10 to I.00, XI.65) contains a larger number of migmatitic fragments than most of the member, and is overlain and underlain by more normal buff and pinkish-brown strata. A count shows that the clast content of sample number 26-64-19, collected just west of Seymour Creek (J.51, X.30) stratigraphically beneath the gray migmatitic layer, is abnormally high in alaskite and light-colored gneiss. These layers may be equivalent to the basal unit exposed in Dry Canyon for the following reasons: On Wagon Canyon road, near Dry Canyon, pinkish-buff Caliente conglomerate devoid of augen gneiss clasts but rich in coarse anorthosite and varied volcanic debris passes transitionally downward through about 40 feet into coarse gray beds containing cobbles and rounded boulders of augen gneiss, anorthosite, and volcanics. This gray unit is basal Caliente as de-

* See table 2 for characteristics of clasts of members one and three.

fined by Adams (1956), and is rich in gneissic clasts reworked from Plush Ranch beds.

Member Two. Member two occurs in a group of low hills that border the road to Plush Ranch on the north (N.7, VI.7, etc.). Here, thinly bedded green and orange siltstone and gray-green clay shale containing fresh water gastropods are interbedded with soft biotitic sandstone, and a few thin layers of white limestone. These are overlain by a white to gray pebbly sandstone. The exposed section is at least 850 feet thick (pl. 2, sec. 2). These beds finger out in the anticline eastward across Middle Fork, where they appear as hard, laminated and ripple-marked sandstone layers a few tens of feet thick overlain by a three-foot bed of white vitric tuff. A thin green silty and clayey layer, identical to the beds of member 2 across Middle Fork to the west, lies within typical member one beds on the south limb of the anticline (M.70, VI.85 and pl. 2, sec. 3). This layer thickens rapidly westward, and thins northward and eastward, pinching out in the fluted cliffs which display the north limb of the fold (M.86, VII.40). Member 2 reappears in the core of the anticline on the western edge of the area (S.60, IV.60). Here the pebbly sandstone has a pale yellowish-green cast and contains anorthosite and grey lapilli fragments.

The lithology and stratigraphic relations show that member two is a lenticular lacustrine unit within member one. It definitely interfingers with member one in the anticline east of Plush Ranch; moreover, there is evidence that it is underlain by that member farther west. Member one is very thin above member two in the anticline on the western edge of the area, but north of the fold a series of fault blocks expose hundreds of feet of member one, essentially conformable beneath the overlaying Quatal Formation, with no beds of member two (pl. 2, sec. 1). The conclusion is that member two pinches out northward and member one passes above and below it in the anticline (pl. 2, sec. 1).

Member Three. The third member is thickest where it crosses Seymour Creek, there measuring 1,000 feet (pl. 2, sec. 4). It is the most variable of the Caliente units, and has limited exposure. It forms the upper portion of the formation between Middle Fork (M.88, VI.43) and the north-south portion of the county road (H.35, X.25), and in a small area east of Snedden Ranch (G.85, V.15). The member does not weather to badland topography, and is in most respects more like the overlying Quatal Formation than the other members of the Caliente Formation. The western two-thirds of the unit consists of white to pale yellow-orange layers, ranging from arkose to cobble conglomerate, interbedded with orange and red-brown sandy clay and silt. These are lenticular beds, only a few feet thick. The conglomerate contains a more nearly oligomictic assemblage than other Caliente rocks, and anorthosite and volcanics are relatively rare, whereas basement types, typical of the terrane south and southeast of Lockwood Valley, predominate (table 2, sample number 21-147-26). East of Seymour Creek the lower part of the member is less highly colored, more homogeneous, and consists of pale cream pebble and cobble conglomerate containing subangular clasts of alaskite and light-colored gneiss of Frazier Mountain crystalline types. The upper parts contain coarse-grained and indistinctly bedded to fine-grained and laminated, pale orange, cream, and tan arkosic sandstone interbedded with a few light grey silty shale beds. There is a white limy bed at the top. Montmorillonitic clay is moderately abundant in the matrix of member three in the west, but eastward more sandy and clean beds have a calcareous matrix.

Northeast of Seymour Creek, along the Big Pine fault zone, (I.65, XI.50) is a wedge of rocks that fit the general description given for member 3 east of Seymour Creek, except for a comparison of clasts. The faulted wedge contains subangular to subrounded cobbles and boulders of light-colored granite, aplite, pegmatite, quartz diorite, migmatite, biotite schist, and quartzite. The rocks in this wedge are tentatively assigned to member three.

Age and Correlation. The dating of Caliente beds in Lockwood Valley involves several problems. No fossils were found in the Caliente Formation in the Lockwood Valley area, so its precise age is unknown; furthermore, the vertebrate fauna mentioned earlier, found in Caliente beds 10 to 12 miles northwest, has been subject to some dispute as to age (Gazin, 1930b; Wood, A. E., 1937; Vanderhoof, V. L., 1939). The best upper and lower age limits for Caliente beds come from the section on the north side of Caliente Mountain, 20 miles northwest of Quatal Canyon (fig. 6) where non-marine and marine sections interfinger. But the Caliente of Quatal Canyon is not contiguous with that on Caliente Mountain; moreover, there is some disagreement between the invertebrate and vertebrate time scales in this area.

Gazin first dated Caliente beds (1930b) as Barstovian on the basis of *Merychippus sumani* from a locality on the south side of Quatal Canyon. The fauna "is scattered through these upper beds from the bottom of a very conspicuous dark brown gypsiferous clay stratum (Lockwood Clay) to a level at least several hundred feet lower" (Gazin in 1930b, p. 59). Gazin (1930b, p. 63) concluded: "While the Cuyama fauna is too incompletely known to permit a satisfactory determination of exact time relationships to the Mint Canyon, it appears possible that the former is slightly older than the latter or occupies perhaps an early stage in the longer period represented by the entire Mint Canyon assemblage."

A second locality, on the north side of Apache Canyon, and also under the Lockwood Clay, yielded specimens identified by Gazin as *Protohippus* sp. and *Hipparion* sp., as well as a group of rodents.

Wood (1937) considered the Caliente Formation to be "basal Pliocene" (early Clarendonian) on the basis of a horse calcaneum "near *Plesippus*" and some rodents and logomorphs he collected at the Apache Canyon locality. Vanderhoof (1939) reported *Pliohippus tantalus* from the Apache Canyon locality and also concluded that the beds are "lowest Pliocene." Gazin * now believes that the Apache Canyon fauna is possibly "Pliocene" (early Clarendonian), and somewhat younger than the Quatal Canyon forms, which he still places in the "upper Miocene" (late Barstovian). The terms Miocene and Pliocene are obviously being used in the sense of most American vertebrate paleontologists (fig. 7). Since both fossil localities are stratigraphically near the Lockwood Clay, it is probable that unconformable relations between the clay and underlying beds, seen in Dry Creek Canyon (Gazin, 1930a, p. 22 and fig. 9), bring beds of different age into

* Abstract of contribution by Gazin for GSA Memoir on the Continental Cenozoic of America (in preparation).

contact with the clay. Dibblee and Schwade (Schwade, 1954), in recent regional mapping in the eastern Cuyama Valley, date the Caliente Formation as "middle (?) and lower (?) Miocene," using the invertebrate time scale (i.e., "Briones" and "Temblor," cf. fig. 7). They base this age on lithologic and stratigraphic correlation with Caliente beds on Caliente Mountain, which have been considered to be of "Temblor" and "Briones" age (Eaton, J. E., et al., 1941, fig. 8; Dougherty, J. F., 1940). Thus, they essentially agree with Gazin (fig. 7) if allowance is made for the difference in time scales.

Current work by D. E. Savage (1957) in Cuyama Valley is refining the dating of the Caliente Formation even further. New mammalian assemblages have been found a little below the Lockwood Clay in Dry Canyon as well as in Quatal and Apache Canyons. In this region Caliente beds "range in age from Hemingfordian (southeast side of Dry Canyon), through Barstovian (in Quatal, Apache, and Dry Canyons), and into Clarendonian or later (Quatal and Apache Canyons)" (D. E. Savage, personal communication, 1957). On Caliente Mountain, Savage (1957) reports fossil mammals in Caliente beds and these mammals range in age from Hemingfordian through Hemphillian. In the lower portions there is good agreement between vertebrate and invertebrate dating, with beds above and below the "Triple Basalts" being dated as Barstovian (?) and Hemingfordian respectively by Savage (1957), and "Briones" and "Temblor" respectively by Eaton, et al. (1941, fig. 8). However, the findings of Savage higher in the section do not match Schwade's conclusions. Savage (1957) dates the Quatal Formation overlying the Caliente as "late Pliocene" (vertebrate scale), apparently Blancan, and no older than late Hemphillian. Schwade, on the other hand, considers the Quatal to be "upper (?) Miocene" (invertebrate scale), and equivalent to marine Santa Margarita sandstone with which it is said to interfinger subsurface southwest across Cuyama Valley (cf. also Weaver, et al., 1944). Thus, the Quatal would be no younger than Neroly or upper Clarendonian (fig. 7). Evidence discussed in the section on the age of the Quatal Formation supports Savage's dating for Quatal beds in Lockwood Valley.

These considerations make it impossible to place a certain upper limit on the age of the Caliente Formation. Tentatively, it is placed high in the Hemphillian, following most recent dating from the Caliente Range (fig. 7). Evidence in southeast Cuyama Valley indicates Hemingfordian (?) through lower Clarendonian age. This age is tentatively applied to Caliente members one and two in Lockwood Valley. This part of the Caliente Formation would thus approximately correlate with the Mint Canyon formation (fig. 7). The presence of the tuff in Caliente member two, and a possibility that the unusually high clay content of member one may partly reflect tuffaceous content, lend credibility to a temporal correlation of the two formations, since the Mint Canyon section contains numerous tuffs. Caliente member three is similar to Quatal lithology, suggesting that the Lockwood Valley Caliente Formation may include beds as young as late Clarendonian or even Hemphillian. This approximate age is tentatively assigned to member three.

Origin and Conditions of Deposition. Lithology and fossil content demonstrate that the Caliente is continental and chiefly fluvial. The presence of clasts apparently foreign to the immediate area suggests that the sediments represent the channel of a through-flowing river. The coarseness of some beds and the localized increase in numbers of clasts of local basement types (table 2, samples 26-64-19 and 20-128-20) indicate fans building into, or tributaries entering, a main valley of a large river. Caliente beds of southeastern Cuyama Valley are replaced northwestward by a marine section (Reed and Hollister, 1936, p. 82; Hill, M., personal communication; Eaton, et al., 1941), and it appears that the region around Lockwood Valley and Mount Pinos was a fairly low coastal region in late Barstovian and Clarendonian time.

Clay is thoroughly mixed through coarse and fine layers, especially in member one, and its proportion is abnormally high (up to 30 percent). It distinguishes the strata from adjacent formations as well as from more well-washed deposits forming today in many streams of southern California. The occurrence is perhaps a reflection of the different climate which prevailed in this region during Barstovian and Clarendonian time. Nearby floras of this age show that the climate was arid subtropical with a biseasonal distribution of rainfall that averaged 25 to 30 inches annually (Axelrod, 1950, p. 238, and personal communication). The climatic conditions that most nearly fit this description exist today in southern Sonora and in Sinaloa, Mexico. In that region the high year-round temperature, with rainfall distributed through a large part of the year and concentrated in heavy summer showers, results in strong chemical weathering and periodic high discharge of streams heavily loaded with clay and coarse material (Axelrod, personal communication). Under these circumstances, the mixture of large amounts of clay with coarse fluvial deposits is to be expected as the streams rapidly lose volume during the short dry periods. Or, as mentioned earlier, the clay may be the result of decomposition of a tuffaceous matrix in these rocks.

The source of clasts is also a problem. Many are probably of local derivation, such as granitic and gneissic rocks of various sorts, but the volcanic and anorthosite cobbles and boulders are apparently foreign. Caliente clasts show a wide variety of compositions among the volcanic types, ranging from basalt to rhyolite, but intermediate types dominate. There are notably few fragments of Plush Ranch-type basalt. Rhyolite plugs on Frazier Mountain are dated as probably upper Pliocene (Crowell, 1950, p. 1631), and these rocks have not been detected in the Caliente beds. Large volcanic pebbles occur in the Eocene conglomerate on San Guillermo Creek. These clasts are smaller than many appearing in Caliente beds; moreover, they are more restricted in lithology and color, mostly dark brown and green, heavily iron-stained andesite. It is doubtful whether these Eocene layers contributed more than minor amounts to the Caliente rocks.

The Miocene volcanics of the southern coast ranges, southwest to northwest of the Caliente Formation, range from basalt to rhyolite, but these are almost entirely submarine (Taliaferro, 1943, pp. 142-144). Cobbles quite similar to the Caliente volcanics of Lockwood Valley are abundant in conglomerates 35 miles to the northeast (Chanac Formation of Clarendonian age), and 40 miles to the southeast (Mint Canyon Formation of Barstovian-Clarendonian age).

Tertiary extrusives of a wide variety of composition, textures, and colors are abundant in the Mojave Desert, as may be seen near Rosamond in the western portion and in the Calico Mountains farther east. At least some of these have been dated as middle Miocene or older (McCulloh, 1954, p. 22), and so are as old or older than the Caliente Formation. Furthermore, in view of the probability that drainage was dominantly westward or southwestward in Vaqueros through Neroly time (Reed, 1933, p. 184; Reed and Hollister, 1936, pp. 80-82; Eaton, J. E., et al., 1941, figs. 1, 4; Corey, 1954, figs. 4-7), the Mojave Desert is considered the most likely ultimate source for the volcanic clasts.

The anorthosite presents a different problem. The occurrence of anorthosite boulders one to two feet in diameter, with only subrounded shape, indicates that they have not had a complex history of transportation. In the Transverse Ranges anorthosite is known to occur in place only in the San Gabriel Mountains (fig. 6). Possible other places of exposure have been discussed by Crowell, (1952b, pp. 2030-33; 1954a, pp. 49-50), in connection with the occurrence of anorthosite in marine beds of middle Mohnian age south of the Piru Mountains and just west of the San Gabriel fault. He concludes that the source area is the San Gabriel Mountains, using as evidence the directions of fingering-out and coarsening of anorthosite clasts, which indicate an eastward source across the San Gabriel fault. Reconnaissance of basement terrane northeastward for about 20 miles from the southern Ridge Basin does not reveal anorthositic rocks (Crowell, 1952, p. 2031). Uppermost Tertiary sediments conceal a large area in the northern Ridge Basin (fig. 6), and this area is a possible source. However, the sediments are mostly continental beds of local derivation, and though they are seen to overlap crystalline rocks (Crowell, 1954b, Map Sheet 7) and their clasts reflect the composition of the basement, they do not contain anorthosite fragments. The basement rocks of the Piru Mountains south of Lockwood Valley are only slightly known, but there is no indication yet of anorthosite, and farther south the crystalline rocks are overlapped by a thick marine Eocene section. To the west the Transverse Ranges are also underlain by a thick section of Eocene and younger marine rocks. Northward the basement rocks of most of the San Emigdio and Tehachapi Mountains are likewise only slightly known. Anorthosite might occur in the more remote regions which might have supplied clasts for the rocks of Lockwood Valley. If such occurrences exist they have supplied virtually no detritus to many younger beds rich in known basement-types (Chanac Formation, Hungry Valley beds, Quatal Formation). Further, the almost ubiquitous appearance of anorthosite in the Caliente beds from their easternmost exposures to Quatal Canyon, a distance of about 25 miles, makes it seem highly improbable that the source for the clasts is a relatively restricted mass such as would be necessary to have escaped notice. Although a major portion of the other sediments surrounding the northern part of the Transverse Ranges are not known to contain anorthosite, they have not been studied with such a thing in mind by most geologists, and it may have been overlooked. Obviously, more information is needed concerning the types of basement rocks and the occurrence of anorthosite in the sediments, especially in the regions northwest, north, and northeast of Lockwood Valley.

Since the anorthosite in the Caliente beds is identical to that occurring in the San Gabriel Mountains, it is worthwhile to investigate the possibilities arising if we consider this to be the ultimate source of these rocks. Two chief avenues of transport are possible. The first avenue is suggested by the Miocene anorthosite-bearing breccias and associated rocks south of Piru Mountains and west of the San Gabriel fault. The breccias lap out northward onto basement and are too young to have contributed to Caliente beds; but they are underlain by Oligocene (Sespe) and Eocene rocks that also contain anorthosite (V. McMath, personal communication). Perhaps these older anorthosite-bearing beds covered the basement now exposed to the north in the Piru Mountains, and Caliente and older anorthosites were derived from them. This requires reworking of the anorthosite clasts and they should be fairly well rounded. Moreover, augen gneiss was apparently exposed to the south immediately before deposition of the Caliente beds, as shown by the nature of augen gneiss clasts in Plush Ranch member five. The eastern equivalent of member five includes beds containing rocks apparently related to anorthosite (see discussion of member five), but these related rock types are not found in the Caliente Formation.

The second possibility is that the Caliente beds are equivalent, in part, to the Mint Canyon Formation, and represent a westward extension of its general depositional environment. The Mint Canyon strata contain anorthosite and volcanic clasts identical to those in the Caliente Formation. The connection between the units could occur in either of two ways. The Mint Canyon sequence occurs east of Castaic (fig. 6), and disappears north-westward under Ridge Basin deposits, under which it might continue, and at the time of deposition have extended across Frazier Mountain to connect with Caliente member one. Here, the lack of Caliente-type volcanics and anorthosite in Pliocene Hungry Valley beds of the northern Ridge Basin gives difficulty, because those beds should reflect the stripping of beds extending over Frazier Mountain. A more likely circumstance is presented by Crowell's hypothesis of lateral displacement on the San Gabriel fault since late Miocene (middle Mohnian) time (Crowell, 1952 and 1954). Figure 6 shows the position and distribution of the Caliente, Mint Canyon, Plush Ranch, and Vasquez Formations, as they are now, and their position before postulated movement on the San Gabriel fault. The Plush Ranch and Caliente Formations would have lain opposite a westward extension of the Mint Canyon beds under the Ridge Basin deposits, and across the San Gabriel fault. The connection is remarkably close, and the author favors this explanation.

The influx of the volcanics, together with anorthosite, as foreign elements began early in the deposition of the Caliente, as indicated in the outcrop of basal Caliente beds mentioned earlier on Wagon Canyon road west of the area. Here, the beds consist of conglomerate containing volcanic and anorthosite cobbles together with abundant augen gneiss cobbles and boulders. The lithology of member three shows that the Lockwood Valley region was cut off from the source of volcanics and anorthosite sometime during deposition of the Caliente Formation (Mohnian?), and that thereafter the major source of

Photo 17. Looking east toward exposure of Caliente, Lockwood clay, and Quatal Formations in anticline on western edge of area. Clay overlies Caliente member one (right); right of center, clay is pinching out. Section, bottom to top, is Caliente member one (Tc 1), Lockwood Clay (Tlc), badland-weathering lowermost Quatal member three (Tq 3a), orange and brown siltstone of member three (Tq 3b). Left of center, same section with clay gone and Caliente and Quatal essentially conformable. Middle of left half, Quatal (right) dropped against Caliente (left) on fault. Exposure is 40 feet high in center. Locality R.6, V.3.

clasts was local crystalline rocks. These events probably match the start of postulated lateral movements on the San Gabriel fault (Crowell, 1952b, p. 2034).

The above discussion leads to a picture of changing conditions during Plush Ranch deposition, with reduction of rugged topography that gave rise to the great breccia sequences and rocks of local derivation. The rivers flowing westward on this surface apparently worked headward and tapped regions near the present Mojave Desert containing either the volcanics themselves or sediments with such clasts in them. The anorthosite washed northward from the San Gabriel Mountains into these rivers and the two types of clasts became mixed in their westward transport. As the area around Lockwood Valley became lower, the foreign clasts began to predominate due to capture of more easterly basins; although locally relief was great enough for alluvial fans to form distinctive interbeds. Lateral movements on the San Gabriel fault and accompanying uplift in the Piru Mountains combined to cut off the Lockwood Valley area from the sources of foreign clasts during late Mohnian time.

Lockwood Clay

The Lockwood Clay was named by Gazin (1930a, unpublished), and the unit as here presented is identical with his. The name has also been used in an economic report on expansible shale (Rogers and Chesterman, 1957, p. 522). The clay is predominantly montmorillonite, and forms a remarkably persistent and uniform layer. The excellent exposure in the eastern portion of Lockwood Valley (G.40, IX.03; Mount Pinos Quadrangle, T. 8 N., R. 20 W., Sec. 30, NE.¼) is here designated as the type locality. The unit is best exposed around the type locality and crops out intermittently through the low central and southern portions of the valley. It also occurs in the core of the anticline on the western edge of the area. The formation varies in thickness, pinches out locally, and attains a maximum thickness of about 275 feet. The latter figure includes several tens of feet of silt and fine sand interbedded in its upper and lower parts; the thickness of true clay is probably not over 100 or 150 feet. West of Lockwood Valley the clay maintains a strikingly uniform thickness of about 75 feet over wide areas, as can be seen in upper Dry Canyon, and it extends at least as far as the north wall of Quatal Canyon.

Lithology. The Lockwood Clay is pale tan to gray when fresh, but it weathers dark to brown, red-brown, and greenish brown. It gives rise to a friable granular soil which is soft and porous when dry. The typical exposure of the beds is that of low rounded hillocks devoid of vegetation, whose surfaces commonly display excellent adobe structure characteristic of soils rich in montmorillonitic clay (Kelly, 1942). Sandstone interbedded with the clay is fine-grained, friable, and biotitic. It ranges from white, through grey, and grey-green, imparting a grey or grey-green cast to weathered surfaces. White bentonitic zones are found locally at its base (I.40, VIII.84) and in sandstone a few feet above the base (G.92, IX.10). In a few places it contains gypsum.

Eight specimens from various localities were analyzed with the X-ray diffractometer. All showed high montmorillonite content, to the near exclusion of other clays.*

* The X-ray charts were compared with standard charts made from API standard clay samples.

A little kaolinite occurs in two specimens, and may be present in several more. Quartz, oligoclase, and muscovite are present in all specimens, and calcite is abundant in some. A thin section shows the material to be extremely fine-grained, to contain sparse angular quartz and feldspar fragments, and to have a few angular and thin lunate patches of montmorillonite which could be interpreted as relic shard structure, but which are of uncertain origin.

The Lockwood Clay is visibly unconformable on Caliente beds in Dry Canyon (Gazin, 1930a); it bears complex relations to these beds on the western edge of the Lockwood Valley area (R.50, V.23) where the beds reveal local reworking of both units and local unconformity with overlying beds of the Quatal Formation; and it appears to overlap Caliente member three southwest of Adobe hill (M.35, VI.67 to M.81, VI.48). Mention has been made of the faunal differences in beds between Quatal and Apache Canyons. From these observations it is concluded that the clay is generally unconformable on the Caliente Formation; though locally, as east of Snedden Ranch (G.95, V.27), there is apparent conformity. The upper contact shows mostly gradational and interfingering relations with overlying Quatal strata (M.20, VI.63).

Age and Correlation. The only means of dating the Lockwood Clay is by its stratigraphic position since no fossils were found in it. The faunas collected in Apache and Quatal Canyons occur just beneath the Lockwood Clay (Gazin, 1930b; Wood, 1937), and its greatest possible age is thus near the Barstovian-Clarendonian boundary. However, contact relations indicate that the clay is more closely related in time to the deposition of the Quatal than the Caliente Formations. It is therefore taken to be of essentially the same age as the lower parts of the Quatal Formation, the age of which is discussed later, and determined as Blancan.

Origin. The origin of clay deposits of this type is a complex problem and there are a number of possible solutions. Gazin (1930a, pp. 22-23) was undecided on its origin, but he pointed out that the unusual persistence and constant thickness of the beds suggested volcanic origin. Establishment of the fact that the material is highly montmorillonitic, the presence of white beds of nearly pure montmorillonite at its base and just above it, and the suggestion of a relic tuffaceous element in the main clay, all indicate that it is of volcanic origin and probably nearly a true bentonite in the sense defined by Ross and Shannon, ". . . . a rock composed essentially of a crystalline clay-like mineral formed by the devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash." (See Ross and Hendricks, 1945, p. 65). The interbedding with other sediments shows that the unit does not represent a single ashfall, and suggests that some of the clay, or its parent material, was transported by water.

The conclusion that this unit is of volcanic derivation assumes considerable importance with regard to dating the overlying formation; for the Lockwood Clay thus forms an essentially synchronous unit within this sequence of beds and cannot be considered to have transgressed a great deal of time.

Quatal Formation

Arkose and conglomerate overlying the Lockwood Clay have been designated the Quatal Formation by Hill, Dibblee, and Schwade, who include the Lockwood Clay in the formation (Hill, Dibblee, to be published; Schwade, 1954). The Lockwood Clay was called the "Quatal red clay member" in a recent economic report (Ver Planck, 1952, p. 35), but the present author prefers to reserve the name "Quatal" for the thick continental sequence above the clay. In the Lockwood Valley region these rocks are best exposed on the slopes of Sunset Ridge on the western margin of the area (P.50, III.25 to R.50, VI.25). Four members are recognized in Lockwood Valley, the lower two of which are discontinuous and pinch out in such a way that at different places various ones rest on the Lockwood Clay.

Distribution, Thickness, and Topographic Expression. Quatal rocks crop out mostly in the southern half of the area and in Little Cuddy Valley. They do not occur north of the Big Pine fault in this region, but westward they have wide exposure in Dry Canyon, uppermost Apache Canyon, and across Quatal Canyon. Inasmuch as the top of the unit is not exposed in the Lockwood Valley area and its members thicken and thin rapidly, its total thickness is not determinable. At least 1,600 feet are exposed in Little Cuddy Valley, and, although the boundaries are obscured by terrace and alluvial deposits, it is probable that the section measures at least 2,100 feet (pl. 2, sec. 5). The portion of the section exposed on Sunset Ridge is over 1,000 feet thick, whereas in Dry Canyon Gazin (1930a) found it thinning to a few hundred feet.

The formation weathers into sharp ridges with smooth slopes where stream cutting is most active, and it weathers into low, rounded, rubble-strewn hills in the main valleys. In both cases exposures are poor, and only in the deepest gullies and most freshly cut stream banks can the details of texture and structure be seen. Badland topography has developed locally on outcrops of the basal part of member three along Lockwood Creek (K.07, V.12) and on the western margin of the area.

Lithology. The lithology of these beds is more varied than that of the Caliente Formation. The section consists chiefly of a series of interbedded pale-colored arkosic pebble and cobble conglomerate, brown and orange siltstone, and mudstone. Minor elements are thin-bedded buff and white limestone lenses; coarse conglomerate, fanglomerate, and breccia; and dark-colored clay layers. Most of the Quatal Formation differs from the Caliente beds in that the rocks are more clean-washed, well-sorted and bedded, more nearly oligomictic (Table 2), and pebbly arkose dominates over coarser conglomerate. Bedding ranges from laminated to coarse massive layers several feet thick in which virtually no stratification is seen, except for small lenses of pebbles and cobbles. Cross-stratification, scour-and-fill, and graded bedding are common. The grains are mostly angular, although the larger clasts in the conglomerates are subangular and subrounded. The chief constituents of the conglomerates are alaskite, Mount Pinos Granite and other light-colored granitics, augen gneiss, light-colored gneiss, and some migmatite. Volcanic clasts of the types seen in Caliente beds are common in a few layers, but they are more restricted in type and much smaller than those in the lower formation. The formation is very calcareous, and some rocks are nearly white due to interstitial calcite. Hardpan layers are common, and, exposed on the low hills in Lockwood Valley (e.g. M.90, V.58), they give evidence of an old water-table level in an earlier phase of erosion.

Member One. Member one is mostly a coarse gray-green sandstone and conglomerate with interbedded shale and clay bands. The member is well exposed on the south limb of the syncline on San Guillermo Creek (L.65, IV.07 and south). The beds are exposed north of Yellowjacket Ridge almost to the outlet of Lockwood Creek (G.90, IV.70) and along the eastern base of Sunset Ridge (P.15, IV.50). The unit rests on crystalline rocks on San Guillermo Creek (L.51, I.40) and along the north side of Yellowjacket Ridge (G.87, IV.60) where it has a maximum thickness of about 400 feet (pl. 2, sec. 3). There it is a coarse, gray-green sedimentary breccia and conglomerate, composed of local basement-type clasts, with interlayered brownish-orange clay streaks. The beds thin and become finer northward, westward, and eastward. Thus, at the base of Sunset Ridge they consist of medium- to coarse-grained biotitic sandstone with numerous granitic, gneissic, and migmatite pebbles and granules. These layers grade upward and downward into buff and orange-tan siltstone, characteristic of the lower portions of member three. In the anticline to the west (R.85, IV.75), the unit gives way to member three and its occurrence is only suggested by a light brown sandstone containing a few green streaks interbedded with the buff and orange siltstone. Between Middle Fork and Amargosa Creek, and across Seymour Creek, it appears locally as a green fine-grained sandstone, too thin to map, resting on the Lockwood Clay. East of Snedden ranch it is a basal conglomerate from a few feet to only inches thick.

Stratigraphic distribution and lithology show the member to be an alluvial fan deposit built northward from the vicinity of Yellowjacket Ridge tapering out into Lockwood Valley.

Member Two. This member consists chiefly of pale buff, cream, and yellowish arkose and pebble conglomerate with numerous thin lenses of limestone in its lower portions. The member occurs at and near the base of the Quatal Formation, often lying on the Lockwood Clay. Most of the low rounded hills in the central portion of Lockwood Valley are cut from member two and are covered by a characteristic light gray to pale yellowish-orange, powdery, pebble- and cobble-rich soil. The beds of member 2 rest on Lockwood Clay and Quatal member one at the eastern base of Sunset Ridge, where they are only a few tens of feet thick, and they do not appear west of the ridge. They thicken considerably eastward and attain their maximum thickness of about 700 feet on the western side of Frazier Mountain, where they overlap the Lockwood Clay and rest on augen gneiss (F.20, V.43). There, a white arkose band overlies the more yellow and buff-colored, limy lower layers (F.50, V.85). This white band is not seen elsewhere and it is arbitrarily placed in this member, rather than the more orange-colored and clay-streaked overlying unit. Stratigraphic and structural relations indicate that this member interfingers with members one and three southward across central Lockwood Valley and westward under Sunset Ridge (pl. 2, secs. 3 and 8), is cut out along north-northwest-trending faults in northeastern Lockwood Valley (G.75, X.26), and thins considerably northward from the southeastern corner of the valley. The beds are not differentiated in Little Cuddy Valley, chiefly because of poor exposures, though layers of similar lithology do occur.

Locally in the lower parts of the member, gray-green and brown clay, shale, and mudstone are associated with very thin-bedded sandstone and limestone. This lithology suggests deposition in a small, shallow, periodically desiccated lake or series of ponds.

Member Three. The third member is well exposed on Sunset Ridge. There it rests on the Lockwood Clay and is made up of interbedded coarse orange-colored arkose, conglomerate, and some clay, with brown and orange siltstone concentrated in its lower portions. Orange hues predominate in the member, though buff, tan, and yellow zones are common. The same strata overlie member one in the syncline north of Yellowjacket ridge, and rest on member two in a north-south belt along the west flank of Frazier Mountain (F.95, V.65, to H.25, XI.75). They pass under the Frazier Mountain thrust at the southeast, whereas on the north they are bounded by the same north-northwest set of faults that truncate member two. Beds with the same lithology occur in the undifferentiated Little Cuddy Valley section. A local coarsely conglomeratic phase at the base of member 3 appears in eastern Lockwood Valley (G.95, VIII.98, to G.30, X.03). This rock is very poorly sorted and contains chiefly subangular gneiss and migmatite pebbles and cobbles. Gray streaks are common in some of the fresh exposures, but the rock weathers to a rather bright orange. This conglomerate lithofacies differs from the rest of the member in its coarseness, and it probably represents an alluvial fan or a local channel deposit. This member is at least 1,000 feet thick on Sunset Ridge, but the top is not seen and a complete section is not exposed in the mapped area.

Member Four. This unit rests on member three in a narrow band along the west side of Frazier Mountain (F.55, VII.90 to H.14, XII.08). It also forms the northern upper portion of the undifferentiated beds in Little Cuddy Valley.

The rock is predominantly pink and reddish-gray, pebble and cobble conglomerate. Pebble counts show similarity with Caliente member one (table 2, 20-127-1 and 20-168-1). It weathers into badland topography in one place (F.87, IX.73), but mostly its slopes are smoother than those of the Caliente beds. The clay fraction is localized into layers rather than being scattered through the coarse parts, as is the case with the beds having typical badland surfaces. Also, the clasts are smaller, concentrated in thicker more evenly distributed beds, and conglomeratic lenses typical of the older formation do not occur. It is by these features, together with its stratigraphic position, that member four is distinguished from the Caliente rocks. However, the local distribution, and striking similarities with older beds make it likely that it represents a reworking of the Caliente rocks.

Age and Correlation. No fossils were found in the Quatal Formation and its dating can only be approached indirectly. The age of the Quatal in Cuyama Valley was mentioned in connection with the age of the Caliente Formation. As concluded there, the disparity between Schwade's (1954) and Savage's (1957) dating cannot be resolved in this area. Tentatively, Savage's dating is accepted and Quatal beds on Caliente Mountain are considered Blancan.

Of course, caution is required in applying this age to beds 35 miles away in Lockwood Valley. It is in this connection that the Lockwood Clay is important stratigraphically; for it is apparently a nearly synchronous ash fall unit and is everywhere closely related to Quatal beds. It seems most likely, therefore, that the Quatal Formation is reasonably uniform in age and not strongly transgressive of time. Thus the dating of Quatal beds across southeastern Cuyama Valley should hold approximately into Lockwood Valley and a late Hemphillian-Blancan (Etchegoin-San Joaquin) age is likely. Strong support for this view comes from the dating of Hungry Valley beds east of Frazier Mountain. These are lithologically very similar to Quatal beds and they extend westward under the Frazier Mountain thrust. Quatal beds extend eastward under the thrust, and the two units are only about two miles apart in the unmapped region south of Frazier Mountain. Professor Chester Stock dated lower Hungry Valley beds as probably "late Hemphillian or early Blancan" (in Crowell, 1950, p. 1638).

Origin. The lithology and stratigraphic distribution of Quatal members indicate probable continental and fluviatile origin in Lockwood Valley. Beds of equivalent stratigraphic position and lithology in southeast Cuyama Valley are considered continental (Schwade, 1954).

Rocks of Uncertain Age

An isolated group of shale and sandstone with minor conglomerate, limestone, and tuff occurs in the northeastern corner of the area in the wedge at the intersection of the Big Pine and San Andreas faults. There is little evidence of their age and they are mostly unlike any of the other formations. At points one and two miles west of Cuddy Ranch, they seem to rest on granitic basement (G.54, XIV.10, and I.40, XIV.85), but terrace deposits obscure relations. The beds exhibit mostly rounded surfaces with poor exposures, though a thin layer, caught in complex imbricate structure northeast of Cuddy Ranch, shows badland weathering (E.35, XV.00). The thickness of this section is unknown due to faulting and other complexities of structure, but it is more than several hundred feet (pl. 2, sec. 6).

The high hill north of Cuddy Ranch (D-G, XV-XVI) is composed dominantly of gray-green, gray, and brown shale with interbedded layers of hard slabby sandstone, siltstone, and mudstone, all of which weather to dull greenish-brown. There are a few locally distinctive layers, such as, cream-colored tuffaceous beds a few inches thick, a deep-red, hard, gritty sandstone band, and a coarse, yellow, well-indurated arkose bed. These sandy layers are a few feet thick and are discontinuous; whether this is due to faulting or conditions of deposition is unknown. The more brown slabby sandstones are much like those which comprise low hills to the west and north of the larger prominence, and are gritty, brown and gray arkose and feldspathic sandstone, rich in blue-gray feldspar, which weather to various shades of brown. The fabrics vary from fine-grained and laminated, to coarse-grained and unsorted, and to pebble conglomerates, in which good bedding is developed. Cross-stratification, graded beds and local cut-and-fill are common. The grains are angular, but the clasts in conglomeratic layers are mostly subrounded. The sandstone and arkose contain dark-brown and gray limestone and limy siltstone layers several inches thick, which with the coarser clastics, are ramified with white calcareous seams.

The shale mentioned above lies with apparent conformity on a band of pale brown to gray limestone which is ten to fifty feet thick. The limestone is travertinous, highly porous, and contains fresh-water gastropod remains. This bed rests, also with apparent conformity, on a coarse, soft, yellow arkose, the thickness of which is unknown. The arkose contains two beds of dense blue-gray tuff, each about six feet thick, and several distinctive blue-gray layers set with pinkish-orange feldspars. Badland weathering occurs in these arkoses.

These rocks are not easily matched with previously described formations. Lithologically, the shale and slabby sandstone are closest to the Eocene rocks. They are of marine aspect, except for the travertinous limestone and coarse soft arkose. Dibblee (personal communication) and Gazin (1930a) both correlate them with the Eocene section to the west on Mount Pinos. However, the shale is darker and less fissile, and the sandstone is more highly colored than any seen in the Eocene section. The shale is more like Crowell's (1947, p. 60) shale of unknown age and the Santa Margarita shale farther east than any others seen in the Frazier Mountain-Mount Pinos region. White arkosic conglomerate crops out in three places northwest of Cuddy Ranch (G.22, XV.25; G.35, XV.40; F.22, XIV.82). It has the aspect of either the light arkoses of the Quatal Formation, or upper Caliente beds. An exposure of clay, several acres in extent, (G.35, XIV.84) appears to be identical with the Lockwood Clay, even to having fine-grained gray sandstone streaks interbedded. The relations between the conglomerate and clay and the more abundant topographically higher surrounding sandstone are not known certainly, but it is possible that these are underlying beds that show through the sandstone, and are in fact part of the continental section which appears in Lockwood Valley. Support for this view comes from a recent find of equid remains of probable Barstovian age in the varicolored badland-weathering sequence just northeast of Cuddy Ranch (D.E. Savage, personal communication, 1957).

Quaternary Rocks

The Quaternary rocks of the Lockwood Valley area have been divided into three units. The oldest of these, the Frazier Mountain Formation, rests unconformably under younger terraces and valley alluvium (pl. 3). It represents alluvial fan, landslide, and channel-fill material which has been dissected into terrace-like forms. A second unit consists of terraces capping the older group. These are composite, having been tilted and reworked, and, though they cannot be separated lithologically, two "levels" have been distinguished (pl. 3). The third division is alluvium which mantles the valleys and shows a succession of bench-cut terraces.

Pleistocene Rocks

Frazier Mountain Formation

The Frazier Mountain formation consists mainly of coarse clastic deposits, and is named for exposures on the flanks of Frazier Mountain. No single section includes all members of the unit, but two—member one (conglomerate) (G. 60, X.81 to F.80, XI.00) and member four (landslide debris) (C.74, XII.52 to C.50, XII.58)—are well exposed on the northwest side of Frazier Mountain. These are designated as type sections exemplifying the lithology and stratigraphic relations of the formation as a whole. In the Lockwood Valley area, the formation has four members, each with lithologic characters and distribution reflecting a distinctive mode of origin (pl. 3). Though even younger terraces have minor dislocations, the members of this formation display effects of stronger faulting and to some extent are correlated on this basis. In general, however, position under younger terraces, and unconformity on Tertiary rocks are the features which relate them.

Distribution, Thickness, and Topographic Expression. Most of the Frazier Mountain Formation is exposed in a curved band between elevations 5,500 and 6,000 feet on the northwestern and western flanks of Frazier Mountain. Here massive detrital-slope, channel-fill and landslide materials are divided into two members, designated as members one and four. Remnants of a fanglomerate, designated member two, occur on Seymour Peak and on a small hill west of Cuddy Ranch (H.0, XIV.4). At the western edge of the area a coarse channel-fill deposit, called member three, is exposed along the trace of the Big Pine fault (R.80, VI.55 to T.00, VI.00) and under the main peak to the south (R.90, VI.18). These members are poorly consolidated and have generally poor exposures. The material of Chuchupate landslide, member four, is the most resistant unit, forming a row of hills across the northwest front of Frazier Mountain (D.80, XI.65 and D.22, XI.88). Only the two members on Frazier Mountain are superimposed stratigraphically, the other two being isolated remnants of what was once probably a more contiguous unit. Their thicknesses are extremely variable, but each member attains a maximum of at least 200 feet, and member one is over 450 feet thick (pl. 2, sec. 8).

Lithology. Details of lithology are given in a discussion of each member. The Frazier Mountain Formation is characterized by coarse clastic deposits derived from heights surrounding Lockwood Valley. The deposits were graded to a different surface than that of today, but they reflect the composition of the rocks that are still immediately around them. In this study it was not possible to reconstruct the regional drainage pattern under which the formation was deposited. It is believed that this could be established by mapping a somewhat larger area. In regions just west and south of Lockwood Valley, deposits under high terraces are undoubtedly related to this formation, and probably are the key to the determination of the direction of outlet of Lockwood Valley drainage during early Quaternary time.

Member One. Member one is exposed around the lower flanks of Frazier Mountain. It attains the maximum thickness of 450 feet at the west end of Little Cuddy Valley (F.70, X.90), and thins progressively east and south of that point. The base is irregular, with relief of at least 100 feet. Along the northwest slope of the mountain, the member resembles channel-fill in that it is elongated parallel to the length of Little Cuddy Valley and laps out valleyward as well as up the slope of the mountain.

The northeast-trending portion of the member is polymictic, crudely bedded, unsorted, brick-red conglomerate with distinctly water-worn subangular to subrounded fragments set in a coarse biotitic arkosic matrix. The clasts are dominantly pebbles, cobbles, and small boulders of the gneisses and migmatite of Frazier Mountain, with a few percent of rounded volcanic, granitic, and quartzite cobbles. They are iron-stained and many are highly decomposed. At one place, bedding dips about 15 degrees north into underlying rocks (F.22, XI.78). At least part of this dip is ascribed to tilting (fig. 8). Southward from Little Cuddy Valley, along the west side of Frazier Mountain, this red conglomerate laps over the Frazier Mountain thrust (F.93, X.10) and interfingers with brown and greenish-gray pebbly clay, augen gneiss conglomerate, and sedimentary breccia. These brown and greenish rocks are exposed discontinuously along the edge of the thrust into the southeast corner of the area. The whole sequence is made up of augen gneiss detritus and has several sharp local unconformities. The manner in which the sequence originated is shown in a cliff exposure on the south side of the mountain (F.20, V.90). The Frazier Mountain thrust is exposed here, and the border of the over-riding block is highly sheared, brecciated, and reduced to clay-like gouge. This is a transitional feature, and shows a passage from solid gneiss to tectonic breccia in about 150 yards. The breccia is overlain by clayey augen gneiss conglomerate reworked into younger terraces. This conglomerate is lithologically identical to brown and greenish-gray beds of member one capped by these terraces farther west and north. Two exposures of augen gneiss breccia appear some distance from the scarp that marks the present site of the thrust mass (F.26, VI.03, and G.17, VI.52). Both are preserved by down-faulting and probably represent either remnants of a wide-spread apron of member one, or local channel deposits; although they might indicate a former position of the edge of the thrust mass which has receded by erosion.

The foregoing description shows intimate association of the southerly portion of this member with the Frazier Mountain thrust fault, and its derivation in part from the edge of the upper block. The unconformities within it suggest that it was forming partly during movements on the thrust. The member thus represents the debris fan which encased the foot of Frazier Mountain as it rose along its bounding fault.

Member Two. About 200 feet of member two, a fanglomerate deposit, appears on the flanks of Mount Pinos. On Seymour Peak, its base lies at 6,250 feet elevation and projects westward over Big Spring Valley. However, its basal contact is irregular, and the rock is virtually unconsolidated and subject to a great deal of landslide and slump, so that accurate mapping of most of it is impossible. The member is a boulder fanglomerate, with a loose pebbly arkosic matrix. The fanglomerate spreads along the southeastern slopes of Mount Pinos, and is composed almost entirely of granitic bedrock types that occur high up on the mountain. This distinguishes it from neighboring younger terraces which reflect immediately local lithology to a greater extent. No bedding or other structures were detected. The unit is correlated approximately with member one on the grounds that it lies at a higher elevation than adjacent terraces and therefore is older; it has a sizeable fault along one contact (J.65, XI.70); and its clasts are more decomposed than those of younger terraces.

Member Three. A gray to gray-green channel-fill rests with marked discordance on Caliente member one south of and along the Big Pine fault zone at the western edge of the area (R.90, VI.17 and S.56, V.55). This rock is overlain unconformably by the higher of the younger terraces and hence is assigned to the general period of deposition of the Frazier Mountain Formation. The beds are coarse boulder breccia, composed of a mixture of augen gneiss, granitic, and sandstone fragments from the Plush Ranch Formation, Caliente-type cobbles and pebbles and clay. The beds weather like the Caliente, but their composition and color make them easily distinguishable here. They might be mistaken for rocks at the base of the Caliente Formation farther west, the compositions of which are similar, but their discordance and channel-like nature are obvious in the places mapped. Outcrops caught in the Big Pine fault zone dip steeply south into Caliente strata (S.20, VI.28) and thus give evidence of rather recent movement*.

Member Four (Debris of Chuchupate Landslide). The row of hills south of Chuchupate Ranger station is underlain by one of the most striking sedimentary units in the area. It extends in a narrow band from the road leading to the Jewel mine (E.30, XI.70) northeastward to the outcrops of the Plush Ranch Formation (A.90, XIV.35).

The rock is a brown to gray-green breccia composed chiefly of augen gneiss and associated rocks. Fragments of gneiss range in diameter from a fraction of an inch to 30 feet. The matrix is sandy breccia composed of comminuted gneiss. At many localities, the impression that the exposure is bedrock in place is dispelled only by measuring planar structures in adjacent large outcrops. The structures show complete randomness over a few tens of feet, which is not found in the bedrock. Furthermore, in some of the better exposures one can observe jumbling of huge blocks of similar but not identical rocks, mixed on a more intimate scale than they are when actually in place.

The unit is a large landslide, strongly modified by erosion (fig. 8). Its base is well exposed in the aforementioned hills where it rests on both member one and on Caliente rocks. The base dips about 15 degrees north, while the base of the overlying terrace deposit dips 20 degrees north. The magnitude of these dips, together with the attitude of bedding in the underlying rocks of member one cited earlier, suggest tilting of these rocks. The disposition of the unit along the base of a prominent scarp, which marks the location of the Cuddy Canyon fault, suggests that the slide resulted from the presence of the scarp and possibly from movement on the fault (fig. 8).

Age and Correlation. The coarsely clastic Frazier Mountain Formation is related to movements on the Frazier Mountain thrust and Big Pine fault. It occupies the same stratigraphic position as similar rocks on the east side of Frazier Mountain which rest unconformably on late Pliocene rocks. It is cut by moderate faulting and is overlain by extensive younger terraces. These facts suggest that the formation is contemporaneous with the major mid-Pleistocene orogeny that affected most of Southern California (Bailey & Jahns, 1954, pp. 92-93). The unit is too discontinuous for correlation with rocks farther away than those on eastern Frazier Mountain. However, rocks in similar relation to late Tertiary beds and younger terraces crop out south and west of Lockwood Valley, and detailed mapping there may allow extension of the unit.

Pleistocene?-Recent Rocks

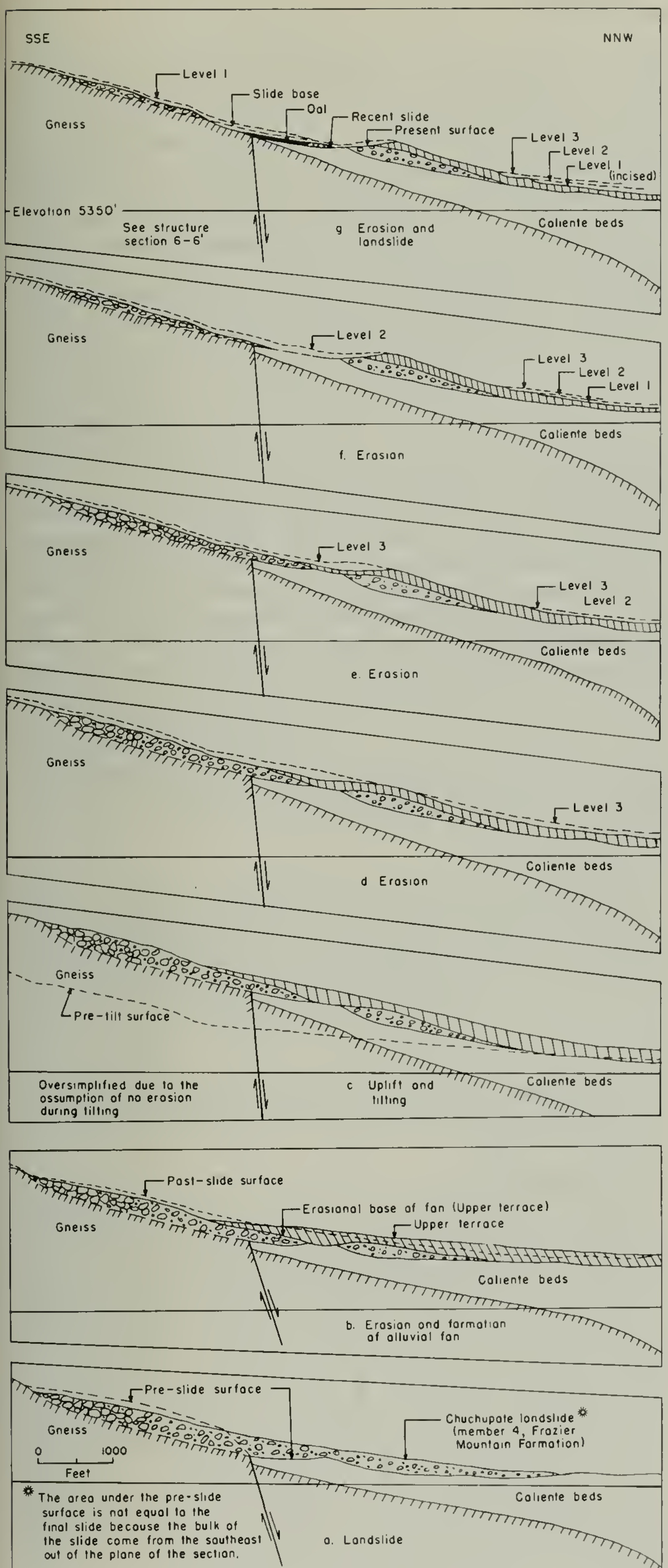
Terrace Deposits

Terrace deposits up to 150 feet thick are developed throughout the Lockwood Valley area. They cover low hills in the valleys and extend far up the slopes of Mount Pinos and nearly to the top of Frazier Mountain. Their history is complex and many levels have formed, with reworking of the deposits so that they grade into each other. Several levels were mapped; however, for the sake of brevity, they have been grouped in two divisions, an Upper level and a Lower level (pl. 3). The terraces will be discussed later as geomorphic features; here they are treated briefly in terms of lithology and gross aspects.

Lithology. The terrace deposits reflect the composition of local bedrock to a large extent and show differences of lithology which, if studied in detail, might serve to unravel their complex history. They consist of brown, black, pale yellow, gray, and orange-colored coarse clastic deposits, some of which are crudely bedded. The clasts are of all the types of exposed resistant bedrock, and range from pebbles and cobbles to boulders several feet across. These are set in a granular soil matrix, which commonly has a large powdery fraction owing to derivation from clay-rich rocks.

The lithology at a few specific localities will point up relations to bedrock and origin of the deposits. Upper level deposits due west of Big Spring Valley are composed exclusively of Mount Pinos Granite, and do not contain other granitic types that occur higher on the mountain. In Big Spring Valley and at the westernmost end of Little Cuddy Valley, Lower level dissected fans contain all of the Mount Pinos crystalline rock-types. The Lower level, as expressed in central Lockwood Valley, has a mixture of all rock types with a preponderance of metamorphic rocks exposed on Frazier Mountain and Yellowjacket Ridge. Large boulders are typical of these beds. On the slopes of Frazier Mountain, a large part of the terrace cover is characterized by a dominance of rounded volcanic and quartzite pebbles and cobbles distinctive of the Caliente and Quatal beds. Along the San Andreas fault the deposits show two distinct phases, in which a lower layer is rich in coarse bluish and white marble and hornfels derived from areas northeast of the fault, and an overlying layer contains sandstone, granitic,

* *Note:* An alternative interpretation for the exposures along the Big Pine fault is that the rocks actually are lower Caliente beds dragged up along the fault zone. While the exposure south of the fault zone is definitely channel fill, the base of which is easily visible, that in the fault zone is less certain. Hence, age of movement is not so clearly shown as suggested above.



and schistose clasts, most of which are found in place south and west of the fault zone. The Upper level deposits capping Sunset Ridge differ from most other terrace beds in that they contain several percent clasts of the same marble as that appearing nearly twelve miles to the east, across the San Andreas, together with some fossiliferous Eocene sandstone cobbles.

These beds are unconsolidated and slumping makes their base difficult to map. It has been assumed that most exposed contacts represent the base, and generally these have been extrapolated through slumped material. However, many exposures show the base of the terraces to be one of considerable relief, up to 100 feet or more. Moreover, reworking of deposits to successively lower levels has caused complications. Thus, if one follows the practice of extrapolation too freely, he runs the risk of "developing" false terrace levels.

Age, Correlation, and Origin. The terrace deposits are distinctly unconformable on the Frazier Mountain Formation, and relations to present topography indicate that they probably range in age from late Pleistocene into early Recent. The higher levels correlate with a broad surface developed on San Guillermo Mountain and with San Emigdio Mesa which lies on the west flank of the Mount Pinos mass. The deposits are chiefly fanglomerates, although evidence discussed in the section on geomorphology suggests that some of those on Frazier Mountain may represent remnants of stripped surfaces.

Recent Rocks

Valley Alluvium

Lockwood, Little Cuddy, and Cuddy Valleys are extensively alluviated. The material is chiefly dark brown, sandy conglomerate, rich in clay, with locally developed crude soil profiles. Though the deposits are of recent origin and reflect in great detail the rock types now exposed, they are incised as much as 40 to 50 feet in the lower reaches of Lockwood Valley.

Figure 8 (opposite). Development of range-front hills near Chuchupate campgrounds. (a) Pre-slide surface with steep fault scarp, where Caliente beds were dropped along the Cuddy Canyon fault, and the subsequent landslide. The landslide descended from the southeast and moved diagonally northwest across the section. (b) The landslide was eroded and some of it severed from the main mass. A thick alluvial fan, now the high terrace capping, also developed. (c-f) Progressive tilting and erosion occurred, and a tributary to the main drainage moving laterally downslope along the contact between the more resistant landslide and less resistant terrace deposits caused down-cutting behind the hills. Upon reaching the buried ridge of Caliente beds it cut downward rapidly and expanded to separate the row of hills from the mountain front. (g) Final events included the ponding of alluvium behind a recent slide which locally trapped the drainage, and incision of the broad fan developed in Little Cuddy Valley during the reworking of the higher terrace deposits.

STRUCTURAL GEOLOGY

The Lockwood Valley area is near the focal point of some of California's major structural features and topographic provinces. The Tehachapi Mountains join the Transverse Ranges a few miles to the east; the San Emigdio Range, generally considered as part of the Coast Ranges, meets the northernmost Piru Mountains of the Transverse Ranges at Lockwood Valley; the San Andreas, Garlock, and Big Pine faults join in or near the area; and in this region the generally northwest-trending San Andreas swings in direction and strikes east-west for several miles in Cuddy Canyon and north of Mount Pinos (fig. 6). Several other large faults separate topographically low-lying blocks of sedimentary rocks from upland crystalline masses.

The most important faults of this region are the San Andreas, Big Pine, Garlock, San Gabriel, and Frazier Mountain thrust, all of which converge near the bend in the San Andreas. The Big Pine and Garlock faults are reported to have left lateral displacements measured in miles (Hulin, 1925; Wiese and Fine, 1950; Hill and Dibblee, 1953; Hill, 1954); the San Andreas and the San Gabriel (Crowell, 1952b) are right lateral faults, also with movement measured in miles; and the Frazier Mountain thrust nearly encompasses Frazier Mountain. The pattern formed by these features is shown in figure 6.

The structural pattern of the mapped area, and the depositional history of its Tertiary rocks gives evidence of possible middle Tertiary block-faulting along northeasterly trends, followed by late Tertiary and Quaternary faulting along northeasterly and northwesterly lines. Much of the latter involved strikeslip movement on the faults and was accompanied by major thrust faulting and some folding. The folding seems less important than faulting; this is chiefly due to recent occurrence of major fault movements which truncate most folds, and seem to have caused or controlled much of the minor folding.

Faults

The faults of this region are varied in trend, type of displacement, and age of movement. For convenience only, they are grouped as follows (see pls. 1 and 4): northwest-trending, including the San Andreas, San Guillermo, Lockwood Valley, and Little Cuddy Creek faults; northeast-trending, including the Big Pine, Big Spring, Mount Pinos, and Cuddy Canyon faults, together with subsidiaries associated with each, as well as a postulated Buried fault and smaller fractures localized in folds; Frazier Mountain thrust; minor faults. Four faults, the San Andreas, Big Pine, San Guillermo, and Frazier Mountain thrust extend well beyond the area, and to a large extent they control the structural pattern of the region. Other fractures are either subsidiary to these faults, or their regional significance is not known.

NORTHWEST-TRENDING GROUP

San Andreas Fault

This classic example of a strike-slip fault has been much discussed and described. It is known to have right lateral displacement that is measured in miles in some places; the kind and magnitude of other movement is subject to dispute, as is its age (Noble, L. F., 1926, 1933, 1953, 1954 a,b; Willis, B., 1938 a,b; Taliaferro, N. L., 1943; Hill and Dibblee, 1953). The fault zone has definitely been active over most of its length since mid-Pleistocene time, as shown by disruption of late Quaternary deposits. Most recent movements show strike-slip offset (San Francisco, 1906, and Imperial Valley, 1940); and Noble (1954b, pp. 44-47) summarizes convincing evidence for at least 30 miles of right lateral displacement since upper Miocene near Cajon Pass. Crystalline rocks northeast of the fault zone differ fundamentally from those juxtaposed southwest of it around Cuddy Valley. Similar circumstances are reported by Crowell (1952a, p. 19) and Noble (1954b, p. 47) in areas to the southeast. Nevertheless, a large area of unmapped basement is exposed north of Lockwood Valley, and data at hand are still insufficient for drawing conclusions concerning correlation of crystalline rocks on opposite sides of the fault.

Relatively recent displacements give rise to the peculiar rift topography seen along the fault trace. The zone of rift features is about one half mile wide in Cuddy Valley, being outlined by a set of anastomosing branches (pl. 1). Most of the branches are expressed by local sags and scarplets in terrace deposits and alluvium. Cuddy Valley is divided by a line of low hills whose northeast side is a straight fault scarp, near the east end of which is a typical sag pond (G.00, XVI.80). Other features, such as beheaded valleys and valleys that are blocked by hills in their lower reaches adjacent to the rift, occur on the eastern edge of the area (D.15, XVI.10 and D.07, XV.95).

San Guillermo Fault

One major fault, the San Guillermo, located in the southwest corner of the area, has not been studied in detail. It is a prominent, steeply dipping, heavily limonitized fracture zone along which Eocene marine rocks on the south have been raised against the Quatal Formation on the north. Hill and Dibblee (1953, pl. 4) show it to be a high angle reverse fault. The amount of displacement is unknown, but placement of Eocene against upper Miocene suggests several thousand feet of apparent relative vertical movement.

Lockwood Valley Fault

This fault, buried under the alluvium, is postulated on the grounds that juxtaposed sections do not match in structure or lithology (P.0, VI.5, to Q.8, VI.9; pl. 2, secs. 2, 3, and 8). Direct evidence, interpreted as due to a branch of this fault, is found along Lockwood Creek, where beds are steepened and overturned (J.80, V.12). East of Snedden Ranch, good evidence of the fault is lacking, and it apparently dies out eastward. There is no evidence for it north of the Big Pine fault. Apparent relative vertical displacement is several hundred feet three quarters of a mile east of Plush Ranch (pl. 2, sec. 8) where Caliente beds oppose Quatal beds, upthrown side on the north; but one mile farther east the vertical displacement is only about 150 feet, inasmuch as the Lockwood Clay is near the surface south of the fault (N.35, V.75; pl. 2, secs. 2,3). In this same region the anticlinal axis north of the fault opposes a synclinal axis south of it (N.8, VI.1), and folding north of the fault is tighter than to the south. The tight folding dies out eastward, and beds are only gently warped north of the fault in central Lockwood Valley.

A possible explanation for these relations is that in response to movements on the Big Pine fault, the wedge of rocks between the Big Pine and Lockwood Valley faults has been squeezed eastward, strongly folded, and uplifted. The deformation becomes gradually less intense eastward from the fault's juncture, and is absent in southeastern Lockwood Valley. The rocks south of the fault have not been squeezed so intensely, and are thrown into more gentle folds. This requires right lateral movement on the Lockwood Valley fault. One difficulty is that the sense of movement shown by the overturned beds on the branch fault on Lockwood Creek (J.80, V.12) indicates left lateral movement.

Little Cuddy Creek Fault

A hypothetical fault, suballuvial along Little Cuddy Creek, is postulated to explain the offset of the basement and Plush Ranch Formation contact, and of the gneiss and granite contact across the creek (J.8, XIII.3, to about 1.5, XIII.3). However, the attitude of Plush Ranch beds along Little Creek indicate an east-west trend. If the Plush Ranch contact with basement is depositional where covered by alluvium and if the gneiss with granite contact is sufficiently irregular, there is no need for this fault to explain present disposition of the rocks.

NORTHEAST-TRENDING GROUP

Northeast-trending faults are represented mainly by the Big Pine-Big Spring fault system, on which there has been post-Tertiary movement, and by the Mount Pinos and Cuddy Canyon faults together with a hypothetical Buried fault, all of which seem to reflect pre-late Tertiary movements. The breccias of Plush Ranch members three and five suggest that the earlier faulting, which may also include movement on the Big Pine, was essentially normal, with the development of graben in which the sediments accumulated.

Big Pine Fault

The Big Pine fault has been traced about 50 miles westward from its juncture with the San Andreas fault zone in Little Cuddy Valley (Hill and Dibblee, 1953). Its main trend is east-west, although in Lockwood Valley and eight miles westward it is west-southwest. This fault separates the uplands leading to Mount Pinos from Lockwood Valley proper, and is marked by a fault-line scarp along the line of basalt-capped hills which bound the valley on the north. High terrace remnants, which nearly extend over these hills, show that the scarp is due in part to differential erosion which has lowered the surface of soft rocks south of the fault. The scarp is reduced in the northeast corner of Lockwood Valley and in Little Cuddy Valley, and the fault trace is mostly hidden under alluvium. The Big Pine fault is a complex system of branching and anastomosing, nearly vertical fractures and shear zones. In some places it is a zone about 500 yards wide, composed of slivers of rock which bound it (J.O., XI.O). These features are typical of large strike-slip faults, although the Big Pine shows no rift topography in Lockwood Valley, owing to a lack of a very recent movement on it and the slight induration of rocks south of the fault. Within and bordering the main zone, rocks are badly crushed and contorted, show gouge along individual shear planes and slickensides here and there in harder rocks, and locally contain limonite and caliche. Exposures are too poor for measurement of reliable attitudes on fault surfaces, but the trace of the fault across valleys shows that it is very steep (N.00, VIII.75; J.80, X.55).

Little direct evidence of the type of movement on the fault was found in the Lockwood Valley area. To the west, near Ozena, Dibblee observed offset streams on it which suggest left-lateral displacement, and he found separated fold axes and offset contacts that suggest as much as eight miles strike slip movement (Hill and Dibblee, 1953, p. 452). It should be recalled, however, that apparently offset streams can be caused by headward erosion locally following the fault line, and that large offset of contact in gently dipping sequences can easily result from dip slip movement. Finally, it appears that many fold axes in later Tertiary rocks of this area are localized above and reflect shifting and deformation of deep basement segments, and thus may develop independently on opposite sides of faults. Offset fold axes would have to match in detail to be conclusive. For these reasons it seems that the case for strike slip movement on the Big Pine needs more support.

A more conclusive argument can be made from the nature of the Plush Ranch member five fanglomerate. As pointed out earlier, this unit is localized along the Big Pine fault and is a strikingly long, narrow, and thick deposit, such as would form along a fault scarp (fig. 5). The presence of Eocene beds south of the San Guillermo fault and on San Guillermo Creek restricts the possible sources for the gneissic clasts of the fanglomerate to the narrow wedge between the San Guillermo and Big Pine faults in western Lockwood Valley, or to the crystalline areas now exposed south and east of that valley. The wedge just mentioned is now overlain by Caliente and younger rocks, but there is evidence that basement might be shallow and that Caliente beds rest on it in Lockwood Valley. For example, Caliente and younger rocks rest depositionally on basement wherever their lower contacts are seen south of the Big Pine fault, and the slope of basement is relatively gentle where the overlapped surface appears east of Snedden Ranch. Also, in Dutton No. 1, drilled on Middle Fork, intrusive rock was reported at 2,150 feet below the valley floor. The descriptions of the rock found at this depth are inconclusive; the observer related it to Plush Ranch basalt, but described it as having orthoclase phenocrysts in a greenish black granular groundmass, which description fits augen gneiss more closely than basalt. Since only two feet of core were recovered, and beds underlying the Caliente Formation farther west carry boulders of augen gneiss over two feet in diameter, there is obviously much room for interpretation of the results of drilling. Nevertheless, extremely high resistivity shown in the electric log at about 2,120 feet, and slow drilling rate (eight to ten feet per hour) below that depth to bottom at 2.198 feet, indicate that basement or an extrusive may have been reached.

In the event of shallow basement (pl. 2, sec. 3), the fan might have been derived from a scarp along the Big Pine fault. If this is so, the Big Pine fault must have had large reversal of apparent movement since Plush Ranch deposition, because apparent movement is now up on the north. Further, the wedge between the San Guillermo and Big Pine faults is quite small when compared to the great thickness of the Plush Ranch fanglomerate (member 5) and the wedge is restricted west of Lockwood Valley (fig. 5). This suggests a more easterly source, around the present site of Frazier Mountain, where augen gneiss is more extensively exposed and where Caliente beds lap onto basement. The strong suggestion then is that the Plush Ranch fanglomerate has been offset laterally along the Big Pine fault, moving west-southwest on the north side of the fault.

A similar conclusion is reached with the alternative of an extrusive in Dutton No. 1. The extrusive would most likely be Plush Ranch basalt, and the presence of Plush Ranch beds south of the Big Pine fault strongly suggests the occurrence of a buried fault along the south margin of Lockwood Valley (pl. 2, sec. 3; pl. 4). This fault could have given the scarp from which the Plush Ranch fanglomerate was derived. Here again the source is well east of the main development of the fanglomerate, and large left lateral movement is suggested.

The age of the Big Pine fault is not known, though its inception may pre-date deposition of Plush Ranch rocks as suggested by Plush Ranch member five. Most recent major movement must have been post-Blancan in order to bring Quatal beds against Plush Ranch rocks. Movement has continued into the Pleistocene, because the Frazier Mountain Formation is cut by it; but the fault is cut by a few northerly trending cross faults of very recent origin, and terraces younger than the Frazier Mountain Formation do not appear to be displaced.

Buried Fault

The presence of a buried fault is postulated on the basis of stratigraphic relations of Tertiary rocks in Lockwood Valley and is therefore not shown on the main geologic map, but it is portrayed on structure sections (pl. 2, secs. 2, 3, 4; pl. 4).

If basement is shallow in Lockwood Valley, overlap southward may well occur, and there would be no necessity for the Buried fault. On the other hand, if Plush Ranch beds are present under Lockwood Valley, as mentioned in connection with the Big Pine fault, overlap would have to be more extreme than any exposed basement contacts indicate, and the Buried fault offers a more likely solution. The Buried fault may have originated during deposition of the Plush Ranch Formation, and formed the scarp from which the sedimentary breccias of member five were derived. The fault also may have been active later during deposition of the Caliente Formation. This would fit with the cutting-off of the Lockwood Valley area from sources of foreign clasts and the predominance of local gneissic types in Caliente member three.

Big Spring Fault

The southerly dipping Big Spring fault borders Plush Ranch basalt north of the Big Pine fault and swings into the Big Pine zone a mile west of Middle Fork (P.83, VII.25), thereby outlining a prow-shaped wedge between the faults. The fault is marked by termination of lithologic units and by crushed rocks.

Plush Ranch beds occur in a gently westward-plunging syncline truncated by the Big Pine fault. Member five should overlie member four adjacent to the Big Pine fault south of Big Spring Valley, in keeping with the shape of the fold and the gentle plunge displayed on North Fork. However, with squeezing of the fold, rocks deep in the syncline on the west have been brought to the surface in the wedge between the Big Spring and Big Pine faults, exposing only member four basalt. The wedge moved obliquely upward toward the southwest as shown by the offset of the reconstructed fold axis. Minor manifestations of the movement are observed in southerly plunging drag folds in member four north of the Big Spring fault between Middle Fork and Amargosa creeks (0.2, IX.4 and N. 95, IX.57). Further evidence of the movement appears in the small northeast-trending faults which cross Middle Fork just south of the Big Spring fault. Most of these are nearly vertical tension fractures showing progressive step-down northwestward, and are the type of fracture to be expected if a "prow-shaped" block, narrowing at depth, moved upward and southwestward. The wedge is essentially a seed in a large left lateral zone and appears to have formed at a time when displacement on the Big Pine fault increased northeastward from North Fork.

The Big Spring fault is closely related in time to movements on the Big Pine fault. However, the Big Spring fault is overlain by the fanglomerate of Frazier Mountain member two, of Pleistocene age. Rocks of the same age are cut by the Big Pine fault, hence movement on the Big Pine fault continued later than that on the Big Spring fault.

Mount Pinos Fault

The south flank of Mount Pinos is a dissected fault-line scarp which rises abruptly from the flat tread cut on sedimentary rocks in the northern part of the area. This scarp is the result of juxtaposition of crystalline and sedimentary rocks across the steeply south-dipping Mount Pinos fault. Extension of the fault under the terrace east of Little Cuddy Creek is conjectural, and structure north of the Big Pine fault in Little Cuddy Valley is not fully understood. The Mount Pinos fault cuts Eocene beds in the western half of its exposure and transects Plush Ranch member one to the east. These sediments dip steeply, nearly parallel to the fault, and only locally strike into it (0.68, X.17). Shearing, gouge, and mineralization show in some places where beds otherwise appear depositional on crystalline rocks.

Displacement on the Mount Pinos fault is not known with certainty; it appears to be normal, with sedimentary rocks downthrown against basement (pl. 2, secs. 2, 3, 4), but in most instances the beds so nearly parallel the fault that relative movement cannot be assessed. Breccias in Plush Ranch member three suggest faulting in the region of Mount Pinos during pre-Barstovian times, but whether these breccias are due to movement on the Mount Pinos fault at that time is not certain, as shown by the following discussion. The presence of Eocene beds, possibly depositional on granite north of the fault on North Fork (S.37, IX.65), suggests that the approximate upper surface of granitic rocks immediately north of the fault during Eocene time is near the present erosion surface and may never have been higher. However, any reasonable projection of Plush Ranch member three breccias northward places them at least two or three thousand feet above the present erosion surface. This gives rise to three alternative possibilities: (a) The breccias were not derived from the Mount Pinos fault, but one farther north; in which case the Mount Pinos fault may not be a major dislocation. (b) The breccias were derived from the Mount Pinos fault, and there has been subsequent folding and large reverse movement on the fault. (c) The Mount Pinos fault has had strike-slip movement, and present apparent vertical displacements are therefore deceptive. The second alternative is discussed in detail in Carman, (1954, pp. 148-150 and pl. 10). The solution to the problem awaits further mapping on Mount Pinos.

The Mount Pinos fault is older than the Big Spring fault because it is offset by Little Cuddy Creek fault and by other cross faults all of which terminate against the Big Spring fault (P.8, X.2). The age may be pre-Barstovian, as suggested above.

Cuddy Canyon Fault

In Cuddy Canyon, at the eastern extremity of the area, the gneisses of Frazier Mountain have been raised against the Plush Ranch section along a large shear zone (A.50, XIV.75), herein named the Cuddy Canyon fault. The fault is marked by a steep scarp southwestward across the northwest flank of Frazier Mountain, where Caliente beds are faulted against basement (D.0, XI.0 and northeastward). The scarp continues southwest of the area of overlap of Caliente beds on basement (D.5 and XI.0), but gradually becomes lower until it disappears on the west side of Frazier Mountain. Immediately south of the area of overlap, the fault truncates units in the gneiss, but this expression also diminishes southwestward (pl. 4). The trace in gneiss is marked by shearing and mineralization, but even this evidence for the fault was not found south of grid line IX on the map (pl. 1), and projection southwest from there is conjectural. However, across the southeast corner of Lockwood Valley, and aligned along the trend of the Cuddy Canyon fault, a group of minor faults cut Quatal and Frazier Mountain Formations and dislocate the edge of the Frazier Mountain thrust (F.26, VII.77 and F.35, VIII.10). Also, the offset of the Lockwood Clay contact across Seymour Creek just north of Snedden Ranch is in line with these minor faults. Farther southwest, a prominent and remarkably straight valley is cut in alaskite along the north side of Yellowjacket Ridge. This feature is strongly suggestive of a fault-line valley, and exposures of alaskite in the valley show moderate epidotization. The alignment of this feature with the Cuddy Canyon fault is striking, and it is suggested that the Cuddy Canyon fault extends along Yellowjacket Ridge, is overlapped by Lockwood Clay and Quatal beds in southeast Lockwood Valley, and had pre-Blancan major movement. Faults in Tertiary rocks along its trace and the scarp in the northeast represent relatively late movement which increases northeastward. If the Cuddy Canyon fault is extended southwest along Yellowjacket Ridge, it shows no appreciable offset across the Frazier Mountain thrust. This interpretation greatly restricts the amount of lateral movement on the thrust on the west side of Frazier Mountain.

Subsidiary Northeast-Trending Faults

A group of nearly vertical, east-northeast-trending faults cuts the Plush Ranch section across North Fork and other creeks to the east. These are mainly longitudinal fractures, but locally they transect bedding and cut out section. In hard units the faults sometimes display gouge and breccia zones, but in soft beds they are difficult to distinguish except in some places where they contain much caliche. Displacements are normal, relatively small, diminish in throw laterally, and die out; however, each fault is at least three miles long. One is apparently cut by the Big Spring fault (P.25, VII.85), and all may be older than it, judging from the transection by cross faults which terminate at the Big Spring fault.

FAULTS LOCALIZED IN FOLDS

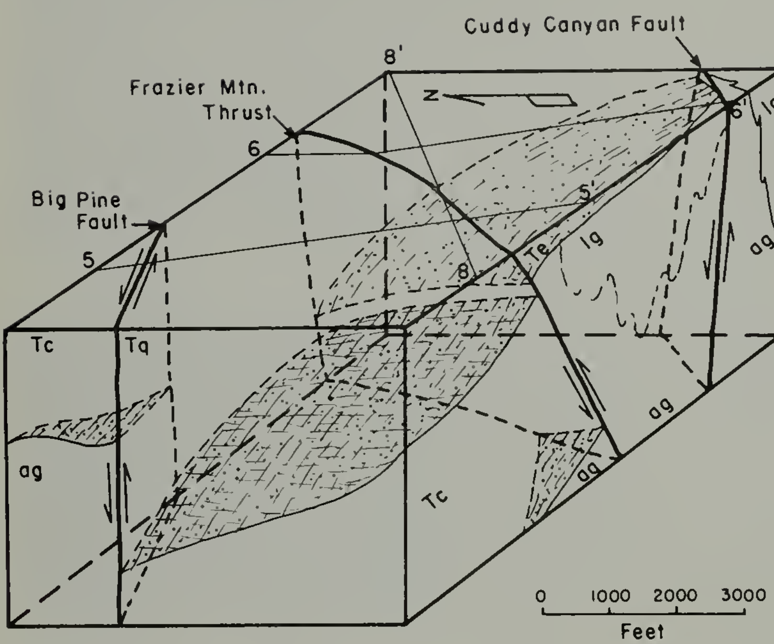
Another group of faults occurs in folds south of the Big Pine fault in the western part of the area (S.0, V.0). These minor dislocations are concentrated in an anticlinal crest at the western extremity of the area, and here these faults may be a reflection of folding. Northeastward, however, branches diverge and truncate the folds, implying relation to more regional movements on the Big Pine and Lockwood Valley faults. There is a little mineralization along them, and displacements amount to tens of feet.

FRAZIER MOUNTAIN THRUST

This thrust has been known for some time (Buwalda, Gazin, and Sutherland, 1930). Its age is post-Blancan (Crowell, 1950) and appears to be at least in part Pleistocene *. Crowell (1947, p. 106), mapping on the east and southeast sides of Frazier Mountain, found it nearly flat over most of its extent and slightly folded. Figure 6 shows the trace of the fault outside the mapped area to the southeast and east, but the region between Hungry Valley and Lockwood Valley is not yet mapped and the interpretation is speculative. The thrust is exposed southeast of Lockwood Valley (pl. 1 and 4), where it strikes about N. 60 E. and dips nine degrees northwestward. It is not exposed where it turns northward on the west side of Frazier Mountain, and it can be traced only by the scarp of the overriding block until the northeast corner of Lockwood Valley is reached. Here, the fault is well exposed near the heads of two streams (F.76, IX.73 and F.79, X.15). It strikes N. 15 E. and dips 50 degrees eastward, showing that the thrust has steepened to a high-angle reverse fault. Directly south (G.12, VIII.60), a small subsidiary thrust developed in Quatal beds in response to movement on the main thrust (pl. 2, sec. 9). The main thrust is concealed under terrace and alluvium north of the above-mentioned exposures, but can be located because thick sections of Quatal and Caliente rocks are juxtaposed across the south side of Little Cuddy Valley (fig. 9; pl. 2, secs. 5, 6, 7, 8).

The Frazier Mountain thrust and the San Andreas delineate Frazier Mountain as a great wedge-shaped block that dips steeply on its west and north sides and gently on its south and east sides. Movement on this block has been upward and outward on all but possibly the north side. Crowell (1950, p. 1645) reports a minimum of two and a half miles southeasterly movement over Hungry Valley sediments. The steepness of the northern and western sides of the block show that any horizontal movement would have to be southerly or easterly, but if the Cuddy Valley fault is correctly interpreted its lack of appreciable offset indicates only minor southerly

* See discussion of Frazier Mountain Formation, member one.



Tq – Quatal Formation
Tc – Caliente Formation
lg – Leucocratic gneiss
ag – Augen gneiss
5–5', 6–6', 8–8' Lines of cross sections

Figure 9. Block diagram showing relations on the northwest side of Frazier Mountain and under Little Cuddy Valley.

movement on Frazier Mountain thrust. Over most of its length the Frazier Mountain thrust has brought the gneiss of Frazier Mountain against late Tertiary rocks, and the amount of displacement in Lockwood Valley cannot be measured. However, subsurface reconstruction of sedimentary contacts beneath Little Cuddy Valley allows making a rough deductive estimate (fig. 9). If it is assumed that the Caliente section east of Chuchupate was originally not much thicker than that now exposed, then the dip-slip component is at least 3,000 feet (pl. 2, sec. 5). Crowell's observation (1950, p. 1645) that similar kinds of gneiss are superimposed along the fault also holds for the southeastern corner of Lockwood Valley; although gneisses here are slightly different, the ones below the thrust being more quartzose than those above.

The southern edge of the thrust has been traced about a mile east of the mapped area across the north side of Long Dave Valley (figs. 1,6). If it continues its same strike in this region, it will join the portion of the thrust mapped by Crowell about 2½ miles north of its southernmost limit; in this case the south side of Frazier Mountain may contain at least three imbricate thrusts, two of which Crowell has distinguished (1950, p. 1642, sec. AA), and the amount of horizontal displacement would be considerably less than that postulated by him. Another possibility, in view of Crowell's interpretation, is that the slight anticline he shows in the thrust has an east-northeastward plunge and, rising to the west, brings the thrust to the level of Long Dave Valley, causing the trace of the fault to curve around the east end of Long Dave Valley and swing back southward sufficiently to meet Crowell's southernmost extension of the fault (fig. 6). This involves a minimum of about three miles movement on the fault in a south-southeast direction.

The problem of apparent increase in volume of the mass, with three sides dipping inward and the block moving upward, should be mentioned. It is believed that east-west expansion due to the upward-outward movement would be largely taken up in the form of block faults which would allow large sections of the terrane to settle, but these faults have not yet been detected. This explanation, however, does not answer the question of what happens with two and a half or three miles of southerly movement.

OTHER FAULTS

Young Northerly-Trending Faults

Small faults with trends mostly north-northwest or north-northeast are common in the area. They are young, cut all other faults, and some even cut terrace deposits. Evidence of apparent movement suggests that those having angles of 30° to 45° to a direction of about N25W have chiefly lateral offset (e.g., R.00, X.00; P.90, X.20; near L.00, XII.60), whereas those nearly parallel to that direction are normal or "tension" faults (e.g., M.56, X.00; near G.0, X.0; and F.00, V.68). This suggests recent compression along the line N25W, with development of tension fractures and shear sets.

Imbricate Structure

Distinctive rock units have allowed tracing of four small thrusts north of Cuddy Ranch (E.00, XV.10, and pl. 2, sec. 6). These faults are well exposed in the hillside, and some of them show strongly developed gouge zones. They trend east-west, dip northward at various angles, and die out laterally within several hundred yards or pass into tear faults which cannot be traced. This structure provides good evidence of local strong compression directed in an approximate north-south direction. The occurrence of a klippe overlying some of the vertical shear zones associated with the Big Pine fault (E.60, XIV.80) suggests that imbrication is recent, and probably is related to forces mentioned in the foregoing paragraph.

San Guillermo Creek Fault

In the southernmost part of the area, a fault was mapped in San Guillermo Creek which drops Eocene rocks overlain by the Quatal Formation on the west against alaskite overlain by Quatal beds on the east, and which also has displaced the basal Quatal contact with the same sense of movement (L.50, I.25). These relations suggest recurrent movement on the fault: first, dropping Eocene beds on the west and erosion of them from the east side of the fault; later, movement in which the Quatal beds, deposited across the fault in the interim, were also dropped on the west.

Structure East of Chuchupate Ranger Station

The Caliente and Plush Ranch Formations are cut by a complex system of faults at the eastern edge of the area. The faults are related to the convergence of the Big Pine, Frazier Mountain, Cuddy Canyon and San Andreas faults and undoubtedly have a complicated history.

The main faults bound major lithologic units and may have had considerable displacement, but they are as yet too imperfectly known to fit into the regional pattern.

Folds

Steeply inclined sedimentary rocks north of the Big Pine fault are broadly interpreted as a sharply folded, gently west-plunging syncline, truncated on the south by the Big Pine fault (pl. 2, secs. 1, 2). Within this unit, the structure in the wedge of Plush Ranch rocks south of Big Spring Valley is interpreted as an overturned anticline. This is based on the assumption that the light-colored tuff of Plush Ranch member four occurs only above the basalt, and thus that north-dipping beds immediately north of Frazier mine (I.00, IX.80) are overturned and are the same as those occurring on hilltops west of the mine (M.50, X.00). The tuff occurs at two other localities than those near Frazier mine. One, north of Plush Ranch, is too small to map; the other, at the eastern extremity of the map, is too intimately mingled with sediments to be shown on the map. In both instances relations in the section are clear and the tuff is definitely above the basalt.

The unconformity between Eocene and Quatal rocks, seen on San Guillermo Creek (L.60, I.19), indicates post-lower Tertiary and pre-Pliocene deformation. Elsewhere, Eocene and Plush Ranch beds were seen only in fault contact, and it is not known how much deformation attended transition from marine (Eocene) to continental (Plush Ranch) conditions. Deformation certainly occurred during Plush Ranch deposition, as shown by breccias. Unconformity between Plush Ranch and Caliente beds west of Lockwood Valley, and the unconformity between the Caliente and Lockwood Clay indicate continuance of deformation through Barstovian time. How much of this involved simple tilting and how much folding is uncertain.

Folds in Caliente and overlying rocks in southern Lockwood Valley are open and gentle (pl. 2, secs. 1, 2, 3, 4, and pl. 4) with axes trending roughly east-northeast parallel to the axis of Lockwood Valley and the Big Pine fault, reflecting general south-southeast—north-northwest compression. These folds plunge gently (pl. 2, sec. 8) and die out so that none extend completely across the valley. North of the Lockwood Valley fault, folds in Caliente and younger beds developed in response to lateral movement on the fault and become more gentle eastward. In eastern Lockwood Valley fold axes are deflected sharply northward and tend to parallel the front of the Frazier Mountain mass (pl. 4). Folding here is almost certainly a reflection of movement on the Frazier Mountain thrust (here really a reverse fault).

The anticline between Middle Fork and Amargosa Creek (M.60, VII.32) is asymmetric, with a steeply north-dipping axial plane (pl. 2, secs. 2 and 3). No other folds can be as carefully measured as this one, but there is a suggestion of similar asymmetry in the anticline at the western edge of the area (pl. 2, sec. 1). The asymmetry is probably due to proximity of the Big Pine fault and a buttressing effect it may exert. If the more southerly block was pressed against the mass to the north, which was in turn moving relatively upward, overturn in the sense noted might be expected.

Folds in Lockwood Valley clearly indicate localization, orientation, and cause by relative movements on major faults. The behavior of the sedimentary rocks is that of relatively thin incompetent layers spread over crystalline blocks which move along the faults in response to regional stresses.

Discussion

Some aspects of the pattern of recent deformation suggest that the area has recently undergone, and perhaps still is undergoing, compression along a line approximately N. 25 W. Features indicating this are: The Frazier Mountain thrust fault; the San Andreas and Lockwood Valley strike slip faults; the imbricate structure near Cuddy Ranch; and the subsidiary northerly trending faults, arranged in a tension and conjugate shear pattern.

The pattern of recent deformation under approximately northerly compression fits that found by Crowell (1947) in Hungry Valley, the regional one suggested by Hill and Dibblee (1954), and evidence from many major faults and folds in the Transverse Ranges (Bailey and Jahns, 1954).

The San Guillermo fault is compatible with such a stress plan, but might result from other stress arrangements.

Structures definitely or possibly incompatible with northerly compression are the Big Pine and Big Spring strike slip faults; the Mount Pinos fault (early normal movement); the Cuddy Canyon normal (?) fault; and the Buried fault (?) in Lockwood Valley (normal fault?).

Partial answer to the incompatibility is that the Mount Pinos, Cuddy Canyon and Buried faults are the oldest in the region and most imperfectly known. They may not be normal faults or they may indicate an earlier tectonic setting in which northeast trending faults developed, giving a structural grain to the country and controlling basins of deposition until deposition of Quatal beds.

However, the near contemporaniety of late Tertiary and Quaternary movements on the Big Pine, San Andreas, and Frazier Mountain thrust poses mechanical difficulties if an attempt is made to analyse the faults in terms of a conjugate shear pattern resulting from a simple regional stress. For example, roughly north-south compression would explain the San Andreas and Frazier Mountain thrust simultaneously, but the Big Pine fault is close to right angles to such compression and should not have strike slip movement as the result of that compression. Thus, to make the Big Pine and Garlock faults a single strike slip shear fracture, offset by the San Andreas, as postulated by Hill and Dibblee (1953 and 1954), requires either major reorientation of the regional stress pattern in a very short time, or perhaps, as pointed out by Cloos (1955, pp. 254-255), a great deal of rotational deformation.

Too little is known concerning the disposition of basement elements, the nature of the regional stress pattern in southern California, and the detailed local response of crustal units to regional stress fields to solve the problem posed by these faults. Structural details reflect local influence of forces that cause larger scale features, and also give evidence of reactions to local stress patterns set up by movement along major structural trends. The fold pattern, smaller thrust faults, the Big Spring fault, and the group of northeast trending faults near its western termination may be cited as examples.

Possible Regional Significance of the Structural Evolution

The discussion above is mostly restricted to the region of Lockwood Valley and Frazier Mountain. The possible older pattern of block faulting on northeasterly trends with subsequent lateral faulting can be matched in the Soledad basin about 25 miles southeast (Muehlberger, 1954; Jahns and Muehlberger, 1954), and possibly in several other places. Recalling Crowell's evidence for large right lateral movement on the San Gabriel fault, we arrive at the postulate that the Lockwood Valley area is approximately a westward extension of the Soledad basin (fig. 6). This is suggested by the general age and lithologic similarity of Barstovian and older sedimentary rocks (fig. 7) and basement types of the two areas, the possible occurrence of similar deformation at about the same time in both areas, and independent evidence to the south of lateral movement with the required magnitude and sense on the San Gabriel fault at the correct time (Crowell, 1952b; 1954a).

Truncation of Plush Ranch and Caliente rocks by the San Gabriel fault, and their movement along it, implies that the San Gabriel fault meets the San Andreas under Frazier Mountain. The complex wedges and great shearing at the west end of Cuddy Canyon (B.0, XIV.5) may be a manifestation of this juncture. There is the further implication that the Mount Pinos mass has been moved some twenty miles, to the northwest and that possibly north of Mount Pinos there may be found rocks corresponding to the Pelona Schist which appears north of the Soledad Basin.

GEOMORPHOLOGY

Lockwood Valley and its environs are at the headwaters of three major drainage systems where remnants of previous erosion cycles are especially apt to be preserved. The location, together with manifestations of Recent diastrophism, place a complex geomorphic imprint upon the landscape, particularly with regard to various terrace deposits and erosional surfaces (pl. 3).

General Features

Erosion. Streams in the area are downcutting very actively. Broad interfluves and remnants of old upland surfaces would indicate "youth" in a standard cyclic classification; but evidences of several periods of recent widespread alluviation followed by deep dissection to form terraces suggests that the term is meaningless in normal sense. Rather, the region has passed through a sequence of erosional cycles in which major and minor rejuvenation have caused waves of "youth" to sweep through it and prevent any one cycle from reaching an advanced stage. As yet these cycles cannot be correlated with general factors of climatic change, eustatic shifts in sea level, or diastrophism, since all are known to have operated strongly within the time recorded by present surfaces.

Slope-wash is the major agent of erosion since plant cover is relatively sparse. Streams have developed V-shaped gorges and canyons in slopes surrounding Lockwood Valley. Rather low rainfall, together with the fact that all but a few rocks are either sandy and permeable, or decompose to sandy waste, combine to inhibit thorough soaking and consequent widespread landslide and creep such as that found on the north slopes of the San Emigdio Range (McGill, 1951). Nevertheless, several small slides were mapped where oversteepening has occurred due to erosion or diastrophism, as on steep slopes along the northeastern trace of the Cuddy Canyon fault, and especially along the scarp of the Big Pine fault.

Primary Fault Features. Examples of first-cycle fault features are seen along the San Andreas where elongated swales in hillocks, scarps, sag ponds, and offset ridges makeup typical rift topography. The ovoid hill at the juncture of the San Andreas and Big Pine faults is anomalous and is chiefly due to upthrusting and development of imbricate structure.

Fault-Line Features. Examples of resequent fault-line scarps are developed along the north side of Lockwood Valley. Here differential erosion has more deeply dissected Caliente and younger rocks south of the Big Pine fault than the Plush Ranch basalt and hard breccia north of it. Farther north, on the flank of Mount Pinos, Eocene and Plush Ranch sedimentary rocks have been stripped from granite along the Mount Pinos fault, causing a notable scarp that rises above the nearly flat tread cut on sediments. The southern portion of the thrust mass on Frazier Mountain is outlined by a prominent scarp developed by differential erosion and stripping of its sedimentary cover; but northward, where the basement complex passes under sediments, softer rocks have been beveled to conform to various terrace levels (pl. 2, sec. 6). The straight valley in granite north of Yellowjacket Ridge is interpreted as a fault-line expression.

Development of Valleys. Whereas main valleys are controlled by faults and represent structural depressions in the sense that they are underlain by sedimentary rocks dropped relative to surrounding crystalline blocks, they owe their present development more to differential erosion than to actual depression. This is shown by high terrace levels which pass over some of the valleys and would nearly obliterate them if restored.

Erosional Surfaces

Stripped Surfaces and Summit Uplands. Sandy gravels different from residual material derived from the gneiss of Frazier Mountain, and with rounded volcanic cobbles, occur on broad rounded shoulders and sloping beveled surfaces at elevations above 7,000 feet on the eastern margin of the area (C.8, VII.7). Similar gravels cover the ridge extending westward from under the thrust plate in the southeast corner of the area (E.0, V.0). They are identical with those derived from the Caliente and Quatal Formations, except that no anorthosite was detected in them, and they are believed to be remnants of Tertiary beds which formerly covered the gneiss eastward across Frazier Mountain and southward from Lockwood Valley. Similar features were described to the southeast by Crowell (1947), who refers to them as stripped surfaces.

That the areas capped by these gravels are stripped surfaces is suggested by overlap of Caliente beds on basement on the north side of Frazier Mountain (pl. 2, secs. 6 and 7), and similar overlap of Quatal strata in the southeast corner of the area (pl. 2, sec. 4). In the southeast one can walk from the gravel into Quatal rocks under the thrust, and the surface might be termed alliteratively the sub-thrust stripped surface. The difficulty with this interpretation is that this flat ridge top is at a level coincident with the higher terraces and cannot clearly be separated from them. The matter is different on Frazier Mountain. There is no way of getting the gravel virtually to the top of the mountain without burying the mass in terrace debris, and still the rocks containing the rounded volcanics must have been somewhere higher. It is thus concluded that late Tertiary sediments extended over the mountain. Most of these have since been stripped away, giving rise to the volcanic cobble-strewn terraces on the gneiss at lower levels; while at high levels, only residual patches of original sediments remain. This interpretation leads to the suggestion that the gently undulating "summit upland", which covers several square miles on the top of Frazier Mountain above 7,250 feet, is part of the stripped surface, or at least reflects its original imprint, though modified by subsequent erosion. The question then arises as to the relation between the Frazier Mountain summit upland and the similar essentially accordant surface which covers considerable area above 7,750 feet on Mount Pinos, Sawmill Mountain, and Mount Abel. The low relief of these uplands can be explained either by exhumation of a late Tertiary erosion surface, as suggested above, or by beveling to gentle regional topography in a more recent cycle. Neither Frazier Mountain Formation members nor coarse conglomerates of younger terraces indicate such subdued relief in recent times, and they all lie below the summit uplands. Thus post-Tertiary regional beveling would have to predate the Frazier Mountain thrust. In the case of exhumation, the summits could have formed at any time since Frazier Mountain thrusting, with coarse clastics developing from fault-line scarps and being reworked from sediments overlying the stripped surfaces. Either case necessitates the coincidence of very similar amounts of relative uplift for all the mountains named to account for the accordance. Finally, it is possible that the uplands are results of Pleistocene high-mountain erosional processes, giving local rather than regional beveling, and do not reflect a previous surface (Daly, 1905). In view of the complex recent structural history of these mountain masses, it is beyond the scope of this work to resolve the problem.

Frazier Mountain Formation Surface. The surface of the Frazier Mountain Formation is not preserved, except possibly on Seymour Peak (K.0, XII.5), where an old gently rolling area occurs at about 6,250 feet, well above surrounding terrace levels. This surface does not display debris typical of lower terraces. Elsewhere, as on Frazier Mountain, the formation is capped by younger terrace deposits, but nowhere in the mapped area is the surface seen above 6,250 feet.

Upper Terrace Level. Deposits of the Upper Terrace level lie mostly above 5,750 feet, and occur on Frazier Mountain, where they ascend the flanks of the thrust mass; Sunset Ridge, from which they descend rapidly westward; and the tread southwest of Big Spring Valley. On Frazier Mountain the Upper level merges northward with Lower levels and has been tilted into Little Cuddy Valley (fig. 8). Demarcation of the boundary is thus arbitrary along the northwest flank of the mountain. The unit also grades into the level of the dissected fan in Big Spring Valley and through Amargosa Creek to Lower level deposits, and has apparently been reworked in one of the sub-phases of development. The Upper level projects into Lockwood Valley well above terraces capping low ridges on the southwest side of Frazier Mountain and spurs of Sunset Ridge. This level can be correlated with high terraces covering San Guillermo Peak and those which extend northeast from the Peak nearly into Lockwood Valley. It also extends northwestward along the south side of Mount Pinos and connects with San Emigdio Mesa.

On Yellowjacket Ridge a terrace slopes northward sufficiently to meet Lower levels in Lockwood Valley and terminates upward at about 5,600 feet. It projects between Upper and Lower levels at its eastern end, near the outlet of Lockwood Creek. Thus it could not be assigned to one of the major divisions and is undifferentiated.

The presence on Sunset Ridge of white marble that shows twinning on weathered surfaces, identical with the type occurring across the San Andreas to the northeast, suggests that the subdued surface represented by these terraces drained westward from at least as far as Cuddy Valley.

Lower Terrace Levels. The Lower levels are complex surfaces, composed of several sublevels. In general they form remnants of alluvial fans in Big Spring Valley, Little Cuddy Valley, and southwestern Cuddy Valley, and they cap low hills and flanking ridges in Lockwood, Little Cuddy, and Cuddy Valleys. All are graded to lines parallel to present drainage channels along outlets to the south and northeast. A Lower level was not distinguished west of Sunset Ridge, but closer examination might reveal it on some of the ridge tops (e.g., Q.79, IV.90).

Present Stream Terraces. The major valleys are extensively alluviated and this material is deeply incised. In Lockwood Valley, incision ranges from 40 feet near the outlet at the south to 15 feet near the Big Pine fault. In their lower reaches, stream channels contain as many as four minor benches, and alluvium in the banks shows gentle unconformities and buried soil profiles; all attest to the multiplicity of recent changes in deposition and erosion within the area.

Conclusions. The chief Quaternary deposits, including recent alluvium, show at least three, and possibly four, intervals of erosion followed by strong aggradation. These stages are represented by the Frazier Mountain Formation, the Upper Terrace level, the present valley alluvium, and perhaps the Lower Terrace level. As stated earlier, it is not now possible to trace these to a single cause. Nevertheless, large scale alternations between aggradation and erosion, which in the case of the Frazier Mountain Formation versus younger terraces can be traced completely around Frazier Mountain, are not due merely to local changes in stream pattern, capture, reworking, and so on, but rather are to be traced to causes which act outside of the area, perhaps on a regional scale. Erosional regimes in lower reaches of streams for which Mount Pinos is a headwaters area, climatic changes, eustatic changes in sea level, and diastrophism all must contribute to the pattern observed here. The answer to which is most important lies outside the mapped area. As Crowell has pointed out (1947, p. 122), multiplicity of terrace sublevels is due to minor phases of physiographic development, shifting of streams during progressive downcutting, stream capture, integration of drainage, and the like.

Former Drainage

Little can be said concerning pre-Lower Terrace level drainage lines, except that there was apparent westward drainage across Lockwood Valley during formation of the Upper Terrace level (marble cobbles on Sunset Ridge), which has since been captured by the headwater of Piru and Grapevine Creeks (fig. 1).

Lower levels indicate that present drainage channels have been established for a considerable time. Remnants on the east side of Sunset Ridge show that the drainage divide was about where it is today during the development of Lower terraces. Assuming westward drainage across Lockwood Valley during Upper level time; it appears that capture by a branch of Piru Creek, which has developed into Lockwood and Seymour Creeks, scoured out Lockwood Valley and established a drainage divide essentially the same as the present one on Sunset Ridge prior to Lower level time. That the present divide was not farther west is shown by remnants of the Upper level which rise eastward to Sunset Ridge (S.0, V.3, to R.5, VI.2). However, present stream profiles on opposite sides of the divide show that steep ones flowing westward into Cuyama Valley are encroaching on rather gentle east-flowing streams, and that the west end of Lockwood Valley is now in the process of being captured by Cuyama drainage. The divide at the northeast corner of Lockwood Valley, which separates it from Little Cuddy Valley, is perhaps more stable since streams flowing from it into both valleys have about the same gradient and are cutting in the same rocks.

Structural control of drainage is shown on a large scale, in that valleys are cut in softer rocks between high-standing crystalline masses. In some places smaller details of drainage reflect this control also. For example, the canyon extending eastward from Snedden Ranch is being cut along the contact between sedimentary rocks to the north and augen gneiss to the south. On the other hand, branches of Lockwood Creek flowing south from Mount Pinos show notable lack of structural control, transgressing rocks of very different resistance and structural position with virtually no deviation. It might be said that these streams have been superimposed from one of the higher terrace surfaces. However, the slope of the base and top of the terrace on the tread of Mount Pinos shows that drainage was formerly confined by the presence of the basalt ridge and that it passed eastward across the tread and then southward through Amargosa Creek or Seymour Creek. Therefore, North Fork and Middle Fork, at least, have captured some of this eastward drainage by headward erosion.

Special Problems

Range-Front Hills. A row of three prominent hills breaks the descent on the northwest side of Frazier Mountain (D.80, XI.65; D.20, XI.88; and C.60, XII.50). Passing eastward into a low ridge, they finally merge into the main slope of the mountain. The hills are of composite lithology, the story of which points up several events of importance in the Quaternary history of the area.

The hills are underlain by Caliente beds and the Frazier Mountain Formation (pl. 2, sec. 6); two members of the latter formation (members one and four) are superimposed in them (pl. 3); and they are capped by high terrace deposits. Distinctive rocks of these units allow fairly accurate mapping of contacts, and reveal a base of terrace material which dips about 20 degrees northward. Nowhere else does the base of these or any other terrace deposits dip so steeply; thus it is believed that the beds have been tilted several degrees northward since their formation.

The breccia of Chuchupate landslide member four, consisting of gigantic blocks of augen gneiss set in a coarse matrix of the same material, gives a clue as to the origin of the range-front hills. A massive landslide moved northwestward down the slope of Frazier Mountain, apparently from a fault scarp southeast of the Cuddy Canyon fault (fig. 8). This landslide was covered by subsequent terraces and tilted with them. The coarse blocks of the landslide have rendered it relatively resistant to erosion compared to overlying terraces and underlying Caliente beds; consequently, erosion since tilting has left the striking remnants of the member.

Younger terrace levels at the foot of the hills are separated by breaks in slope that are of uncertain origin (see fig. 8, levels 1, 2, and 3). They appear to have developed in response to tilting of the surface and are unique to it; but they parallel the mountain front, making level two a bench of nearly constant width across the terrace. The physiographic expression is a perfect example of what Blissenbach has termed "telescope structure" (1954, p. 180). It is doubted, however, that his explanation of lateral swinging of streams has caused the parallelism of scarplets. However, these considerations begin to bring in the problems of parallel retreat of slopes, pedimentation, and "pediplanation". They are beyond the scope of this work.

Badland Topography. This erosional phenomenon consists of narrow ridges, the sides of which are sculptured into delicate flutings, resulting in thin septum-like ridges with nearly vertical sides and distal terminations. The feature is largely restricted to the Caliente Formation, occurring only in rocks which range in texture from almost unsorted sandy to coarsely conglomeratic, and are peculiar in that the coarser material is set in a clay matrix which composes a major fraction of the rock.

The origin appears to be due the composition of the rocks and situation in areas of very active erosion. Inception is probably in the development of a rill pattern, as described by S. H. Schumm (1956, pp. 632-634). Further development depends on protection of ridges so formed by a veneer of sandy clay which resists soaking. The details are discussed in another paper (Carman, 1958).

GEOLOGIC HISTORY

In summarizing the history of the area a conventional chronological sequence of events is given in expanded outline form. Two items should be emphasized: a, The order in which the events are listed does not necessarily preclude their overlapping or occurring concurrently, but in general their order does indicate the sequence in which it is believed that they started, and b, the assignment of age to most events is subject to considerable speculation, as is obvious from discussions of age and correlation of the rocks. In the outline below the marine invertebrate time scale is used (fig. 7).

I. Pre-Tertiary
  A. Probably pre-Jurassic
    1. Deposition of sediments, probably marine.
      a. Gneisses, schist, calc-silicate hornfels, and marble northeast of San Andreas indicate a calcareous, shaly, and sandy sequence.
      b. Gneisses, migmatites, and quartzite southwest of San Andreas indicate a pelitic, or semipelitic quartzo-feldspathic, and quartzose sequence.
  B. Possibly Mesozoic
    1. Orogeny and deep-seated metamorphism of sediments.
    2. Plutonism, emplacement of granitic rocks and formation of gneisses and related rocks. Events one and two possibly in part concurrent.
  C. Late Mesozoic
    1. Uplift and erosion

II. Tertiary
  A. Eocene
    1. Late Cretaceous and early Eocene subsidence and deposition of marine shale and sandstone, continuing through the Eocene epoch.
  B. Oligocene(?)
    1. Possible uplift, erosion, and folding of Eocene beds.
    2. Possible faulting with deposition of lower Plush Ranch members, continental (?) conditions, partly lacustrine (?).
    3. Probable faulting on northeast trends, formation of trough, and exposure of crystalline rocks north and south. Continental deposition of middle Plush Ranch members, lacustrine (?) and coarse clastic deposits; the latter being mud-flows and alluvial fans building into trough from its sides. (Faults possibly involved, Cuddy Canyon, Mt. Pinos, Buried fault in Lockwood Valley, Big Pine).
    4. Continued faulting on northeast lines with deposition of upper Plush Ranch members represented by coarse breccias and definite lacustrine beds interfingering.
    5. Concomitant volcanism, extrusion of basalt flows and later deposition of acidic tuff. Probable formation of borate deposits.
    6. Continued faulting on northeast trends with possible folding of beds in subsiding trough, further exposure of crystalline rocks, especially to the south.
    7. Continued deposition of coarse clastic Plush Ranch sediments (rocks exposed west of area).
    8. Moderate folding, erosion of Plush Ranch deposits.
  C. Early through Middle Miocene
    1. Erosion of surrounding uplands, development of through drainage into a hinterland which supplied "foreign" anorthosite and volcanic clasts, deposition of arkosic continental sequence.
      a. Deposition of lower Caliente beds under fluviatile conditions.
      b. Volcanism in vicinity shown by a few tuff beds.
      c. Overlap onto basement in eastern section (Caliente beds rest on basement on Frazier Mountain).
      d. Local small lake gives lacustrine deposits. (Caliente member two).
  D. Middle through Upper Miocene
    1. Faulting and/or folding on southern and eastern portions, cutting off of "foreign" clast source (Movement on San Gabriel fault).
      a. Deposition of upper Caliente arkose.
      b. Continued overlap onto basement eastward and southward.
  E. Pliocene
    1. Continued gentle folding, uplift (?), and erosion of Caliente beds.
    2. Subsidence (?) and volcanism.
      a. Formation of tuff (?), later altered to Lockwood Clay.
      b. Intrusion of rhyolite plugs on Frazier Mountain (?) and possible deposition of gold-bearing quartz veins.
      c. Continued overlap.
    3. Faulting in south and deposition, forming Quatal arkoses.
      a. Lake or pond deposits interfingering southward with coarse fan material in lower portions of Quatal Formation.
      b. Exposure of some Caliente beds for reworking into upper Quatal sediments.
      c. Overlap continues onto Frazier Mountain site and to the south.
    4. Possible (?) overlap of sea.
      a. Connection across the area between western marine sediments, section of unknown age in San Andreas fault zone near Cuddy Ranch, and "Santa Margarita" beds east of Gorman.

III. Quaternary
  A. Plio-Pleistocene
    1. Uplift and beginning of orogeny.
    2. Faulting, folding, and erosion.
      a. Lateral movement on Big Pine fault (?), and on northwesterly trends.
      b. Earliest faulting along northerly trends (?).
  B. Early Pleistocene.
    1. Thrusting and uplift, with gentle folding in Lockwood Valley reflecting fault movements.
    2. Stripping of surfaces and deposition of Frazier Mountain Formation.
    3. Continued slight folding, with faulting on Big Pine and subsidiaries as well as along north-trending lines.
  C. Middle Pleistocene to Recent.
    1. Continued uplift, gentle folding, (thrust sheet folded ?) and erosion.
    2. Local erosion with widespread alluviation, development of higher terrace levels and subdued topography.
    3. Continued erosion, and minor faulting.
      a. Tilting of terraces.
      b. Capture of probable westward drainage through Lockwood Valley by Piru and Grapevine Creeks headwaters.
      c. Cutting of early Lockwood and Little Cuddy Valleys and establishment of present drainage divides.
    4. Alluviation and dissection to form lower terraces and present valleys, continued faulting, and cutting of terraces.
    5. Final alluviation and dissection, with faulting on San Andreas giving rift topography.

ECONOMIC GEOLOGY

Gold

Several gold prospects and former mines are on the west side of Frazier Mountain (pl. 1). Some of these workings are believed to date back to days of Spanish control, and periodic small finds have been reported through the years. The most recent development has been on the Maule property (D.2, VIII.9). Operating his own mill, the owner reported shipping several tons of concentrate in 1952 for which he received about $1,000 per ton.

Gold occurs in quartz veins deposited in shear zones in the gneiss of Frazier Mountain. At the property mentioned above, a nearly flat lamprophyre sheet cuts the gneiss (fig. 3). Both rocks show strong shearing along gently east-dipping planes, but the ore-bearing vein is in a crushed zone along a contact between lamprophyre and gneiss, which strikes about N75W and dips about 60 degrees north (fig. 3). The mine consists of two adits, each about 200 feet long and 20 feet apart vertically, driven along the strike of the vein on different levels. The upper adit follows the intersection of the main vein with a smaller south-dipping one. It is along this intersection that the best ore has been found, occurring in pod-shaped bodies which have been open-stope mined. The largest pod, reaching from upper to lower adit, occurred near the end of the adits and apparently was a shoot from which ore was taken by overhand stoping from the lower adit. The stope has since caved and makes working at the face very dangerous. The gold occurs mostly as disseminated particles in gossan-rich portions of the vein, and was apparently associated with iron sulfides in the quartz. The mineralization followed at least one period of deformation after the formation of the gneiss and its intrusion by the lamprophyre. How much younger it is remains uncertain but it is possibly contemporaneous with intrusion of rhyolite plugs to the east on Frazier Mountain.

Borates

Colemanite was mined between 1899 and 1912 from borate deposits occurring in association with basalt and lake deposits of the Plush Ranch formation. The workings were described by H. S. Gale (1912, pp. 434-456), who had access to the operating mines. Today shafts and adits are badly caved and extremely dangerous. The Lockwood Valley district produced more than 25,000 tons of crude ore valued at more than $1,000,000 (Gale, 1912). It was closed down by development of the richer Death Valley deposits, and has been inoperative for about forty years. The borate minerals were reported by Gale to be colemanite and pandermite. X-ray data on eight specimens from six of the major "pandermite" locations show the mineral to be howlite in every case. Specimens obtained from the dumps show the colemanite to be associated with limestone, clay shale, and gypsiferous layers. Small rosettes and irregular veinlets of colemanite have replaced the limestone in several specimens, a fact also reported by Gale (1912, p. 443), who said that there was suggestive, but inconclusive, evidence that large scale replacement had occurred in the main ore bodies. Gale (1913, pp. 6-9) favored a vein origin of the deposits, involving replacement of the limestones by hot borate solutions associated with the volcanic flows. However, Foshag (1921) felt that was not the case, because flows could not supply a sufficient quantity of the necessary hot borate solutions over enough time to replace the amount of limestone known to have been removed. He observed that Van't Hoff had obtained colemanite by leaching ulexite with NaCl solutions at slightly elevated temperatures, the NaCl being necessary to give the pentahydrate (colemanite) instead of the heptahydrate (meyerhofferite). The reaction for this process is as follows:

$$\underset{\text{ulexite}}{2NaCaB_5O_9.8H_2O} = \underset{\text{borax}}{Na_2B_4O_7.10H_2O} + \underset{\text{colemanite}}{Ca_2B_6O_{11}.5H_2O}$$

$+ H_2O$. The direction in which the reaction will go depends on the amount of borax present. Colemanite will form in a saline solution if borax is removed as fast as it forms, for example, by solution in the case of leaching ulexite. On the basis of this chemistry and the geological occurrence of colemanite in California, in which it is always associated with playa deposits, Foshag formulated the following hypothesis for its origin:

Ulexite develops in playas, and to form colemanite from the ulexite, borax must be removed as it develops. When the playas are still receiving sediments, borax accumulates and only ulexite and borax are deposited. When the beds are later uplifted, allowing drainage from them, percolation of NaCl solutions converts the ulexite to colemanite.

W. T. Schaller (1930, p. 138) reports colemanite crystals growing in ulexite in the Kramer district and he accepts Foshag's hypothesis. However, this close association is not as general, according to Dr. Joseph Murdoch (personal communication), as would be expected if Foshag were entirely correct. It appears that the origin of colemanite is not yet certain, and an equilibrium study of the significant portions of the system $CaO–Na_2O–B_2O_3–H_2O$ will probably have to be made together with a more complete examination of the field associations before the problem is fully solved.

Clay

Quarries in the Lockwood Clay at the east end of Lockwood Valley have in the past produced clay used for drilling mud. At the present time, the clay is being developed for use as a cement aggregate, after "cracking" by a heating process. Should a sufficient demand for this montmorillonitic material develop, considerable quantities could be obtained from exposures in Lockwood Valley and areas to the west. Large parts of the formation are silty and sandy and may locally contain several percent calcite and gypsum, but substantial portions are rather pure and should yield good material.

Oil

Two attempts have been made to find oil in Lockwood Valley. Both wells were drilled in the lower parts of Middle Fork on the obvious anticline in the Caliente Formation, but no oil was found. The history of the latest well, Gene Reid-Dutton No. 1, is mentioned in connection with the hypothetical Buried fault in Lockwood Valley. The possibilities for oil in this region depend mostly on the occurrence of an Eocene section below Lockwood Valley. No younger rocks offer much prospect as source beds, though they might serve as reservoir rocks, and the shales of the Plush Ranch Formation or the clayey Caliente beds might be tight enough for cap rock. However, the structural interpretations shown on the cross sections (pl. 2, secs. 1, 2, 4, 8), and the data concerning wells drilled in the valley and to the west suggest that basement is shallow. Gravimeter tests could determine whether buried faults exist, and possibly give a better idea of thickness of the section.

BIBLIOGRAPHY

Adams, W. (1956), Geology of the Dry Canyon area, Ventura County, California: Master's thesis, Unpubl., Dept. Geology, Univ. California, Los Angeles.

Anderson, G. H. (1937), Granitization, albitization, and related phenomena in the northern Inyo Range of California-Nevada: Geol. Soc. America Bull., vol. 48, no. 1, pp. 1-74.

Axelrod, D. I. (1950), Studies in Late Tertiary Paleobotany: Carnegie Inst. Washington Pub. 590, Contributions to Paleontology, 332 pages.

Barth, T. F. W. (1936), Structural and petrologic studies in Dutchess County, New York, Part II Petrology and metamorphism of the Paleozoic rocks: Geol. Soc. America Bull., vol. 46, no. 6, pp. 775-850.

Bailey, T. L. (1954), Geology of the western Ventura basin, Santa Barbara, Ventura, and Los Angeles Counties: California Div. Mines Bull. 170, Map sheet 4.

Bailey, T. L. and Jahns, R. H. (1954), Geology of the Transverse Range province, southern California: California Div. Mines Bull. 170, Ch. II, pp. 83-106.

Bramlette, M. N., and Posjnak, E. (1933), Zeolitic alteration of pyroclastics: Am. Mineralogist, vol. 18, no. 4, pp. 167-171.

Blissenbach, E. (1954), Geology of alluvial fans in semiarid regions: Geol. Soc. America Bull., vol. 65, no. 2, pp. 175-189.

Buwalda, J. P., Gazin, C. L., and Sutherland, J. C. (1930), Frazier Mountain, a crystalline overthrust slab, west of Tejon Pass, southern California (abst.): Geol. Soc. America Bull., vol. 41, no. 1, pp. 146-147.

Carman, M. F. (1954), Geology of the Lockwood Valley area, Kern and Ventura Counties, California: Ph.D. thesis, unpubl., Dept. Geology, Univ. California, Los Angeles, 194 pp.

Carman, M. F. (1958), Formation of badland topography: Geol. Soc. America Bull., vol. 69, no. 6, pp. 789-790.

Cheng, Yu-Chi (1944), The migmatite area around Bettyhill, Sutherland: Quart. Jour. Geol. Soc. London, vol. 99, no. 395, pp. 107-154.

Cloos, E. (1955), Experimental analysis of fracture patterns: Geol. Soc. America Bull., vol. 66, pp. 241-256.

Corey, W. H. (1954), Tertiary basins of southern California: California Div. Mines Bull. 170, Ch. III, pp. 73-83.

Crowell, J. C. (1947), Geology of the Tejon Pass region, California: Ph.D. thesis, Unpubl., Dept. Geology, Univ. California, Los Angeles, 129 pp.

——— (1950), Geology of the Hungry Valley area, southern California: Am. Assoc. Petroleum Geologists Bull., vol. 34, no. 8, pp. 1623-1646.

——— (1952a), Geology of the Lebec quadrange, California: Div. Mines Special Rept. 24.

——— (1952b), Probable large lateral displacement on the San Gabriel fault, Southern California: Am. Assoc. Petroleum Geologists Bull., vol. 36, no. 10, pp. 2026-2035.

——— (1954a), Strike-slip displacement of the San Gabriel fault, Southern California: California Div. Mines Bull. 170, Ch. IV, pp. 49-52.

——— (1954b), Geology of the Ridge Basin area, Los Angeles and Ventura counties: California Div. Mines Bull. 170, map sheet 7.

Daly, R. A. (1905), The accordance of summit levels among alpine mountains: the fact and its significance: Jour. Geology, vol. 13, no. 2, pp. 105-125.

Dibblee, T. W., and Hill, M. L. (1948), Big Pine fault, California, (abst.): Geol. Soc. America Bull., vol. 59, no. 12, pt. 2, p. 1369.

Dibblee, T. W. (1952), Cuyama Valley and vicinity: Am. Assoc. Petroleum Geologists, Soc. Econ. Paleontologists and Mineralogists, Soc. Exploration Geophysicists Guidebook, pp. 82-84.

Dougherty, J. F. (1940), A new Miocene mammalian fauna for Caliente Mountain, California: Carnegie Ins., Washington Publ. 514, pp. 109-143.

Eaton, J. E. (1939), Ridge Basin, California: Am. Assoc. Petroleum Geologists Bull., vol. 23, no. 4, pp. 517-558.

Eaton, J. E., Grant, U. S., and Allen, H. B. (1941), Miocene of Caliente Range and environs, California: Am. Assoc. Petroleum Geologists Bull., vol. 25, no. 2, pp. 193-262.

Ericson, D. B., Ewing, M., and Heezen, B. C. (1952), Turbidity currents and sediments in the North Atlantic: Am. Assoc. Petroleum Geologists Bull., vol. 36, no. 3, pp. 489-511.

Eskola, P. (1933), On the differential anatexis of rocks: Soc. geol. Finland, C. R., vol. 7, pp. 12-25; and Geol. Comm. Finland Bull., no. 103, pp. 12-25.

——— (1952), On the granulites of Lapland: Am. Jour. Sci., Bowen Vol., pp. 133-171.

Fenner, C. N. (1914), The mode of formation of certain gneisses in the highlands of New Jersey, Part 1: Jour. Geology, vol. 22, no. 6, pp. 594-612.

Foshag, W. F. (1921), The origin of the colemanite deposits of California: Econ. Geology, vol. 16, no. 3, pp. 199-214.

Gale, H. S. (1914), Borate deposits in Ventura County, California: U. S. Geol. Survey, Bull. 540, pp. 434-456.

——— (1913), The origin of colemanite deposits: U. S. Geol. Survey, Prof. Paper 85, pp. 3-9.

Gazin, C. L. (1930a), Tertiary mammal-bearing beds in the Upper Cuyama drainage basin, California: Ph.D. thesis, Unpubl., 62 pp., California Inst. Technology.

——— (1930b), A Tertiary vertebrate fauna from the Upper Cuyama drainage basin, California: Carnegie Inst. Washington Publ. 404, pp. 55-76.

——— (1931), Geology of the central portion of the Mount Pinos quadrangle, Ventura and Kern Counties, southern California (Abst.): Geol. Soc. America Bull., vol. 42, no. 1, p. 316.

Goldschmidt, V. M. (1920), Geologische-petrographische Studien im Hochgebirge des sudlichen Norwegens, V. Die Injectionsmetamorphose im Stavangergebiet: Videnskabsselsk, Skr., I Mat.-Naturv. Kl. no. 10, pp. 87-100.

Higgs, D. V. (1954), Anorthosite and related rocks of the western San Gabriel Mountains, southern California: Univ. California Publ. in Geol. Sci., vol. 30, no. 3, pp. 171-222.

Hill, M. L., and Dibblee, T. W. (1953), San Andreas, Garlock, and Big Pine faults, California: Geol. Soc. America Bull., vol. 64, no. 4, pp. 443-458.

Hill, M. L. (1954), Tectonics of faulting in southern California: California Div. Mines Bull. 170, Ch. IV, pp. 5-13.

Hoots, H. W. (1930), Geology and oil resources along the southern end of the San Joaquin Valley, California: U. S. Geol. Survey Bull. 812, pp. 243-332.

Hulin, C. D. (1925), Geology and ore deposits of the Randsburg quadrangle, California: California Min. Bur. Bull. 95, pp. 1-152.

Jahns, R. H., and Muehlberger, W. R. (1954), Geology of the Soledad basin, Los Angeles County: California Div. Mines Bull. 170, Map Sheet No. 6.

Kelley, W. P. (1942), Modern clay researches in relation to agriculture: Jour. Geology, vol. 50, no. 3, pp. 307-319.

King, B. C. (1950), Some large feldspar augen from near Ilorin Town, Nigeria: Geol. Mag., vol. 87, pp. 30-32.

Kuenen, Ph. H. (1950), Marine geology, Wiley & Sons, Inc., New York.

McCulloh, T. H. (1954), Problems of the metamorphic and igneous rocks of the Mojave Desert: California Div. Mines Bull. 170, Ch. VII, pp. 13-24.

McGill, J. T. (1951), Quaternary geology of the north-central San Emigdio Mountains, California: Ph.D. thesis, Unpubl., Dept. Geology, Univ. California, Los Angeles.

McKee, E. D., and Weir, G. W. (1953), Terminology for stratification and cross-stratification in sedimentary rocks: Geol. Soc. America Bull., vol. 64, no. 4, pp. 381-389.

Muehlberger, W. R. (1954), Deposition and deformation in the northern Soledad basin, Los Angeles County, California: Ph.D. thesis, Unpubl., California Inst. Technology.

Noble, L. F. (1926), The San Andreas rift and some other active faults in the desert region of southeastern California: Carnegie Inst. Washington Yearbook no. 25, 1925-26, pp. 415-428.

——— (1933), Excursion to the San Andreas fault and Cajon Pass: 16th Internat. Geol. Cong. Guidebook 15, pp. 10-21.

——— (1953), Geology of the Pearland quadrangle, California: U. S. Geol. Survey, Quadrangle Map Series No. 24, scale 1:24,000.

——— (1954a), Geology of the Valyermo quadrangle and vicinity, California: U. S. Geol. Survey, Quadrangle Map Series No. 50, scale 1:24,000.

——— (1954b), The San Andreas fault zone from Soledad Pass to Cajon Pass, California: California Div. Mines Bull. 170, pp. 37-48.

Oakeshott, G. B. (1957), Precambrian granulite in the western San Gabriel Mountains, California (abst.): Geol. Soc. America Bull., vol. 68, no. 12, pt. 2.

Read, H. H. (1927), Igneous and metamorphic history of Cromar, Deeside, Aberdenshire: Royal Soc. Edr. Trans., vol. 55, pp. 317-352.

Reed, R. D., and Hollister, J. S. (1936), Structural evolution of southern California: Am. Assoc. Petroleum Geologist Bull., vol. 20, no. 12, pp. 1529-1704.

Rogers, B. H., and Chesterman, C. W. (1957), Expansible shale: California Div. Mines Bull. 176, pp. 521-528.

Ross, C. S., and Hendricks, S. B. (1945), Minerals of the montmorillonite group, their origin and relation to soils and clays: U. S. Geol. Survey, Prof. Paper 205B, pp. 23-79.

Savage, D. E. (1957), Age of the Caliente Formation, Caliente Range, California (abst.): Geol. Soc. America Bull., vol. 68, no. 12, pt. 2.

Schaller, W. T. (1930), Borate minerals from the Kramer district, Mojave Desert, Calif.: U. S. Geol. Survey, Prof. Paper 158, pp. 137-170.

Schlee, J. S. (1952), Geology of the Mutau Flat area: M.A. Thesis, Unpubl., Dept. Geology, Univ. California, Los Angeles, 108 pp.

Schumm, S. A. (1956), Evolution of drainage systems and slopes in badlands, at Perth Amboy, New Jersey: Geol. Soc. America Bull., vol. 67, no. 5, pp. 597-646.

Schwade, I. T. (1954), Geology of Cuyama Valley and adjacent ranges, San Luis Obispo, Santa Barbara, Kern, and Ventura Counties: California Div. Mines, Bull. 170, Map Sheet 1.

Sederholm, J. J. (1926), On migmatites and associated Precambrian rocks of southwest Finland, Part II: Geol. Comm. Finland Bull., no. 77, pp. 1-140.

Stark, J. T. (1935), Border migmatites of the Sawatch Range, Colorado: Jour. Geology, vol. 43, no. 1, pp. 1-26.

Stevenson, L. S. (1947), Pumice from Haylmore, Bridge River, British Columbia: Am. Mineralogist, vol. 32, no. 9-10, pp. 547-552.

Stock, Chester (1947), A peculiar new carnivore from the Cuyama Miocene, California: Southern California Acad. Sci. Bull., vol. 46, no. 2, pp. 84-89.

Taliaferro, N. L. (1943), Geologic history and structure of the central Coast Ranges of California: California Div. Mines Bull. 118, pp. 119-163.

Turner, F. J. (1938), The metamorphic and plutonic rocks of Lake Manapouri, Fiordland, New Zealand: Royal Soc. New Zealand Trans. and Proc., vol. 67, pt. 1, pp. 83-100.

Vanderhoof, V. L. (1939), New evidence as to the age of the Cuyama Beds, California, (abst.): Geol. Soc. America Bull., vol. 50, no. 12, pt. 2, p. 1974.

Ver Planck, W. E. (1952), Gypsum in California: California Div. Mines Bull. 163, 151 pp.

Weaver, C. E., et al. (1944), Correlation of the marine Cenozoic formations of western North America: Chart no. 11, Geol. Soc. America Bull., vol. 55, no. 5, pp. 569-598.

Wiese, J. H. (1947), Geology and mineral resources of the Neenach quadrangle: Ph.D. thesis, Unpubl., Geol. Dept., Univ. California, Los Angeles.

Wiese, J. H., and Fine, S. F. (1950), Structural features of western Antelope Valley, California: Am. Assoc. Petroleum Geologists Bull., vol. 34, no. 8, pp. 1647-1658.

Willis, B. (1938a), San Andreas rift, California: Jour. Geology, vol. 46, no. 6, pp. 793-827.

——— (1938b), San Andreas rift in southwestern California: Jour. Geology, vol. 46, no. 8, pp. 1017-1057.

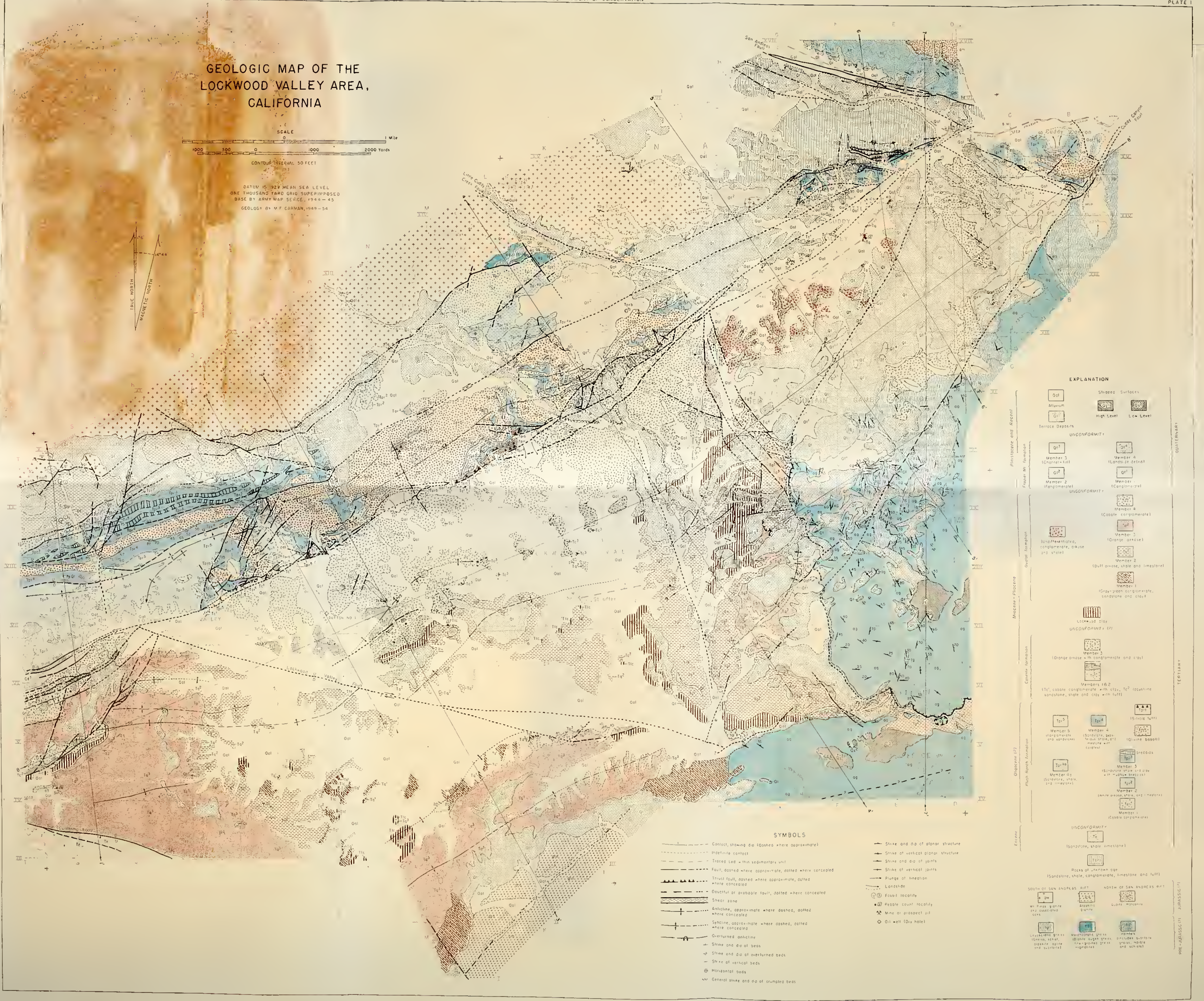
Wood, A. E. (1937), Additional material from the Tertiary of the Cuyama basin, California: Am. Jour. Sci., 5th ser., vol. 33, no. 193, pp. 29-43.

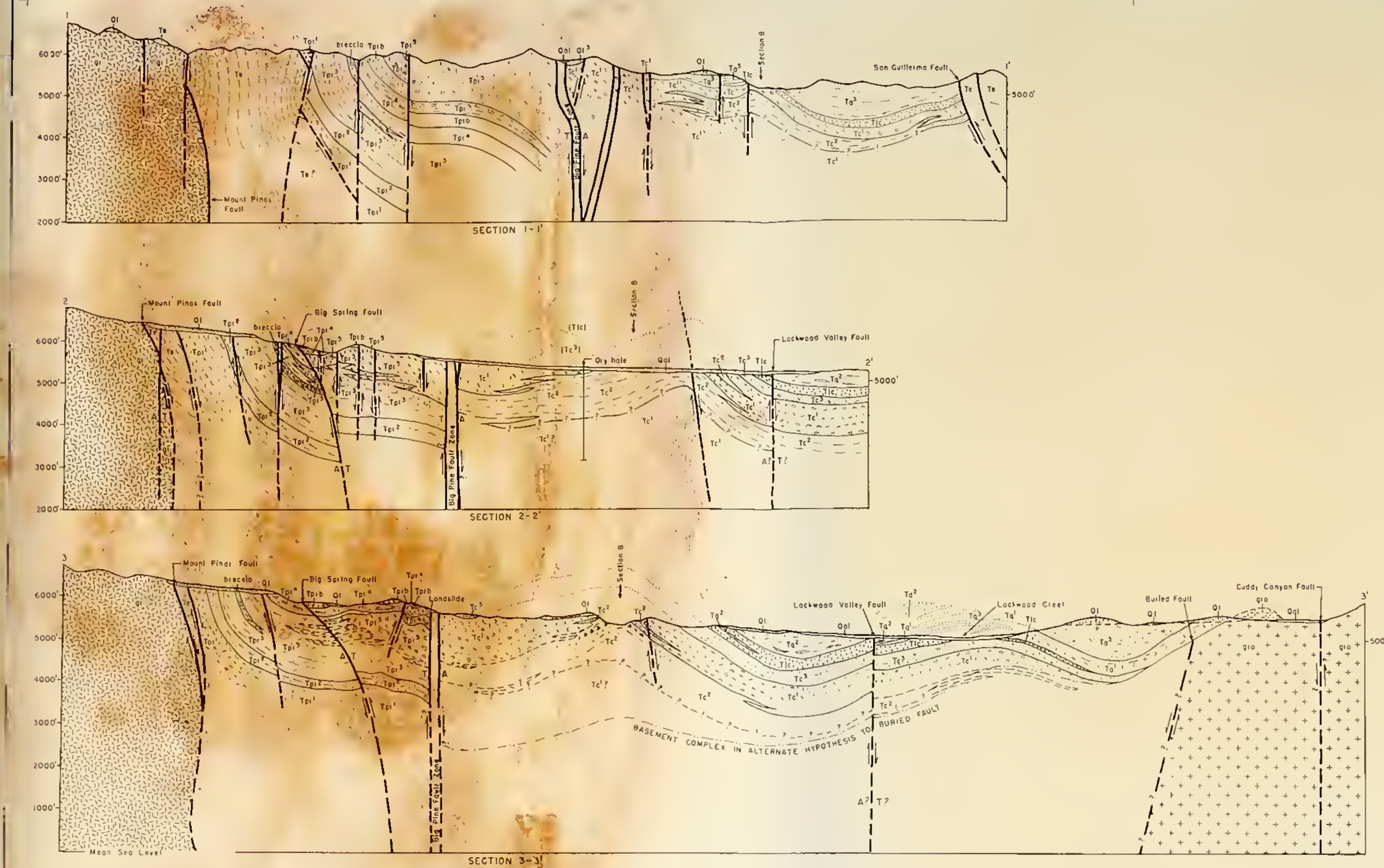
Wood, H. E., et al. (1941), Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., vol. 52, no. 1, pp. 1-48.

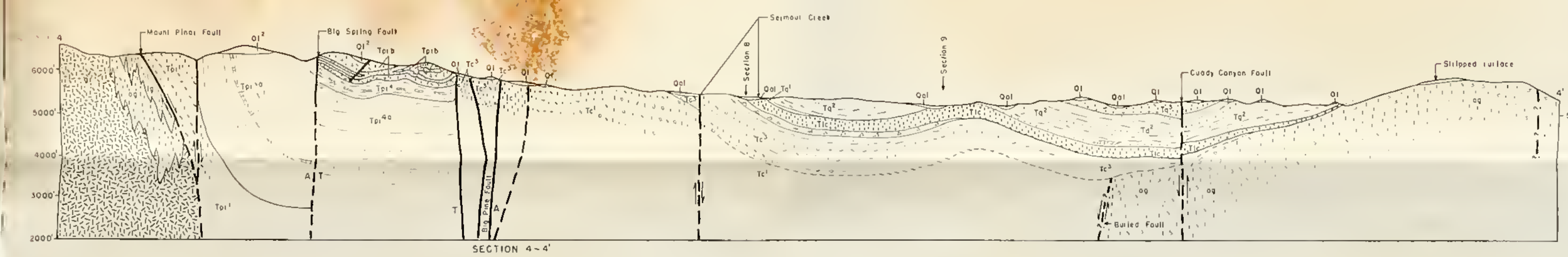
o

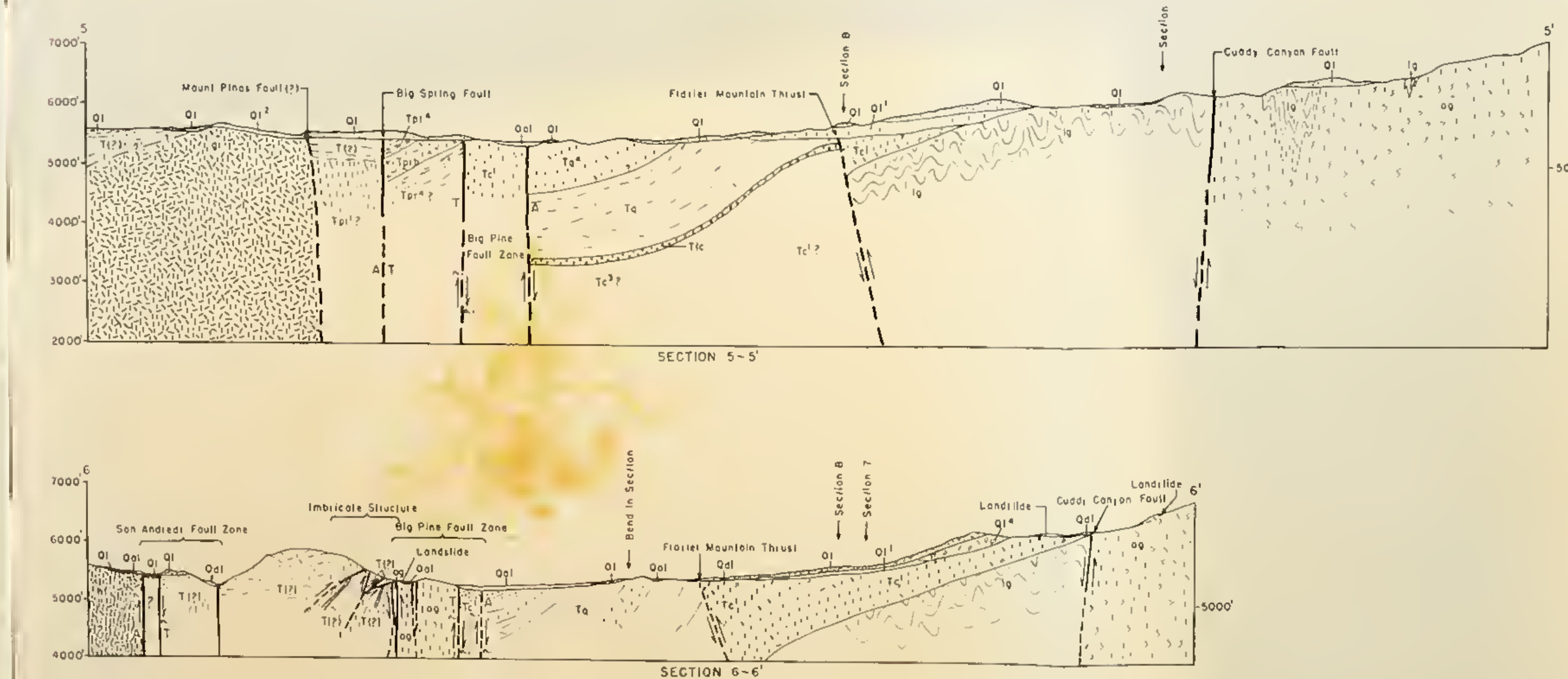
printed in CALIFORNIA OFFICE OF STATE PRINTING

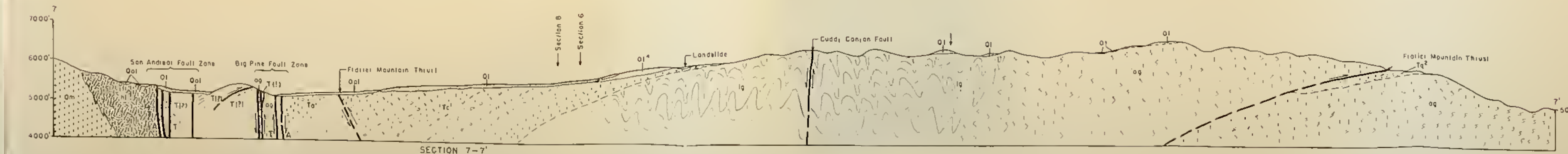
△88697 6-63 3M

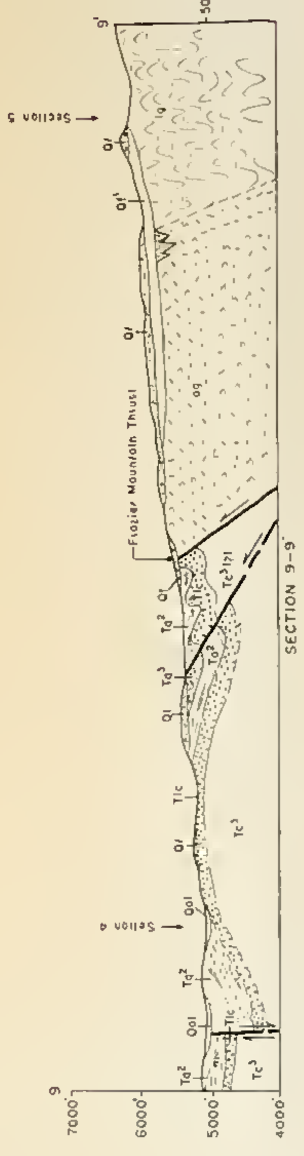

GEOLOGIC MAP OF THE
LOCKWOOD VALLEY AREA,
CALIFORNIA
SCALE
1 Mile
2000 Yards
CONTOUR INTERVAL 50 FEET
GEOLOGY BY M.F. CARMAN, 1949–54
TRUE NORTH
MAGNETIC NORTH
San Andreas Fault
Cuddy Canyon
EXPLANATION
SYMBOLS
QUATERNARY
TERTIARY

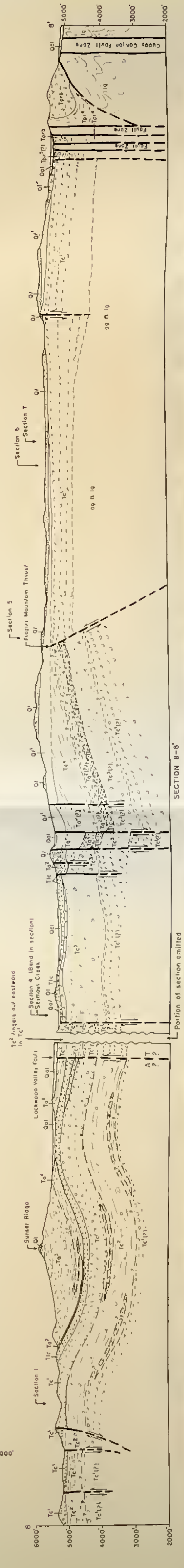












EXPLANATION

Qal — Alluvium
Qs — Stripped surface
Qt — Terrace deposits

Qf — Frazier Mountain formation

Tq — Quatal formation
Tlc — Lockwood clay

Tc — Caliente formation

Tprl — Plush Ranch formation
Tprb — Plush Ranch formation
Tpr — Plush Ranch formation

Te — Sandstone, shale, limestone
T(?) — Rocks of unknown age

gr — Mt. Pinos granite
gra — Alaskitic granite
qm — Quartz monzonite
lg — Leucocratic gneiss
mg — Melanocratic gneiss
hf — Hornfels

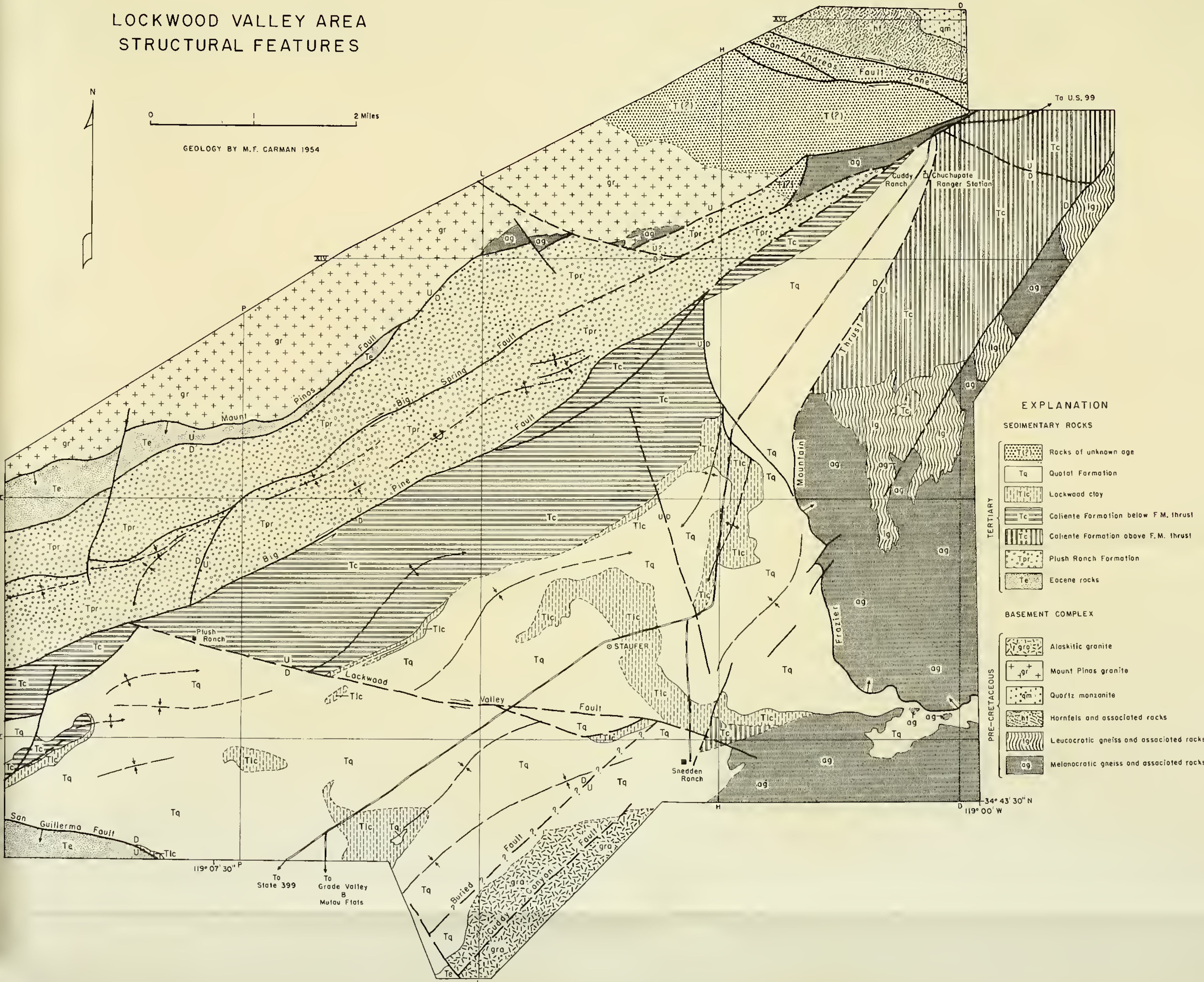
STRUCTURE SECTIONS
LOCKWOOD VALLEY AREA, CALIFORNIA

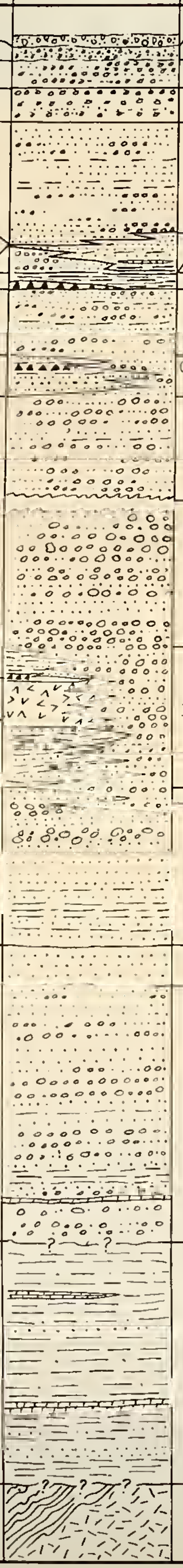
1 0 1 Mile

MAP OF THE LOCKWOOD VALLEY AREA TERRACE DEPOSITS

M.F. CARMAN 1954

LOCKWOOD VALLEY AREA STRUCTURAL FEATURES





SYSTEM	SERIES	STAGE	FORMATION	MEMBER SYMBOL	THICKNESS	LITHOLOGY
QUATERNARY	PLEISTOCENE and RECENT		ALLUVIUM	Qal	0-100'	Valley fill and alluvial fans; variable color and lithology, poorly developed gravelly soil, and stream deposits.
			TERRACE DEPOSITS	Qt	0-150'	Pebbles, cobbles, boulders in dark varicolored soil matrix; clasts of local granite, alaskite, and gneiss, with well-rounded volcanics.
			FRAZIER MTN. FORMATION	Qf		Coarse, soft, red, gray-green, and gray, poorly sorted to unsorted, mostly massive fanglomerate and channel fill; cobbles and boulders from local basement complex and sedimentary units; large landslide deposits in eastern portion.
TERTIARY	MIOCENE-PLIOCENE	Blancan	QUATAL FORMATION	Tq^4	0-600'	Member 4: Gray and buff, with pink to reddish cast, poorly bedded, soft pebble and cobble conglomerate and arkose, with interbedded red-brown clay layers; conglomerate clasts in thickly packed beds and lenses, composed of well-rounded red, pink, and purple volcanics, anorthosite, and gneisses of Frazier Mountain. Member 3: Coarse, massive, soft, orange and buff arkose, interbedded pebble and cobble conglomerate, and red-brown clay lenses; orange and brown siltstone, and dark red-brown clay layers at base; conglomerate clasts subangular alaskite and leucocratic gneiss with some well-rounded volcanic cobbles; local conglomeratic phase at base in eastern Lockwood Valley. Member 2: Pale buff and cream, soft, massive to well-bedded arkose and pebble conglomerate; interbedded pale green shale and clay, and thin white, limestone lenses in lower portions. Member 1: Gray-green, crudely bedded sandstone and cobble conglomerate, local thick, orange and green conglomeratic lenses interbedded with red-brown clay; clasts subangular gneisses of Frazier Mountain, local sedimentary breccia of biotite augen gneiss.
				Tq^3	1000'	
				Tq^2	0-700'	
				Tq^1	0-400'	
			LOCKWOOD CLAY	Tlc	0-275'	Dark red-brown to brownish-gray montomorillonitic clay with local white bentonite at base, and intercalated thin white to gray fine-grained, laminated, biotitic sandstone lenses.
		Hemingfordian-Hemphillian (?)	CALIENTE FORMATION	Tc^3	0-1000'	Member 3: Buff, orange-streaked, poorly bedded, poorly sorted, arkose with pebble and cobble conglomerate layers and intercalated red-brown clay lenses and beds; conglomerate clasts subangular to subrounded leucocrated gneiss, alaskite, and subsidiary biotite augen gneiss. Member 2: Lacustrine lentil, gray and green, fine-to-coarse-grained, massive to laminated, moderately to well-indurated sandstone with intercalated gray pebble conglomerate, green siltstone, shale with fresh-water gastropods, and clay layers and white, vitric tuff beds. Member 1: Pale pinkish-buff, tan, and brown, poorly bedded clay-rich arkose with pebble to cobble conglomerate lenses and red brown clay layers and lenses; clasts well-rounded, acid to basic, pink, red, and purple volcanics; leucocratic gneiss; alaskite; and anorthosite. Badland weathering typical of the member.
				Tc^2	0-700'	
				Tc^1	0-2000'	
	OLIGOCENE (?) MIOCENE (?)		PLUSH RANCH FORMATION (Non-marine)	Tpr^5	1200'	Member 5: Coarse, light gray to gray-green, well indurated, crudely bedded to massive, fanglomerate. Monomictic cobble and boulder layers intercalated with light gray and yellow, soft to hard, moderately well-bedded arkosic sandstone and local gray to brown, soft shale and limestone layers; conglomerate clasts subrounded to angular pebbles, cobbles, and boulders of biotite augen gneiss, leucocratic gneiss, and quartz monzonite.
				Tprt, Tpr^4, Tprb	1250'	Member 4: Lake beds of dark gray-green to brown shale, siltstone, and thin-bedded to laminated, well-indurated, slabby feldspathic sandstone; interbedded dark gray to cream-colored, laminated, gypsiferous limestone; shale contains fresh-water ostracods and limestone nodules with insects, plants, and fish remains of fresh-water environment. Interbedded, olivine basalt flows; water-laid, pale yellow and green sandy tuff containing clinoptilolite (?); and arkose.
				Tpr^3	1400'	Member 3: Lower half, drab gray and buff, poorly to well-bedded, moderately indurated micaceous arkosic sandstone with gray-green and dark gray shale and clay common. Upper half, light orange and orange-brown, well-bedded to massive, moderately indurated arkose with directional-current structures; with interbedded mudflow breccia composed of Mount Pinos granite and local subsidiary biotite augen gneiss in coarse angular blocks. Minor limestone with ostracods.
				Tpr^2	275-375'	Member 2: Soft, pale buff to white, poorly bedded, fine-to coarse-grained arkose; with interbedded gray shale, platy gray limestone, and slabby sandstone.
				Tpr	2300'	Member 1: Coarse, poorly bedded, mostly unsorted, poorly to well-indurated, arkosic pebble and cobble conglomerate; light gray and white in upper portions, variegated red, maroon, brown, and green in lower portions; intercalations of tan to white, poorly to moderately indurated arkose, brown and gray-green shale, clay, and a 2-foot thick bed of gray massive limestone; conglomerate clasts well-rounded granitic and metamorphic with some Eocene sandstone cobbles.
	EOCENE	Capay	(Marine)	Te	2200'	Light and dark gray, buff, and tan, moderately fissile shale with subsidiary thin-bedded limestone, mudstone, siltstone, sandstone, and pebble conglomerate. Sandstone moderately to well-indurated, well-bedded, poorly sorted, arkosic, with angular grains, containing broken fragments of mollusks and gastropods.
PRE-TERTIARY						Crystalline complex of biotite augen gneiss leucocratic quartzo-feldspathic gneiss, biotite schist, quartzite, hornfels, and marble; intruded by granite (Mount Pinos granite), quartz monzonite, hornblende-biotite-quartz diorite, and alaskite.