A PORTION OF THE SAN ANDREAS RIFT IN SOUTHERN CALIFORNIA

Thesis

by

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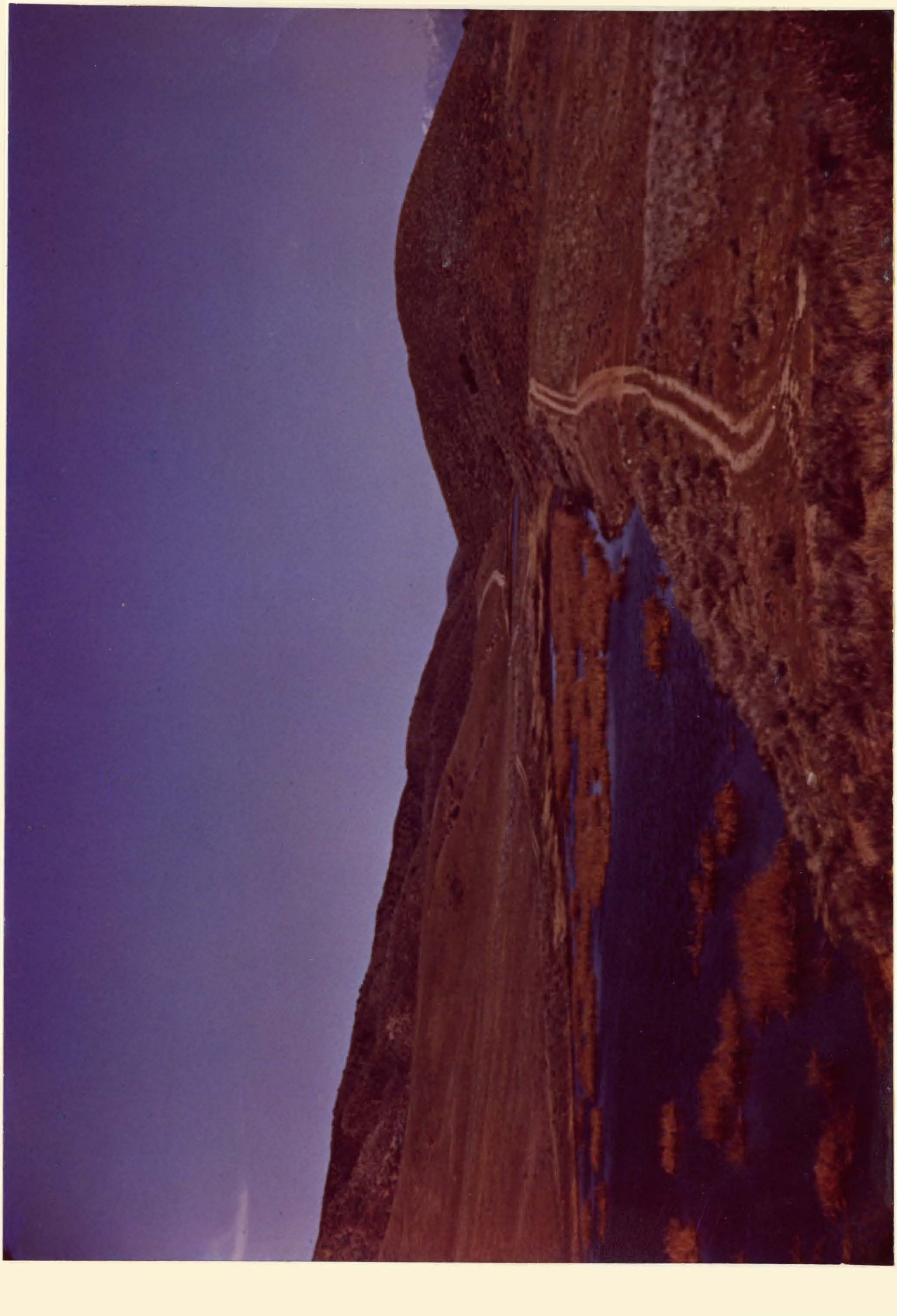

Frontispiece. A typical recent fault scarp and sag pond along the San Andreas rift. View looking southeast from a point 4 miles southeast of Elizabeth Lake. The snow capped San Sabriel mountains are in the distance.

CONTENTS

Page

LIST OF ILLUSTRATIONS

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ABSTRACT

A portion of the San Andreas rift along the south side of the Mohave Desert between Palmdale and Elizabeth Lake has been mapped and described in this paper. The details of geology and geomorphology have been analyzed and their significance in regard to the interpretation of the genesis of the rift has been discussed.

The area includes four principal geomorphic and geologic divisions; a portion of the Mohave Desert, two parallel ridge zones and an intervening trough which marks the rift. The two ridge zones are principally old crystalline rocks whereas the trough zone is underlain principally by a long narrow strip of Tertiary sediments. These sediments outcrop in a low "center-trough" ridge and most are part of the Anaverde formation which, on the basis of paleobotanical evidence, is believed to be of Pliocene age. Other Tertiary formations are the Vasquez volcanics, presumably Oligocene, the Pleistocene Harold beds, and an arkose of undetermined age possibly older than the named Tertiary formations of the area. The presence of this long, narrow strip of sediments between two crystalline masses was a problem for which no conclusive evidence was found.

Two structural trends are prominent in the area. The older rocks of the ridge zones are distributed in more or less bands striking east or slightly north of east. This trend is cut by the rift which in this area has a strike of approximately N. 65° W. There is a suggestion that the east-trending structures are older than the rift and related to a different period of diastrophism.

Terrace deposits and offset streams suggest a horizontal displacement along the rift of the order of 5 - 6 miles since Pleistocene time. The north side of the rift moved southeast with respect to the south side. A block of Pelona schist north of the rift has an apparent horizontal displacement of 9 miles in the opposite direction to that indicated by recent faulting and stream offsets. This relationship is believed to be only apparent and possibly the result of vertical displacements and stripping.

Terraces on the ridge blocks and in the rift zone indicate a great amount of "juggling" of the blocks in and adjacent to the rift. Considerable vertical displacement along the rift is also indicated. The drainage along the rift and in the surrounding areas has frequently been interrupted, reversed, and otherwise changed by the repeated tectonic activity along the rift. Wind gaps, stream captures and unadjusted streams are features which have resulted.

INTRODUCTION

Purpose and nature of study

In a general sense the purpose of the present study was to add a small unit to the stock of information that must be obtained before a final understanding of the nature of the San Andreas rift can be realized. Such a study naturally includes an investigation and analysis of both geologic and geomorphic features. Specific geologic features which challenged investigation included the presence of a tectonic block which apparently had been shifted horizontally in a direction opposite to that found to be the normal case along other parts of the rift. The long narrow strip of sediments which follows the rift also offered possibilities of supplying significant data relating to the structure of the rift zone.

One important consideration was the fact that the area chosen continued westward from a strip between Palmdale and Cajon Pass that has been, and is being mapped, by L. F. Noble, and that the continuity thus offered would be of mutual advantage in the interpretation of both areas. The availability of excellent topographic maps and aerial photographs that could be used as base maps made the area ideal from that standpoint. The area was also easily accessible by good roads.

Location and size of area

The portion of the San Andreas rift mapped in connection with the present investigation lies approximately 35 miles north of the business district of the city of Los Angeles. The area lies along the north flank of the Sierra Pelona Mountains and extends from the Southern Pacific railway tracks a few miles south of Palmdale west to approximately a mile west of Elizabeth Lake. It includes Portal Ridge, Ritter Ridge, and the adjacent portions of that part of the Mohave Desert known as Antelope Valley. Approximately 117 square miles are included in the map on plate I which represents a strip approximately five and a half miles wide and twenty miles long.

Field work

Field work was carried on during the two academic years 1940-41 and 1941-42. Mapping was done on a scale of one inch to a thousand feet both on photographic enlargements of the U. S. Geological Survey topographic maps of Los Angeles county and on aerial photographs obtained from the Agricultural Adjustment Administration of the U. S. Department of Agriculture. The geology was somewhat simplified and drafted in the office onto the original Geological Survey maps which are on a scale of one to twenty-four thousand. The aerial photographs used were on a scale of approximately one inch to a thousand feet and were taken by Fairchild Aerial Surveys, Inc. After the declaration of a national emergency in 1941 when aerial photographs could no longer be obtained from the Government bureau, additional photographs were obtained directly from the Fairchild company, but were contact prints on a scale of approximately one inch to two thousand feet instead of the enlargements of twice that size obtained from the Agricultural Adjustment Administration.

Plate 2. Aerial view of the San Andreas rift looking northwest from above Palmdale reservoir. The four geologic and geomorphic divisions are clearly shown. On the left is Sierra Pelona Ridge; near the center of the picture, the trough and Portal Ridge; on the right, the Mohave Desert. The low, center-trough ridge can also be seen as well as stream divergence by the rift. Photograph by Fairchild Aerial Surveys, Inc.

REORDER No. 0-3321

IDENTIFICATION

San Andreas Fault

Palmdale, Calif.

DATE FLOWN 12-24-32

INSPECTED BY

FAIRCHILD AERIAL SURVEYS, Inc.

224 E. 11th St.

LOS ANGELES, CALIF.

Purchase of this photog[illegible] [illegible] [illegible]
[illegible]

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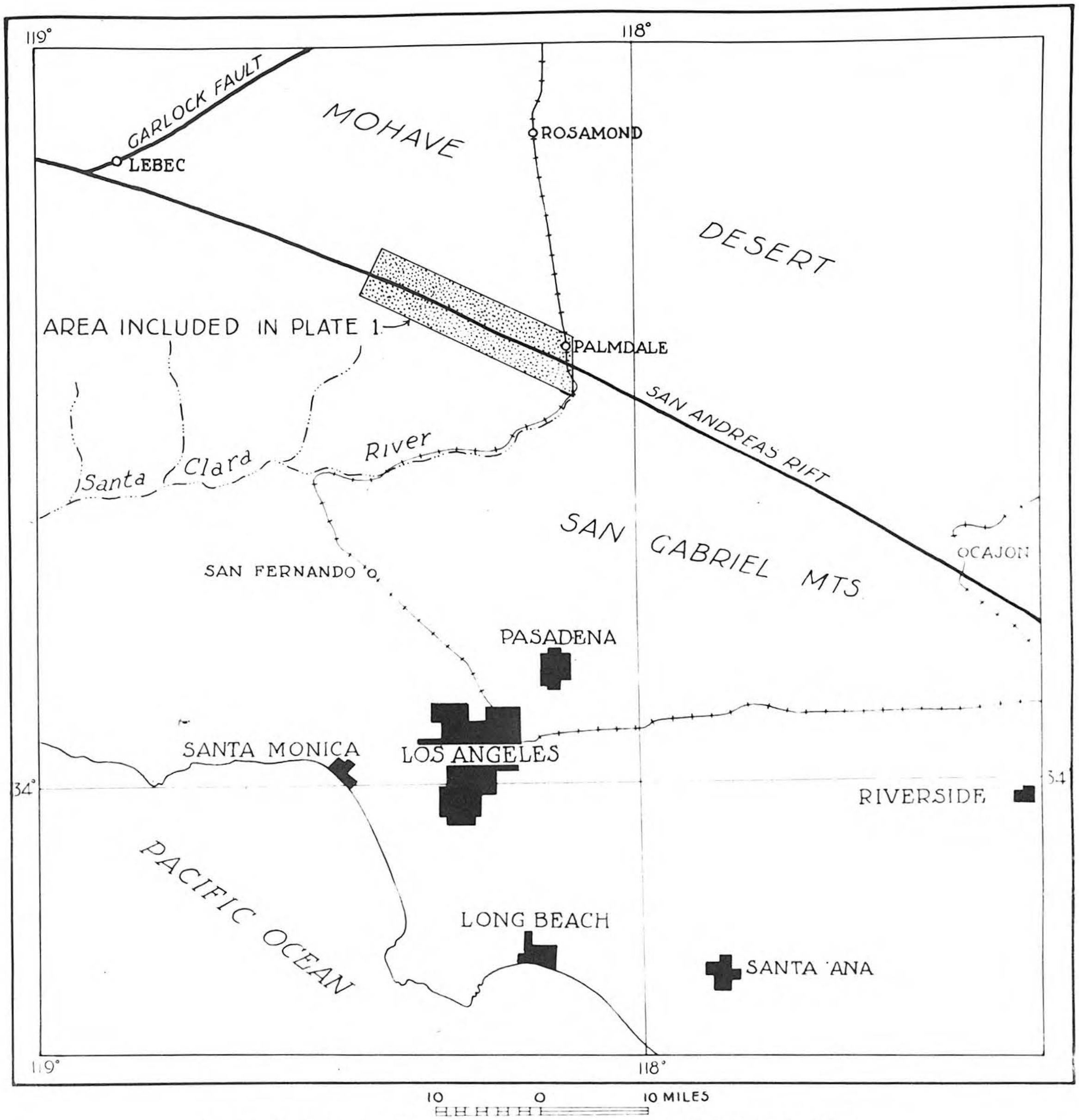

INDEX MAP OF LOS ANGELES AREA

Acknowledgements

The writer wishes to express his gratitude to Professor J. P. Buwalda of the California Institute of Technology not only for suggesting this investigation of the San Andreas rift, but for his guidance and helpful criticism during the progress of the work. L. F. Noble of the Federal Geological Survey kindly spent several days in the field with the author and offered many suggestions and ideas gleaned from the many years that he spent studying the rift. His help and inspiration are greatly appreciated. Dr. D. I. Axelrod studied the plant fossils found in the Anaverde beds and gave the writer a most helpful report on their significance. The kodachrome transparency from which the frontispiece was made was taken by W. M. Tovell of the California Institute of Technology and kindly loaned to the writer to have enlargements made. Finally, the writer wishes to express his indebtedness to the staff of the Division of the Geological Sciences of the California Institute of Technology for making available the equipment and facilities of the department during this study.

Climate, vegetation and culture

The climate of the area is arid, the annual rainfall being approximately 10 inches. Some of the precipitation in the higher parts of Sierra Pelona Ridge is in the form of snow. Most of the precipitation is during December, January and February. During the summer midday temperatures are usually 100° F. or more, but night temperatures are often as low as 60° F. Temperatures during January and February commonly reach a minimum of 10° F.

The vegetation consists principally of grasses and low shrubs in the fault trough and on the Mohave Desert. Several varieties of sage are present including the common *Artemisia tridentata* and *Artemisia frigida*. In some sections of these low areas which are better watered Joshua trees, *Yucca brevifola*, grow. The common, low variety of yucca, *Yucca elata*, is also abundant as are several varieties of cactus. Poplars and willows grow along the edges of sag ponds and creeks, and in protected valleys several varieties of live oak are present. Juniper grows on the hill slopes and in some localities grows to 15 or more feet high. In places these junipers form such a thick undergrowth that passage through them is almost impossible. A few isolated pines grow on the north slopes of Sierra Pelona Ridge near the crest. The town of Palmdale is principally a shipping center for the produce of the southern part of Antelope Valley, a part of the Mohave Desert. Livestock is raised on the ranches situated in the trough, and hay is the chief crop. A few orchards grow in the protected valleys which receive water from Sierra Pelona ridge. In the Mohave Desert on the alluvial slopes of Portal Ridge hay and various grains are grown. Water is pumped from wells which tap subsurface drainage through the alluvium. Considerable irrigation is necessary in this area.

Development of theories regarding the San Andreas rift

Apparently the first published account in scientific literature which recognized the presence of an important structural break along the line of the San Andreas rift was a paper by A. C. Lawson[1/] entitled "The Post-Pliocene Diastrophism of the

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1/ Lawson, A. C., The Post-Pliocene Diastrophism of the Coast of Southern California; Univ. Calif. Bull. Dept. Geol., vol. 1, no. 4, p. 151, 1893.

Coast of Southern California". In this paper, published in 1893, Lawson stated:

"The line of demarcation between the Pliocene and the Mesozoic rocks, which extends from Mussel Rock southeastward, is in part, also, the trace of a post-Pliocene fault. The great slide on the north side of Mussel Rock is near the land terminus of this fault zone, where it intersects the shore line. Movement on this fault zone is still in progress. A series of depressions or sinks, occupied by ponds, marks its course. Modern fault scarps in the Pliocene terrane are features of the country traversed by it."

In the United States Geological Survey annual report for 1896-1897, J. D. Schuyler[2/] indicated that the "great earthquake crack"

2/ Schuyler, J. D., Reservoirs for Irrigation: U. S. Geol. Survey 18th Annual Report, part IV, pp. 711-712, 1896-1897.

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was well known over considerable distance as he states:

"This remarkable line of fracture can be traced for nearly 200 miles through San Bernardino, Los Angeles, Kern, and San Luis Obispo counties, and deviates but slightly here and there from a direct course of about N. 60° to 65° W. There appears to have been a distinct 'fault' along the line, the portion lying south of the line having sunken, and that to the north of it being raised in a well-defined ridge. In many places along the great crack ponds and springs make their appearance, and water can be had in wells at little depth anywhere on the south side of the ridge before mentioned."

He further mentioned geomorphic features observed in his study of the Alpine reservoir (now Palmdale reservoir) as follows:

"This reservoir--lies directly in the line of what is known as 'the great earthquake crack' of this region, which is marked by a series of similar basins behind a distinct ridge that appears to have been the result of the great seismic disturbance."

F. M. Anderson [3] in 1899 described the rift in the region

3/ Anderson, F. M., The Geology of the Point Reyes Peninsula: Bull. Dept. Geol., Univ. Cal., vol. 2, no. 5, 1899.

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north of San Francisco in the Point Reyes Peninsula area.

Investigations previous to the earthquake of 1906, were concerned mostly with the geomorphic features of the rift, and structural significance was little understood. Most of the features observed were attributed to vertical movements along the rift and since no horizontal shears of such nature had been recognized previously in the world, it is not surprising that the significance of the features that indicate horizontal offset were completely overlooked.

The attention of geologists was immediately centered on the rift following the disaster of 1906, and Governor Pardee of California immediately appointed a committee to investigate the rift features. The project was financed by the Carnegie Institute of Washington, and was headed by Andrew C. Lawson. [4] The results of

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4/ Lawson, A. C. and others, The California Earthquake of April 18, 1906: Carnegie Inst. of Wash., Pub. no. 87, 1908.

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this investigation were published in 1908.

During the 1906 earthquake displacements along the fault displayed vividly the horizontal aspect of the movement. As a result of the studies of the phenomena associated with this movement, H. F. Reid 5/ formulated and published his elastic-rebound theory of

5/ Reid, H. F., The Elastic-Rebound Theory of Earthquakes: Univ. of Calif. Pub., Bull. Dept. of Geol., vol. 6, pp. 413-444, 1911.

earthquakes. Interest was also created in all the faults of California, and in the report of the California Earthquake Commission a map showing the distribution of known major faults of the Coast Ranges of California was published. The San Andreas rift was traced for a distance of 530 miles from Point Arena to Whitewater Canyon and the geomorphic as well as major structural features were described in the report of the California Earthquake Commission. The general characters of the rift as recognized by the commission may be briefly indicated by the following quotations from their report. 6/

6/ Lawson, A. C. and others, The California Earthquake of April 18, 1906: Carnegie Inst. of Washington, Vol. I, pt. 1, p. 2, 1908.

"The plane or zone on which the rupture took place is, so far as can be determined from a study of the surface phenomena, nearly vertical; and upon this vertical plane there occurred a horizontal displacement of the earth's crust or at least of its upper part. The displacement was such as to cause the country to the southwest of the rift line to be moved northwesterly relatively to the country on the northeast side of that line. The differential displacement in a horizontal direction was probably not less than 10 feet for the greater part of the rift; in many places it measured over 15 feet, and in one place as much as 21 feet."

Of the geomorphology they summarized as follows:

"Throughout this entire distance it lies along depressions or at the base of steep slopes which are either the direct result of crustal displacement or of stream erosion, operating with exceptional facility along lines of displacement. There can be no doubt that the displacements have been recurrent thru a considerable part, if not the whole of Pleistocene time, and that in parts of its extent, at least, the movements have taken place on fault-lines which originated in pre-Miocene time. The later movements on this line have given rise to minor features which subaerial and stream erosion have not yet obliterated, and it is these minor features chiefly which have attracted attention to the Rift by reason of their striking contrast with more common geomorphic forms due to erosion. These minor features are chiefly low scarps and troughs bounded on one or both sides by low, abrupt ridges in which frequently lie ponds or swamps of quite small extent."

Once the magnitude of the San Andreas rift was recognized, it was frequently called the "master fault" of California. Indeed, it can be classed as a major world tectonic feature. The complexity and magnitude of the processes involved in the development of the San Andreas rift are such that it is probably true that only little of the final understanding has been realized after over half a century of study.

The next important contribution to the study of the San Andreas rift was that of L. F. Noble[7/] in a paper entitled "The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California". In this paper Noble suggested the order of magnitude of the horizontal displacements in the portion of the Rift from Cajon Pass to Palmdale along the north side of the San Gabriel Mountains to be possibly 24 miles since Miocene time. He

7/ Noble, L. F., The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California: Carnegie Inst. of Wash., Year Book no. 25, 1925-26
Also: Bull. of the Seismol. Soc. of Amer., vol. 17, p. 31, 1927.

stated:

"The distribution of certain Tertiary rock masses along the master fault affords a suggestion that a horizontal shift of many miles has taken place along the rift. On the north side of the fault, near Cajon Pass, a small block of strata lithologically similar to beds in the Martinez formation at Rock Creek is associated with Mint Canyon beds. The only other exposure of Martinez associated with Mint Canyon beds anywhere in this region lies on the opposite side of the fault at Rock Creek, twenty-four miles northwest of the locality in Cajon Pass. At both localities the beds of both formations are so intricately faulted that a displacement of any magnitude is conceivable, and it thus appears possible that horizontal movements along the fault have dragged the rock-masses north of the fault to the southeast in relation to those south of the fault, or have dragged the masses south of the fault to the northwest in relation to those north of the fault."

Noble likewise considered the San Andreas rift to be of considerable antiquity.

"The distribution of the Pre-Tertiary rocks along the rift indicates that movements took place upon it as far back as late Mesozoic or early Tertiary time. The first movements whose date can be established approximately, however, took place at some period between late Miocene and early Quaternary time, because they involve the upper Miocene Mint Canyon formation but not a formation that is believed to be either late Pliocene or early Quaternary or both."

That horizontal displacements of the order of many miles occurred elsewhere on associated faults was suggested by Vickery[8/] after studying the Sunol fault of the Livermore region. Vickery

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8/ Vickery, F. P., The Structural Dynamics of the Livermore Region: Jr. of Geol., vol. 33, pp. 6-8-628, 1925.

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found that:

"Measuring between corresponding points, namely, the southerly intersection of the Briones contact with the fault, the strike shift is 12 miles. Between two Lower Miocene localities characterized by the abundance of Pecten propatulus Conrad the measurement is 13 miles, and between two (the only two) Pliocene rhyolitic localities, it is 9 miles. Similarly, near Alum Rock Park sandy

Briones beds which rest on Temblor opalized shale on the westerly side of the Sunol fault correspond to a similar series south of the San Felipe Valley. The strike shift is again 12 miles."

Contrasting with this concept of the rift being an old feature with horizontal displacements of the order of tens of miles is the interpretation of Taliaferro.9/ His conclusions are stated in his summary as follows:

9/ Taliaferro, N. L., Geologic History and Structure of the Central Coast Ranges of California: State of Calif. Div. of Mines Bull. no. 118 & 161, 1943

"1. The San Andreas zone roughly coincides with a zone of profound Eocene faulting which marks the boundary between the ancient crystalline basement and Mesozoic rocks. However, the two do not always agree, and the later zone may be wholly within either the crystalline basement or the Mesozoic rocks.

"2. The movement has been chiefly horizontal but in that part of the rift north of Parkfield the horizontal shift has been small, and has not been greater than 1 mile and probably even less.

"3. The horizontal shifting along the San Andreas zone is a very late feature, as it cuts across structures and topography developed in the late Pliocene and mid-Pleistocene. Although a major structural feature, the effects produced by all of the late Pleistocene and Recent movements along it have not been comparable with those which resulted from the Plio-Pleistocene diastrophism. It has produced no important modification of either the structure or topography formed by these diastrophisms.

"4. The supposed branches or 'barbs' are actually earlier faults which were formed by a very different type of movement, and which may be traced across the San Andreas. No important faults branch off from the San Andreas north of Parkfield with the possible exception of the Hayward; even in this case a direct connection between the two has not been established."

In addition to this contradiction to Noble's suggestion of great displacement is the fact that new vertebrate material has been obtained from the beds which were correlated tentatively on the basis of lithology by Noble and used as evidence suggesting 24 miles of displacement. The vertebrate material has been studied by Dr. Chester Stock,[10] and apparently indicates a differ-

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10/ Stock, Chester, oral communication.

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ence in age of the Cajon beds (likened to Mint Canyon beds by Noble) which outcrop north of the rift near Cajon Pass and the Punch Bowl beds which occur south of the rift near Rock Creek. *Archeohippus* has been found in the Cajon beds and therefore limits the age to not younger than lower Upper Miocene, whereas several large equine forms found in the Punch Bowl beds indicate at least an upper Upper Miocene age and possibly even a Pliocene age for that section.

Even so, in the San Gabriel section of the rift the horizontal displacements appear to have been more than one mile as Taliaferro suggested was possibly the maximum in the Parkfield area. During work conducted with L. F. Noble for the United States Geological Survey, C. L. Gazin[11] found evidence which lead him to make the following conclusions:

11/ Gazin, C. L., unpublished report.

"The Pelona schist gravel in the Pearland and Little Rock quadrangles suggests a minimum displacement of 5 - 6 miles. Furthermore, at many places the physiography north of the rift has changed markedly during the period between the deposition of the first and last gravels. The oldest gravels were deposited before the present stream channels were defined. The largest stream channel, Little Rock Creek, shows as much as a mile displacement. It seems reasonable to suppose that in many cases streams crossing the rift northward have had their lower portions displaced so as to receive drainage from the next creek eastward."

Another suggestion by Noble is that the shifting has been even greater than the 24 miles. There is a possibility the San Gabriel Mountains and the San Bernardino Mountains represent a structural block that has been split by the San Andreas rift. If this were true, the San Bernardino Mountains lying north of the rift would have been shifted eastward with respect to the San Gabriels, a distance of the order of 70 miles. Noble,[12/] however, though apparently of the opinion that the horizontal movements have been great, points out very clearly that there is no definite proof of great displacements. He summarized:

"In brief, the only reasonable conclusion from the evidence available seems to be this - a horizontal shift of many miles along the fault is possible but no conclusive stratigraphic evidence of it is obtainable and the structural evidence, although suggestive, does not amount to proof. That horizontal shifts of a mile or even of several miles have taken place is reasonably certain from topographic evidence available, yet it is not certain that these movements have been consistently in the same direction throughout geologic time. Reversal of horizontal movement on the fault at different times and places is seemingly conceivable if the physiographic evidence is actually and not apparently contradictory."

Returning to the question of the age of the Rift and the differences in opinion expressed by Noble and by Taliaferro, suggestions by other investigators may be added. Willis[13/] indicated that the Rift

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12/ Noble, L. F., The San Andreas Rift in the Desert Region of Southeastern California: Carnegie Inst. Washington, Year Book No. 31, p. 358, 1932.

13/ Willis, Bailey, San Andreas Rift, California: Jr. of Geol., vol. XLVI, no. 6, p. 811, 1938.

is a relatively ancient feature as follows:

"The relations of the rift to young topographic features and to post-Tertiary formations suffice to show that it has been active since pre-Pleistocene time. --- The general relations which have been described and which clearly indicate that the various faults, folds, and minor features may be interpreted as effects of one and the same system of contemporaneous stresses, repeatedly active and repeatedly inactive since Mesozoic time, confirm the impression that the rift is an ancient structural feature. Some details tend to support that inference. There is, for instance, the case of the occurrence of granite boulders in fossiliferous Eocene strata in the very strike-slip zone of the rift itself. It clearly shows that the granite was exposed on the fault line in that immediate vicinity in Eocene time."

Likewise Reed and Hollister[14/] expressed a view obtained from

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14/ Reed, R. D., Hollister, J. S., Structural Evolution of Southern California: Am. Assoc. Petroleum Geologists, p. 84, 1936.

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paleogeographic evidence that the line of the San Andreas rift was marked out before late Jurassic time.

"If the views previously expressed as to Lower Mesozoic paleogeography are correct, it follows that the northern part of the course of the San Andreas fault was marked out, though not necessarily followed by a fracture, before the late Jurassic. It was then a boundary between a negative and a positive area."

Most of the geologists who have worked on the rift realize that there is as yet little evidence to prove conclusively the validity of either view. Reed[15/] aptly expressed this variance

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15/ Reed, R. D., Hollister, J. S., Geology of California: Am. Assoc. Petroleum Geologists, p. 38, 1933.

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in interpretation due to lack of sufficient investigation as follows:

"Among the geologists most familiar with different parts of the long course of the fault, the notions held about its nature and history are very diverse. To some it is an ancient feature which has dominated the geological events along its course and even throughout much of the Coast Ranges since the Jurassic at least. To others it is a recent feature, perhaps developed out of individual faults which were older, but only welded together in Pliocene time or later. At present there is, on the whole, little more reason for holding one of these views than the other. The problems involved in the study of the rift are so vast and far-reaching that the amount of work hitherto devoted to them is entirely inadequate for their solution."

Although, as has been shown, there is wide divergence of opinion regarding much of the history and nature of the San Andreas rift, one point of interpretation seems to be generally accepted by most geologists, that is, that the rift is due to compressional forces. The exact orientation of the forces is not without question, but the interpretation of the rift features as being indicative of shearing and compressional rather than tensional forces is almost universally accepted among geologists. Noble[16/]

16/ Noble, L. F., The San Andreas Rift in the Desert Region of Southeastern California: Carnegie Inst. Washington, Year Book no. 31, p. 358, 1932.

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emphasized this point as follows:

"Except the plane of the main fault, which appears to be nearly vertical, the planes of nearly all the associated or branching faults are the planes of reverse faults. At place after place in the rift zone, one encounters slabs of pre-Tertiary granite thrust over younger upturned Tertiary beds."

Buwalda[17/] has studied one such prominent thrust plate in the

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17/ Buwalda, J. P., oral communication.

Tejon Pass region. He found that Fraser Mountain is an isolated slab of granitic rock resting on Tertiary sediments.

Hill[18] believed the San Gabriel Mountains of southern

18/ Hill, M. L., Structure of the San Gabriel Mountains: Univ. of California Pub. Geol. Sci., vol. 19, pp. 137-170, 1930.

California to be essentially an inverted prism which is being forced upward by lateral compression. Willis[19] stated:

19/ Willis, Bailey, San Andreas Rift, California: Jr. of Geol., vol. XLVI, no. 6, p. 802, 1938.

"The phenomena of secondary shears, thrusts, folds, which are very generally associated with the San Andreas rift, as also with other strike-slip faults, are results clearly attributable to such compression."

Taliaferro[20] recognized many thrust faults near the San

20/ Taliaferro, N. L., Geologic History and Structure of the Central Coast Ranges of California: State of California Div. of Mines Bull. no . 118, p. 160, 1943.

Andreas rift but considers them as "earlier faults which were formed by a very different type of movement, and which may be traced across the later line".

Some major questions regarding the nature and history of the San Andreas rift that cannot yet be answered may be summarized as follows:

1. Is the San Andreas rift an old feature dating back to early Tertiary or pre-Tertiary time? Noble, Willis, and others have suggested this to be the case.

2. Or is the San Andreas rift, that is the strike-slip movement, an extremely recent feature cutting "indiscriminately" across structural features formed by "earlier and very different type movement" as Taliaferro has suggested.

3. Is the horizontal offset of the Rift measured in many miles as Gazin and Noble have thought?

4. Or is the movement less than a mile as Taliaferro believes he has found in the central Coast Ranges?

5. Or is the movement variable on different portions of the rift to an extent that would account for this variance of apparent movement?

6. Has the rift possibly changed direction of movement as is suggested by the apparently reverse offset of the block of Pre-Cambrian Pelona schist near Palmdale, California?

The fact that such basic problems still remain unsolved indicates the complexity of the features associated with the San Andreas rift, for certainly such problems as these would seem to be the first that could be answered.

Previous geologic work in the area of this investigation

The earliest published geologic account of studies centering in the area covered by the present investigation was that of Schuyler[21] in 1897. Schuyler was interested principally in

21/ Schuyler, J. D., Reservoirs for Irrigation: U. S. Geological Survey 18th annual report, part IV, pp. 711-712, 1896-1897.

reservoir sites. In 1902 Hersey[22] described the Pelona schist and

22/ Hershey, O. H., Some Crystalline Rocks of Southern California; Amer. Geologist, vol. 29, p. 279, 1902.

other metamorphic rocks in the area. Hill and associates made a reconnaissance map of the western portion of the area of present study in connection with a report which is in manuscript form on proposed reservoirs at Elizabeth Lake and Bouquet Canyon. Noble 23/

23/ Noble, L. F., The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California: Carnegie Inst. of Wash., Year Book, No. 25, 1925-26, also Bull. Seis. Soc. Amer., vol. 17, pp. 25-39, 1927.

has been studying the San Andreas rift for a period of over twenty years with interest focused chiefly on the area between Palmdale and Cajon Pass, but has also studied many portions of the area covered in this report. Simpson 24/ mapped the entire Elizabeth

24/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of state mineralogist, Calif. Mining Bureau, pp. 371-415, 1934.

Lake quadrangle on a reconnaissance scale and the map and report were published in 1934. Gazin, working with Noble, in recent years has mapped the adjoining Pearland and Little Rock quadrangles in detail and also investigated the present area to some extent. His report is in manuscript form at present and was kindly made available to the writer by L. F. Noble.

Many investigators have studied areas adjacent to the present area. Among the more important papers are those of Kew,[25/] Miller[26] and Jahns.[27/]

25/ Kew, W. S. W., Geology and Oil Resources of Part of Los Angeles and Ventura Counties, California: U. S. Geol. Sur. Bull. 753, pp. 1-202, 1924.

26/ Miller, W. J., Geology of the Western San Gabriel Mountains: Pub. Univ. of Calif. at Los Angeles, vol. 1, no. 1, pp. 1-114, 1934.

27/ Jahns, R. H., Stratigraphy of the Easternmost Ventura Basin, California, with a Description of a New Lower Miocene Mammalian Fauna from the Tick Canyon Formation: Carnegie Inst. of Washington, Pub. no. 514, pp. 145-194, 1940.

STRATIGRAPHY AND PETROGRAPHY

Generalized Section

		Sedimentary rocks	Thickness in feet
Quaternary	Alluvium	unconsolidated sand and gravels	0 - 50 +
		-Unconformity-	
	Terraces	Undifferentiated- unconsolidated sand and gravels, essentially old alluvium	0 - 50 +
	Terraces	Pelona schist detritus--sand and gravels composed principally of mica schist and milky quartz cobbles and pebbles	0 - 50 +
		-Unconformity-	
Tertiary Pleistocene	Harold beds	sand and gravels poorly consolidated	0 - 40 ?
		-Unconformity-	
Pliocene?	Anaverde formation	gypsiferous shale	0 -1000
		-white to buff conglomerate and arkose	0 -800
		-pink to reddish conglomerate and arkose	0 -200
		-Unconformity-	
Miocene? or older	Old arkose	brecciated and pulverized arkose, dark red brown in color	0 -100?

	Igneous and metamorphic rocks	Thickness in feet
Tertiary		
Miocene?	Rosamond volcanics--rhyolite tuffs and flows - -	0 - 300 -
	-Unconformity-	
Oligocene?	Vasquez volcanics--basaltic and andesitic flows, tuffs and breccias -	0 -3000 -
	-Unconformity-	
Pre-Tertiary	Granitic--intrusive, including pegmatitic, aplitic and dioritic phases, also gneissic and mafic schist zones -	
	Diorite intrusive, including granitic phases	
	Gneissic complex--biotite schists injected by diorites and granites, extremely distorted and metamorphosed	
Pre-Cambrian	Pelona schist--metamorphic complex, including meta-sediments, several intrusives, plus quartz vein material	

Pelona schist

Pelona schist is the predominant rock formation in the area mapped. Rocks of this sequence crop out over most of the eastern portion of Portal Ridge and on Ritter Ridge. The major portion of Sierra Pelona Ridge is also composed of Pelona schist forming a block over 30 miles long from east to west so that it extends far west of the area mapped.

A great variety of metamorphic rocks are included in the Pelona schist sequence. For the most part they appear to represent metamorphosed sediments, although some of the rock units almost certainly were originally igneous.

The most common rock type is a mica-feldspar schist. The micas vary from pearl gray muscovite to dark brown biotite and are arranged in parallel planes separating feldspar grains. This gives the schist good clevage. All gradations in color, varying from those rich in muscovite, which have a silvery sheen, to dark brown schists in which biotite predominates, are to be found. Gradations in coarseness of this mica schist range from very fine grained varieties, which approach a slate-like character, to relatively coarse grained mica-feldspar-quartz schists which might be classed as gneisses. No general gradation from the top to the bottom of the schist section was observed.

Other schistose and gneissic types of rocks are also present although they are not as abundant as the mica schists. Schists containing abundant chlorite and amphiboles are common. A schist composed almost entirely of emerald green actinolite

Plate 5. Outcrops of Pelona schist.

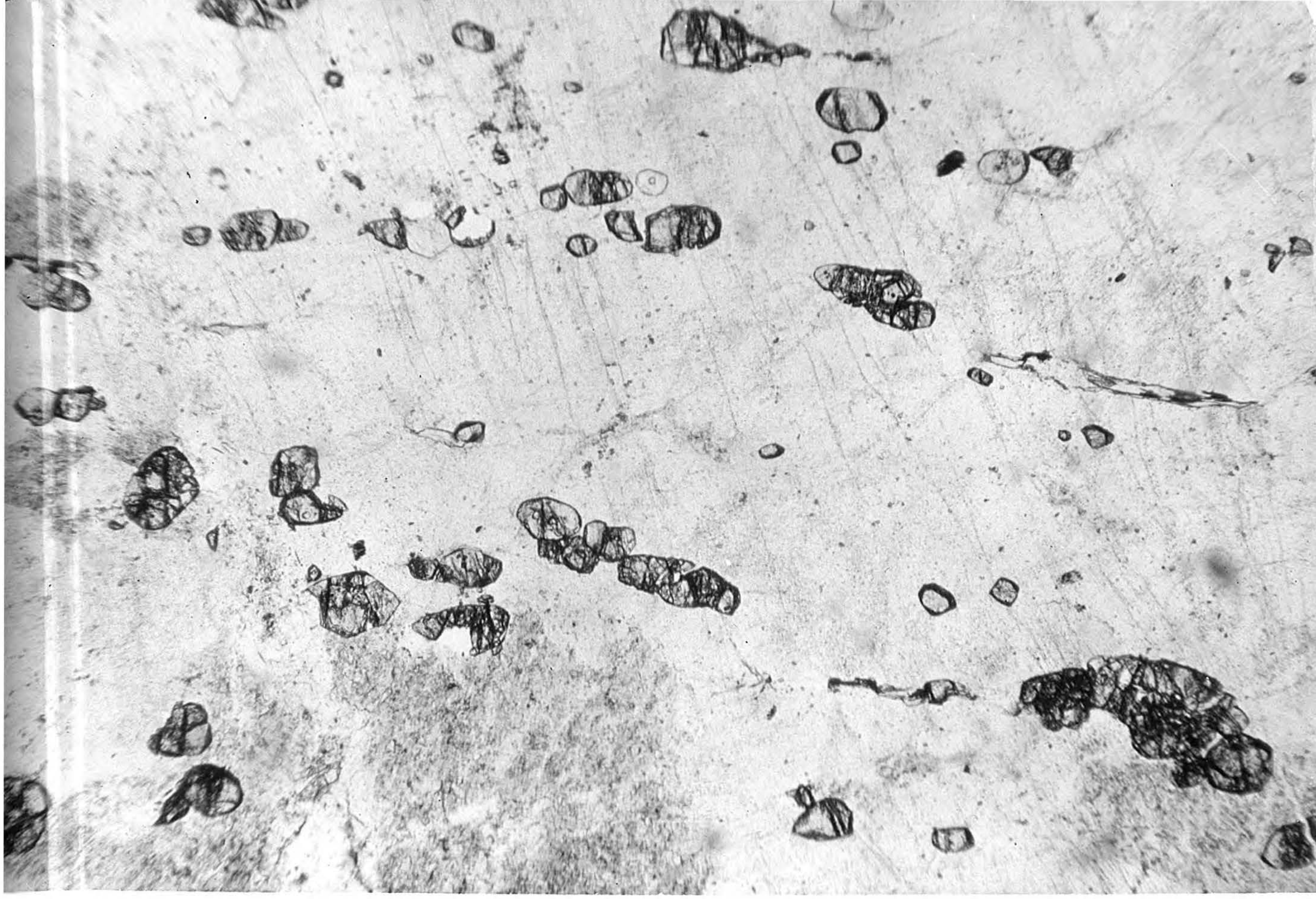
A. Road cut one-half mile south of Elizabeth Lake school, showing mica schist with quartz veinlets both cutting schistosity and paralleling schistosity.

B. Road cut on Goode Hill road. Note contortion of schist and lenticular quartz vein.

Plate 6. Photomicrographs of quartzite in Pelona schist metamorphic sequence.

A. Uncrossed nicols, showing distribution of garnets (high relief mineral) in quartzite. X - 60

B. Crossed nicols, showing recrystallization and elongation of quartz grains. X - 60



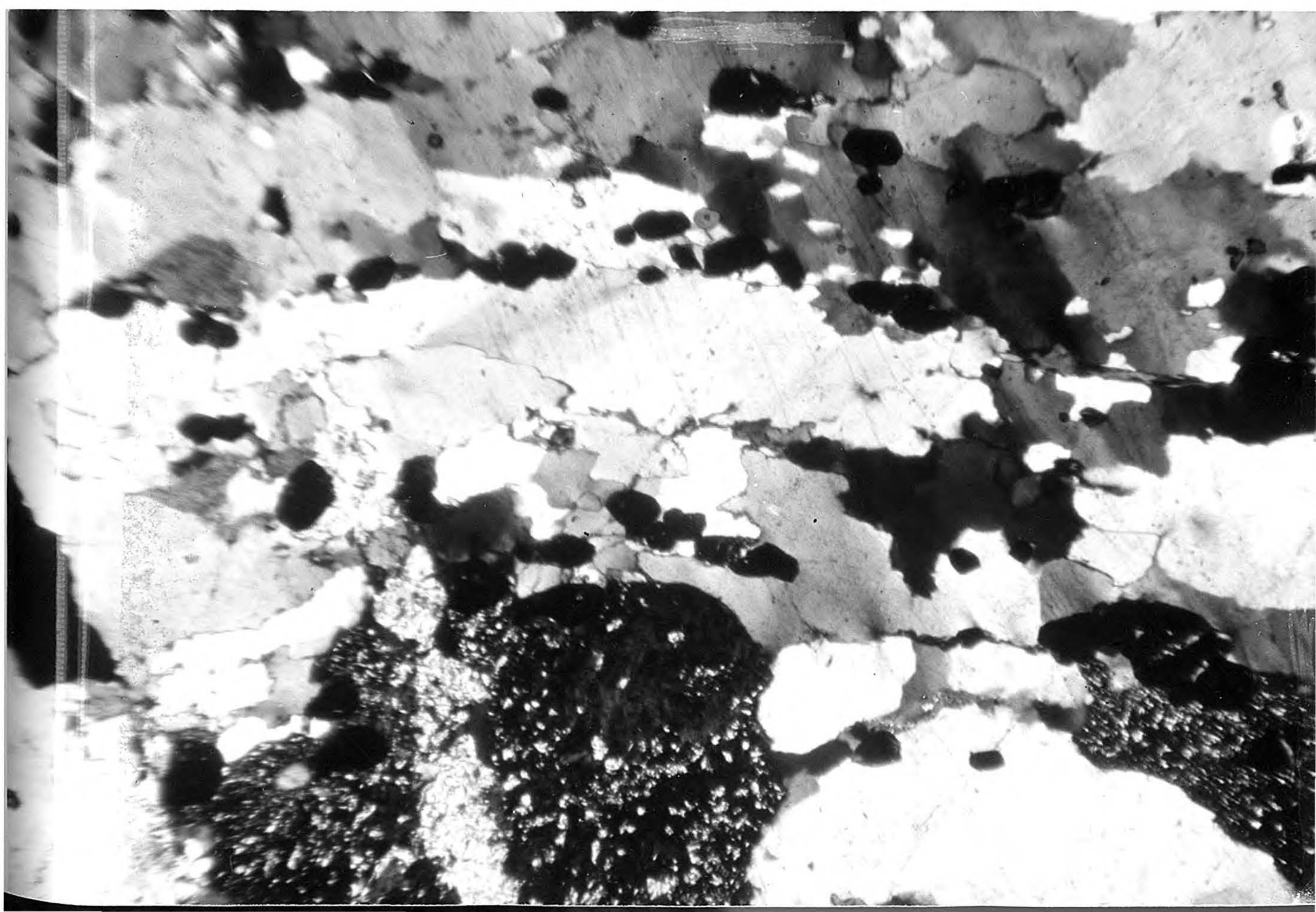
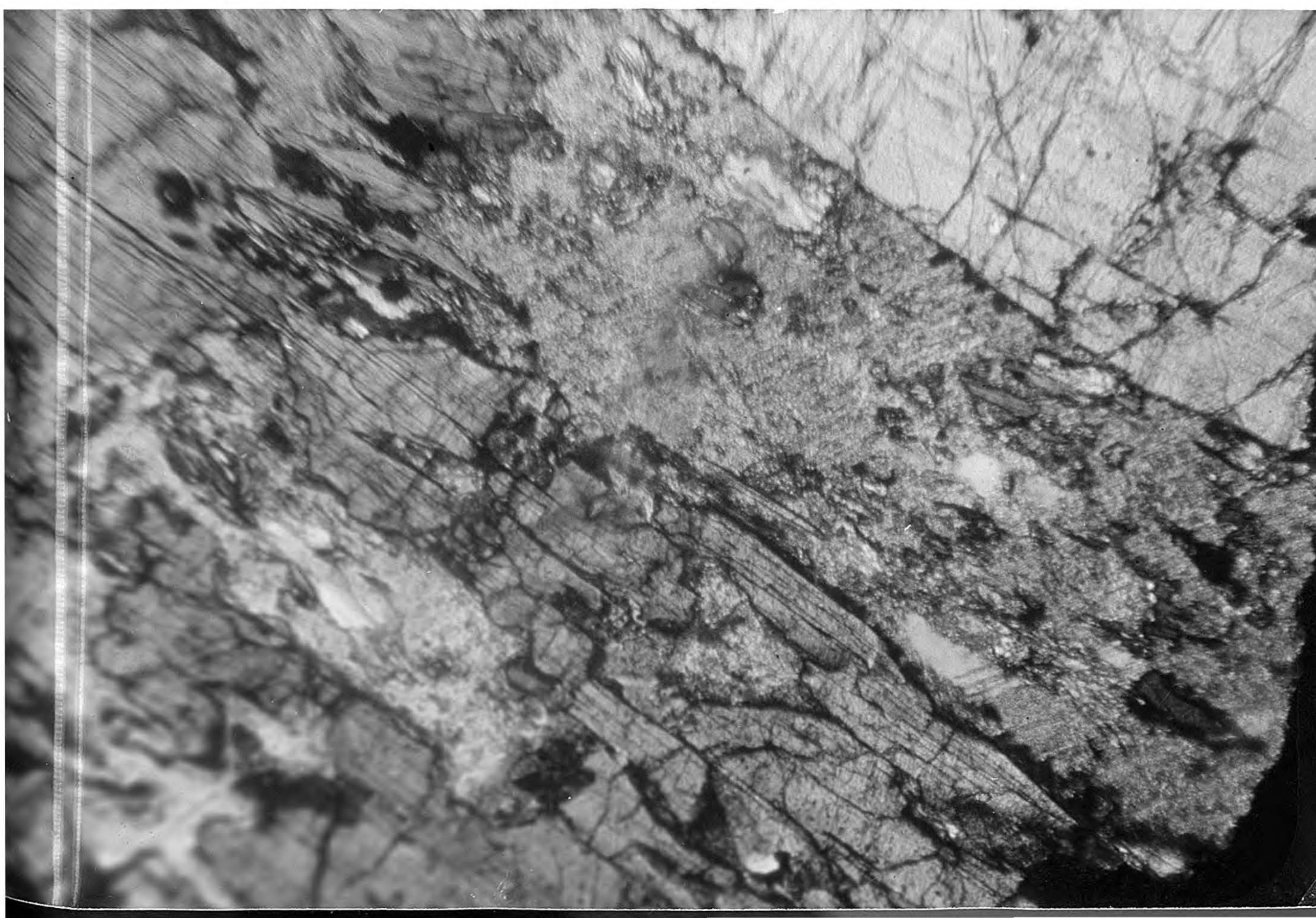


Plate 7. Photomicrographs of gneissic rocks in the Pelona schist metamorphic sequence.

A. Augen gneiss, showing "eye" of albite with chlorite wrapping around it. Uncrossed nicols. X - 60

B. Clinozoisite gneiss. Clinozosite in large blades with oligoclase, sericite, actinolite, and chlorite associated. Crossed nicols. X-60



crystals is a very distinctive type found. The crystals of actinolite are in places several inches long and an eighth of an inch or more wide. White, fine grained talc commonly accompanies the actinolite and fills in the portions between the radiating actinolite needles. In some localities the talc predominates over the actinolite.

An augen gneiss forms several large areas of outcrop. In thin section it displays characteristics of texture and composition suggesting that it was originally an igneous rock of granitic type that had been crushed and dynamically metamorphosed. The "eyes" of the gneiss are composed of recrystallized feldspar grains, mostly albite and oligoclase. An unusual gneiss was found which was composed chiefly of clinozosite. In thin section it could be seen that coarse blades of clinozosite are surrounded by oligoclase which is highly sericitized. Minor constituents include actinolite, biotite, chlorite and magnetite.

Quartzite beds a few feet thick are common in the schist sequence. In hand specimen the sedimentary characteristics are almost entirely obliterated even though there is definite banding which is marked by fine sericite grains. In thin section the banding can be seen to be due chiefly to orientation of elongated quartz grains due to recrystallization. The elongation, however, apparently follows the original orientation of bedding. The quartz grains show shadowy extinction indicating strain, and the borders of the grains are sutured. One specimen showed an abundance of garnets which are arranged in groups of crystals forming thin stringers parallel to the banding. Biotite, chlorite, sericite, and albite-oligoclase feldspars are all common accessory minerals of the quartzites.

Limestone marble beds are of common occurrence in the Pelona schist sequence. They are finely crystalline and are white to gray in color. Graphite grains are common and quartz and feldspars are other accessory minerals. In one locality epidote was abundant where the limestone had been altered.

Quartz veins are abundant throughout the Pelona schist forming pods and lenses which follow the trend of the schistosity in most places but which not uncommonly cut the schisosity. The quartz veins vary in width from a few inches to several tens of feet and consist of white "bull" quartz. In most cases no sulphide or other types of mineralization accompanied the implacement of the quartz veins.

The presence of quartzites and limestone beds, clearly of sedimentary origin, interspersed throughout the mica schists was also originally a sediment, and its composition would suggest that it probably was a shale. Hulin[28/] in analyzing a similar

28/ Hulin, C. D., Geology and Ore Deposits of the Randsburg Quadrangle, California: Calif. State Mining Bureau, Bull. 95, p. 26, 1925.

case in the Rand schist, made the following comment:

"The nature of these three original sediments, sandstone, shale and limestone, their purity and the character of their bedding as well as their areal extent and their thickness all leads to the belief that they represent a former series of marine sediments."

This statement is entirely applicable to the case of the Pelona schist. The actinolite schists may represent intrusives, probably dikes, of mafic composition, although Hulin[29] suggests

29/ Hulin, C. D., op. cit., p. 27, 1925.

that the actinolite rich zones in the Rand schist are the result of accumulations of basic volcanic tuffs in the original sedimentary series.

The schist sequence is folded, in some places rather tightly but commonly in relatively open folds. The folding appears to have been subsequent to the metamorphism. Exposed sections of Pelona schist indicate that a minimum thickness of the sequence is over 5,000 feet. It is very likely much more than that. Simpson[30] was able to measure a thickness of more than 7,500 feet.

30/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of the state mineralogist, Calif. State Mining Bureau, p. 378, 1934.

The Pelona schist is suggested to be Archean in age by its correlation with the Rand schist which Hulin suggested is Archean. Hulin's[31] description of the petrography of the Rand schist in

31/ Hulin, C. D., Geology and Ore Deposits at the Randsburg Quadrangle, California: Calif. State Mining Bureau, Bull. 95, p. 23, 1925.

the Randsburg quadrangle might as well be a description of the Pelona schist. Simpson has also compared the two schist and has concluded that they are correlatives. Hulin suggested a probably Archean age for the Rand schist after noting that Paleozoic sediments in nearby mountain ranges are practically unaltered in comparison to the Rand schist. The Placerita formation, described by Miller,[32] which crops out near the western end of the

32/ Miller, W. J., Geology of the Western San Gabriel Mountains of California: Pub. Uni. of California at Los Angeles in math. and phys. sciences, vol. 1, no. 1, p. 4, 1934.

San Gabriel Mountains in Placerita Canyon, may also be a correlative of the Pelona schist. It is also a series of meta-sediments of presumable pre-Cambrian age.

Miller,[33] however, did not believe that they are correlatives and analysed the situation as follows:

33/ Miller, W. J., Geology of the Western San Gabriel Mountains of California: Pub. Univ. of Calif. at Los Angeles, vol. 1, no. 1, p. 63, 1934.

"A formation very similar to the schist just described, and correlated with it by Noble, is extensively developed in the Sierra Pelona Mountains some miles to the northwest of the San Gabriel Mountains. It is called the 'Pelona schist' by Hershey.[34]

34/ Hershey, O. H., Some Crystalline Rocks of Southern California: Am. Geol., vol. 29, p. 276, 1902.

This formation is different from the meta-sediments associated with the Placerita, and unlike the latter, has not been cut and more or less thoroughly injected lit-par-lit by granite. The Placerita formation is therefore believed to be older than the Pelona schist, and, if the latter is either pre-Cambrian or possibly early Paleozoic, the Placerita is almost certainly pre-Cambrian and probably older pre-Cambrian (Archeozoic)."

Hulin 35/ pointed out in describing the Rand schist:

35/ Hulin, C. D., op. cit., p. 29, 1925

"The most noticeable feature of the Rand schist is the concordance which exists everywhere between the flat lying schistosity and the bedding."

In the Pelona schist the schistosity also parallels the bedding. Hulin continued his discussion:

"The slight amount of folding which has effected these schists, have been developed horizontally and the pressures involved were vertical. The effects of lateral compression are strictly absent."

Although the Pelona schist has been subjected to much more lateral compression than Hulin indicated was true for the Rand schist, the predominence of schistose structures following original bedding planes in the Pelona schist indicates that those structures must have been developed essentially horizontally. The Pelona schist locally is highly contorted as might be expected in an area so close to the San Andreas rift.

Gneissic complex

Two principal areas of gneissic complex outcrops are present on the suth side of the rift. One band of gneiss a half mile to one and one-half miles wide extends southwest from near Palmdale reservoir to the edge of the area mapped. A variety of crystalline rocks are present in this zone. A dark colored, hornblende-quartz diorite band trends east-northeast parallel to the general strike of the gneissic zone and possibly represents a metamorphosed dike which had been intruded into the gneiss. In general the zone is a complex of hornblende-feldspar-mica gneisses profusely intruded by granitic dikes which are themselves somewhat gneissic in structure. Some of the intrusive dikes are of the order of a hundred feet wide. A few small limestone horizons were found and suggested that this gneissic zone may represent essentially a section of Pelona schist thoroughly injected with granitic dike rocks. There very likely have been several periods of intrusion of the original schist complex.

The other area of gneiss borders the south side of Leonis Valley and extends from Grass Mountain east to approximately one and one-half miles west of the Bouquet Canyon road. This zone is a mixture of several gneissic, schistose, and igneous rock types. The typical gneiss of this area can be seen on the road from San Francisquito Pass to Grass Mountain lookout. It consists of alternating light and dark layers, each from a fraction of an inch to several inches thick, in fairly regular bands which are twisted and folded into extremely complex structures. The dark bands are commonly colored by dark biotite and the light bands are principally feldspars and quartz. In some places the gneiss appears very similar to the Pelona schist, but in general it contains much more granitic material. Much of it may represent Pelona schist which has been thoroughly injected with granite and later folded and contorted.

The age of this complex can be indicated only by indirect correlations. The San Gabriel formation described by Miller 36/

36/ Miller, W. J., Geology of the Western San Gabriel Mountains of California: Pub. Univ. of Calif. at Los Angeles, vol. 1, no. 1, p. 49, 1934.

in the San Gabriel Mountains is apparently similar to the metamorphic-igneous complex described here. The San Gabriel formation comprises a mixture of so-called Rubio metadiorite, Placerita metasediments, and an old granite, presumably the Echo granite. Miller 37/

37/ Miller, W. J., Geology of the Western San Gabriel Mountains of California: Pub. Univ. of Calif. at Los Angeles, vol. 1, no. 1, p. 65, 1934.

came to the following conclusion regarding the age of the San Gabriel formation:

> "The available evidence, then, points to the pre-Cambrian, and probably older pre-Cambrian age of the Placerita, Rubio diorite and metadiorite, and Echo granite formations, as well as the greater part of the San Gabriel formation, but it must be admitted that the age is not absolutely proved."

It seems very probable that at least some of the gneissic zone in the area mapped is formed by the injection of Pelona schist by younger granites, so that it should be considered younger than the schist.

Diorite

A mile south of Palmdale reservoir bordering the block of Vasquez volcanics on the north and west sides is an igneous mass which is slightly more basic than most of the granatoid rocks. Although many portions of this block are true granite, much of the mass can be classed as a diorite. The rock is typically brown to reddish and contains little or no quartz. It is definitely in fault contact with the Vasquez series and is thrust up against and over the volcanics. The northwestern boundary was mapped as a gradational contact because no sharp contact was observed. It may or may not be a fault. At the northeastern end of the contact veins several feet wide of nearly pure calcite crop out. This vein material suggests fracture openings along a fault. In a road cut which is in the gneiss near the contact the gneiss is thorougely injected with the granitic rocks suggesting that the main contact is essentially an intrusive one. No other evidence, however, was observed to indicate the nature of the contact.

Granite

Several large blocks of igneous rocks of a granitic type are present in the area studied. The detailed relationships of the gneissic and schistose zones to the granite were not mapped. The granite blocks as mapped, therefore, represent areas which are predominantly granite, but which also have gneissic zones and inclusions of several types of metamorphic rocks. Where dips and strikes are found on the map in areas indicated as granite, they represent the orientation of local gneissic structures.

North of the Hitchbrook fault in the Elizabeth Lake district is the largest exposure of granite mapped. In hand specimens the granite is white, buff, or pinkish colored and graduations in texture vary from coarse, almost pegmatitic, to very fine grained. Microscopically it is found to be a typical granite with large amounts of quartz and albite in sub-equal proportions and with orthoclase and microcline both being common. Mafic constituents are relatively scarce throughout large portions of the granite, but where present brown biotite and hornblende are the most common minerals.

The granite block bordering the rift south of Elizabeth Lake is petrographically similar to that north of the rift.

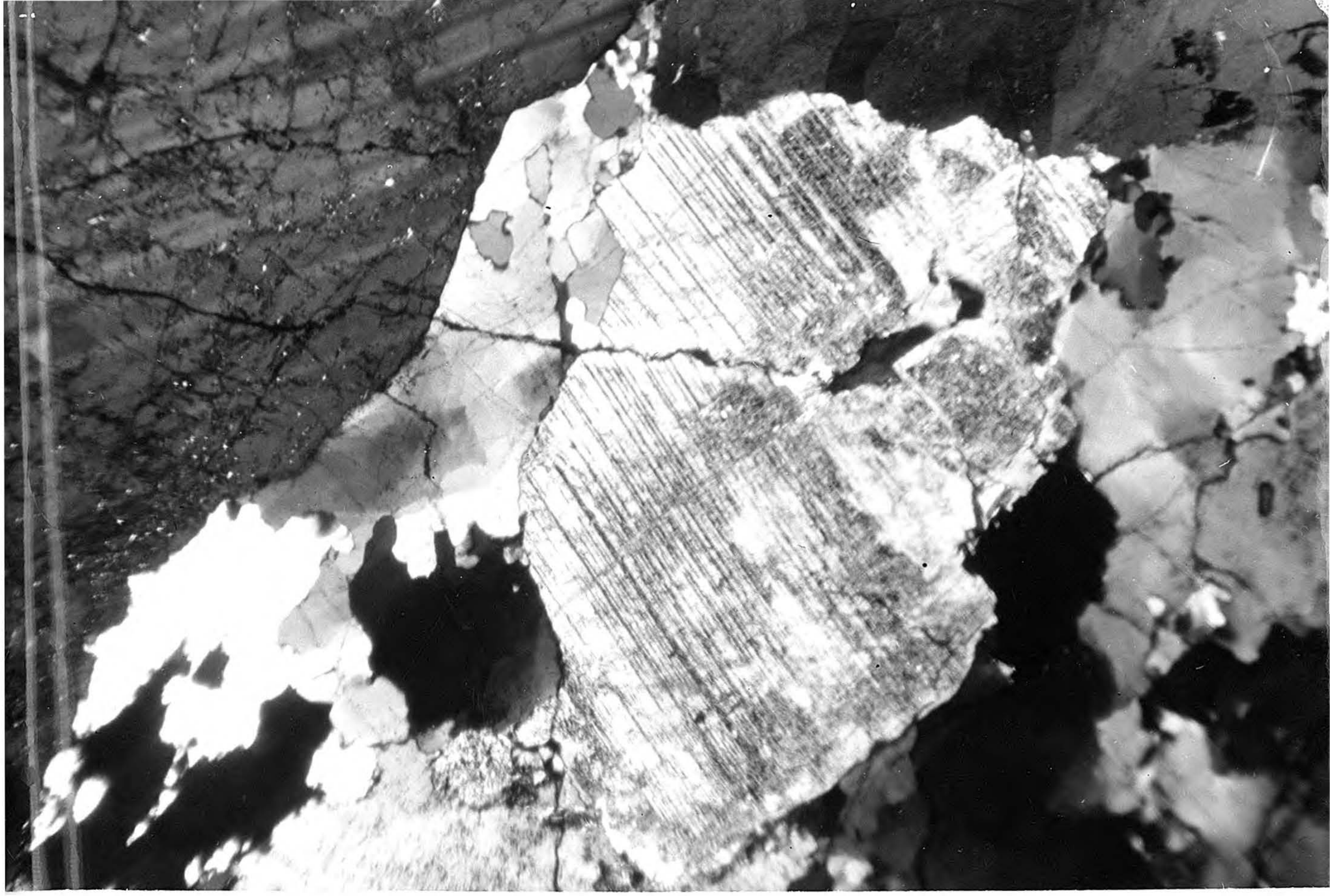
Approximately one mile west of Leonis School a long narrow fault slice is principally granite; however, several gneissic zones are present. These zones strike across the trend of the block approximately paralleling the regional trend of the schistose and gneissic zones south and north of the rift zone. This fact tends to support the interpretation that the cross structures are essentially cut by the San Andreas rift and are not genetically related to the same tectonic forces.

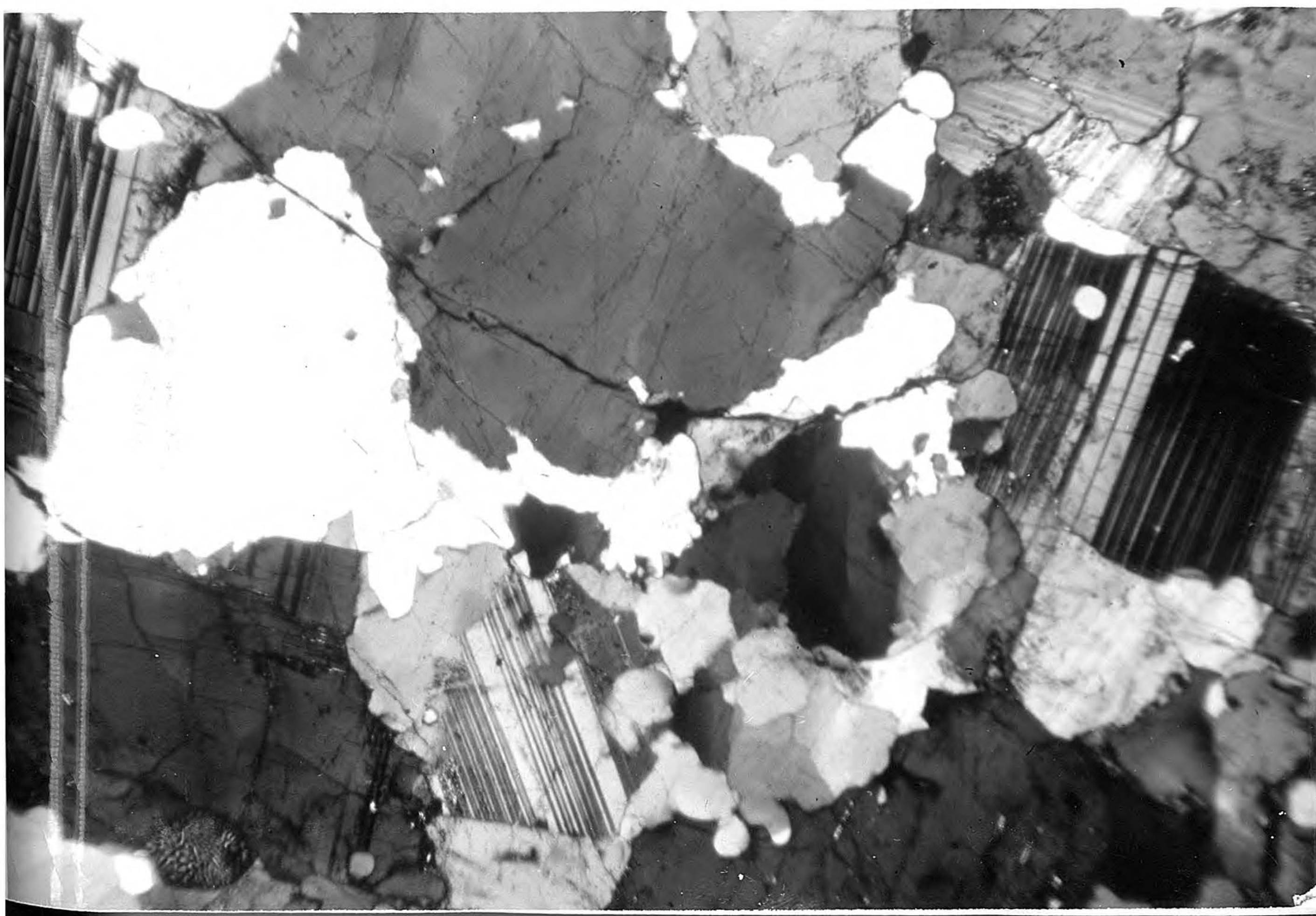
The block of granitic rocks along the south border of Leonis Valley which extends west of Bouquet Canyon approximately two miles is composed of a white to buff colored granite on its eastern end which grades into more and more gneissic rocks toward the west. The western boundary drawn on the map represents a gradational contact. West of the contact the rock is predominantly gneissic although considerable granite is also present. The contact may be intrusive with granite being injected into the

Plage 8. Photomicrographs of granite.

A. Granite cobble from Anaverde conglomeratic arkose. Note lack of mafic constituents. Crossed Nicols. X - 60

B. Granite from Portal Ridge north of Elizabeth Lake. Note lack of mafic constituents. Crossed nicols. X - 60





gneiss along the contact in a lit-par-lit manner. Where good exposures of the gneiss are found it can be seen that the granite is intimately injected into the gneiss in the form of various size dikes and sills. In thin section it was found that the white granite commonly had less than 5 per cent mafic constituents.

North of the rift, approximately two miles west of Palmdale is a prominent ridge composed of granitic rocks. Most of the ridge is a white to buff colored granite, but along a reverse fault which dips south into the rift, darker colored granite has been brought into contact with the white granite. At the western end of this ridge at the mouth of Leonis Valley a small patch of Pelona schist outcrops, and the granite is apparently in intrusive contact with it. Although the contact is not well exposed, garnets in the mica schists indicate that the Pelona schist has been metamorphosed by the intruding granite. Excluding the depositional contacts of alluvium, all other contacts of the block are faults. On the north side of the shale body just east of the mouth of Anaverde Valley small granite outcrops are found indicating that a thin body of granite represents an eastern extension of the large block. This stringer is apparently bordered by faults on both the north and south side.

Near Vincent on the west side of Soledad Pass a block of granite is faulted against the Vasquez volcanics.

As far as the evidence in the area studied is concerned, the age of this granite can only be limited to post-Pelona schist time and pre-Vasquez time. This broad range includes all of the

Paleozoic, Mesozoic, Eocene and Oligocene. The granite, however, is apparently similar to some of the intrusives in the San Gabriel Mountains which have been grouped by Miller[38/] under the name of Lowe granodiorite. Miller has tentatively assigned these

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38/ Miller, W. J., Geology of the Western San Gabriel Mountains of California: Pub. Univ. Calif. at Los Angeles, vol. 1, no. 1, pp. 62-63, 1934.

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rocks to the late Jurassic epoch on the basis of the relationship of similar intrusives elsewhere in southern California to sediments of known age. In the Santa Monica Mountains upper Cretaceous sediments unconformably overlie similar igneous rocks and elsewhere similar granitic rocks intrude Triassic slates. Having essentially limited the age to the Jurassic, Miller favors calling them upper Jurassic because of the known upper Jurassic age of the Sierra Nevada batholith. It is quite evident that the age correlation of these rocks needs further verification.

Old arkose

A sediment which is highly brecciated and mylonite-like appears to be distinct from the Anaverde formation. Outcrops of this rock are present along the north side of the center-trough ridge from approximately one mile east of the junction of the Bouquet Canyon road and the Pine Canyon - Elizabeth Lake road to a point approximately four and a half miles west of the junction. The exposures are poor and commonly are of dark reddish-brown color. In only a few places were whole pebbles and cobbles observed to prove the sedimentary nature of the rock, and even those were highly altered. Elsewhere the rock is so badly altered that no original structure could be distinguished.

No suggestion of age is possible except that the color of the weathered outcrops appears similar to some outcrops of the Vasquez fanglomerates.

Toward the west end of the area of outcrops this rock lies on top of Anaverde sediments, but the rock is so much more highly altered and "older looking" than the Anaverde sediments that this relationship is believed to be due to overthrusting or overturning as a result of compression within the center-trough ridge.

Vasquez formation

In an area of approximately three square miles bordering the west side of Soledad Pass, basalt and andesite flows and corresponding breccias and tuffs of the Vasquez formation crop out. The outcrops of the formation are confined to the south side of the rift. The Vasquez formation was originally named the Escondido formation by Hershey,[39/] but inasmuch as that name was

39/ Hershey, O. H., Calif. Univ. Pub. Dept. Geol. Bull. vol. 3, pl. 1, map, 1902.

preoccupied, Sharp[40/] proposed the name Vasquez. Sharp measured

40/Sharp, R. P., Geology of Ravenna Quadrangle: Pan-Amer. Geol., vol. 63, no. 4, p. 314, 1935

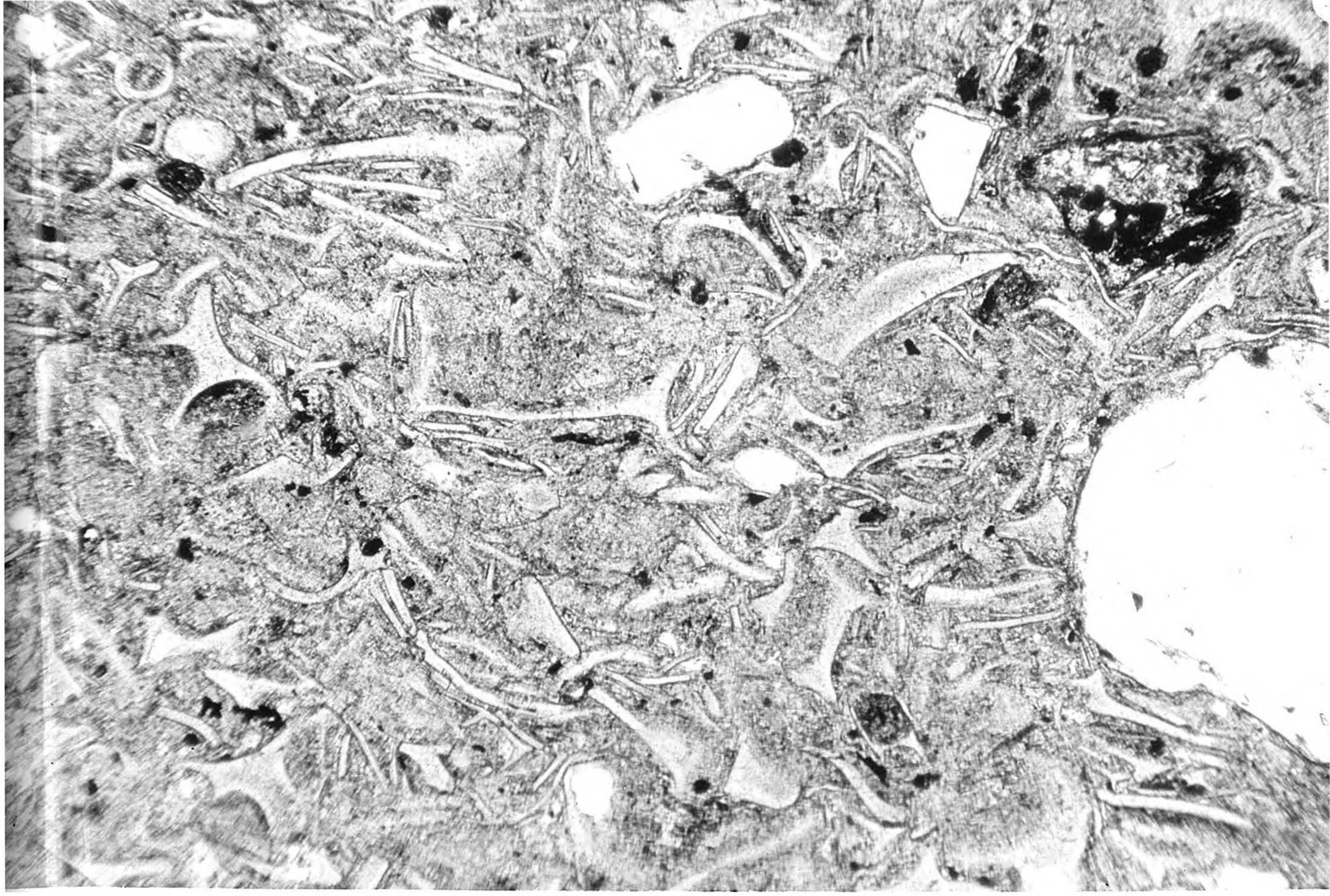
a section of the Vasquez formation in the Ravenna quadrangle which is just south of the area mapped and found an approximate thickness of 9,000 feet of fanglomerates and 4,000 feet of basalts. Only the volcanics are exposed in the area mapped, and represent a thickness of approximately 3,000 feet.

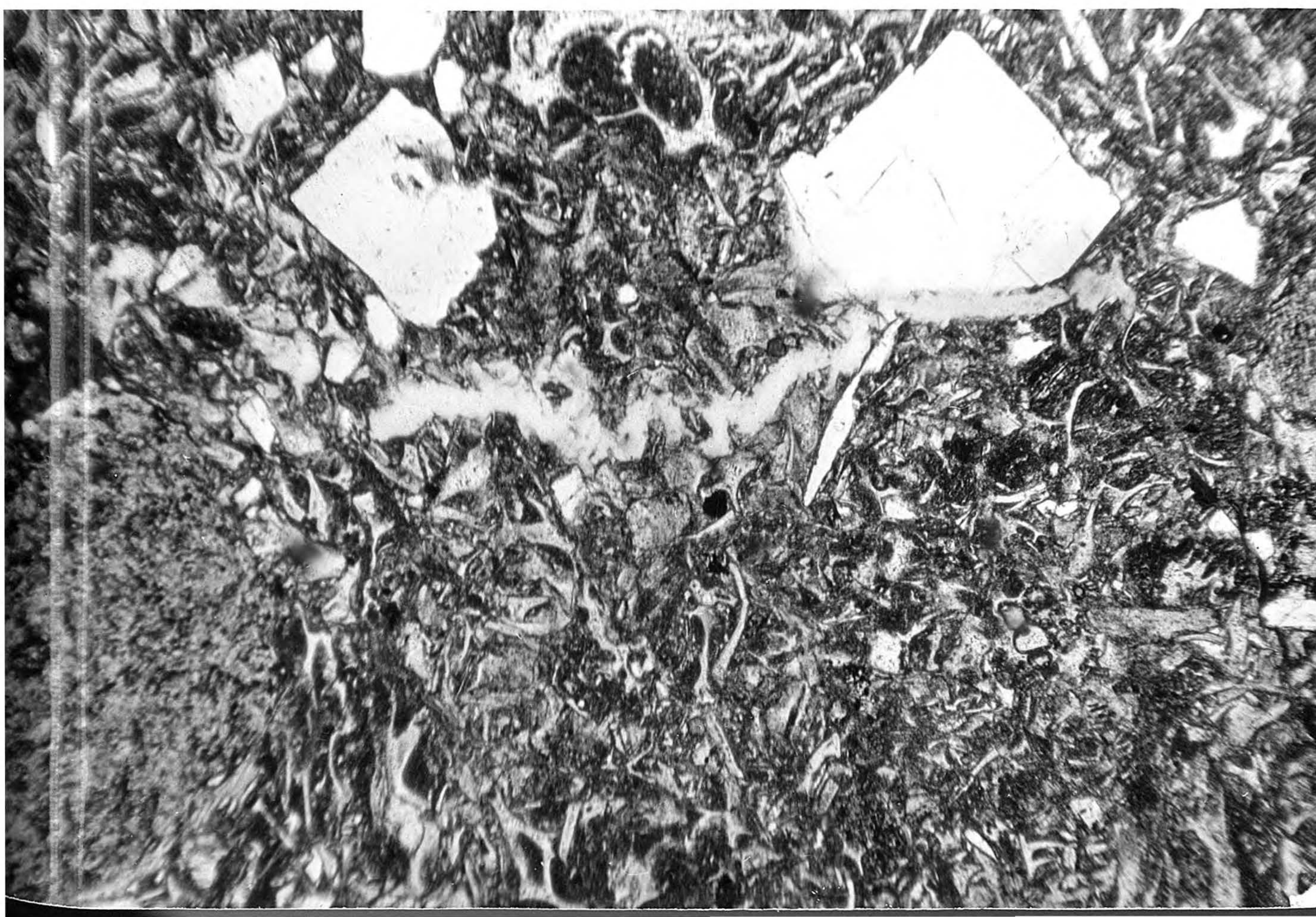
The lavas range in texture from massive, fine-grained basalts and andesites to amygdaloidal and vesicular rocks. The amygdules are commonly filled with an agate deposit which weathers out of the basalt in the form of agate nodules. Some of the nodules are several inches in diameter. The flows are predominantly andesites and basalts. The surfaces of the flows were apparently very irregular so that tuffs deposited on their surfaces and later covered by other flows, now form irregular lenticular bodies. The tuffs are of a crystal-lithic-vitric type, and contain approximately 80 percent glassy material having an index of refraction near 1.49, which corresponds to a composition approximately 75 percent SiO_2. The crystalline portion of the tuff consists chiefly of andesine and labradorite feldspars with some quartz, biotite and other minor accessories. The rock fragments included in the tuff are of the same types as the flow rocks in which the tuffs are interbedded. In hand specimen most of the vitric portions of the tuffs have a distinctive green color. No specific cause for the color was determined, although it could possibly be due to ferrous iron or small quantities of copper in the glass.

Jahns[41/] has tentatively determined the age of the Vasquez

Plate 9. Photomicrographs of Vasquez tuffs.

A. and B. Note shards and crystal fragments.
Uncrossed nicols. X - 60





41/ Jahns, R. H., Stratigraphy of the Easternmost Ventura Basin, California, with a Description of a New Lower Miocene Mammalion Fauna from the Tick Canyon Formation: Carnegie Inst. Washington, pub., no. 514, p. 170, 1940.

to be Oligocene, probably corresponding to at least a part of the Sespe. This determination is based on the presence of lower Miocene, Tick Canyon beds overlying the Vasquez, and the fact that lower Eocene Martinez beds lie unconformably below the Vasquez. A Committee of the Paleontological Society of America[42/] has since

42/ Wood, H. E. and committee, Nomenclature and Correlation of the North American Continental Tertiary: Bull. ~~Biol.~~ Geol. Soc. America, vol. 52, pp. 1-48, 1 pl., 1941.

assigned the Tick Canyon formation to the middle Miocene age in correlating the continental Tertiary deposits of North America. There is, however, a slight discrepancy between the middle Tertiary age correlations based on vertebrate and invertebrate fossil material. The vertebrate correlation tends to place the formations slightly higher in the time scale than does the invertebrate correlation.

Others[43/] have assigned the Vasquez to the middle Miocene

43/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of the State mineralogist, California state mining bureau, p. 391, 1934

43/ Miller, W. J., Geology of Western San Gabriel Mountains: Univ. of Calif. at Los Angeles pub., vol. 1, p. 70, 1934.

chiefly on the basis of a possible correlation of the Vasquez volcanics with the flows of the middle Miocene Topanga formation.

The flows are cut by many faults, but due to the difficulty of distinguishing individual flows, the fractures are somewhat obscure. The northern border of the outcrop area is a reverse fault along which dioritic and granitic rocks have been moved up and over the volcanics. The flows are folded into a syncline which parallels the strike of the fault and probably was formed contemporaneously with the faulting. Near the center of the outcrop area mapped a tabular body of basalt lies in a nearly horizontal position over truncated tuff and lava beds which stand nearly vertically. No other evidence supports the suggestion that the basalt flowed over the truncated ends of the uptilted beds, which would indicate two periods of vulcanism separated by a period of tilting and erosion. Inasmuch as this is an isolated case of such a relationship, it is probably better explained as a result of thrust faulting within the formation and is evidence of the extreme "juggling" of blocks in the areas adjacent to the rift.

Rosamond volcanics

On the north side of Portal Ridge, several small patches of rhyolitic rocks are present. They presumably represent the Rosamond series which is widespread in the Mohave Desert area. Simpson 44/

44/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of state mineralogist, Calif. Mining Bureau, p. 400, 1934.

reported a thickness of over 4,500 feet of Rosamond beds in the Fairmont Hills. Merriam 45/ determined that the upper portion of

45/ Merriam, J. C., Tertiary Mammalian Faunas of the Mohave Desert: Univ. Calif. Publ., Dept. Geol. Bull., vol. 11, pp. 438-585, 1919.

the Rosamond series is Upper Miocene on the basis of vertebrate remains. The rhyolite volcanics present in the area mapped by the writer apparently are in the lower part of the Rosamond as described by Simpson. Presumably this lower part of the section is also of Miocene age but this fact must be verified.

The largest outcrop of rhyolitic volcanics lies along the north side of the Hitchbrook fault so that it is faulted against Pelona schist. The rock is white to buff color in hand specimen and is rather porous. In this section it was found to be essentially a crystal-lithic tuff with fragments of rhyolite, quartz and feldspar in a fine-grained groundmass. Some of the rock fragments are composed of fine-grained chalcedony-like quartz as is much of the groundmass. The whole mass appears to have been highly silicified.

A small outcrop of rhyolite was found protruding through the alluvium in one place suggesting that more volcanic material is covered by alluvium.

On the easternmost granitic block north of the Hitchbrook fault, a small patch of rhyolitic debris was found fragments of which were angular and not water worn, suggesting that it was a remnant of rhyolite in place. Two other similar patches were found on the Pelona schist block south of the Hitchbrook fault. The rock is a rhyolite porphyry with phenocrysts of quartz and albite-oligoclase feldspars in a fine-grained groundmass. The hand specimens are brown due to iron staining.

If these patches of rhyolite were extruded in Miocene times and flowed over a surface cut on Pelona schist, the schist block must have been exposed at least that early in time. That fact is significant when it is considered that the Anaverde formation, deposited in Pliocene times, and now adjacent to the Pelona schist block, contains no schist detritus. The problem is discussed further in the section on structure (see p. 43 and p. 101).

Anaverde formation

The Anaverde formation is the principal Tertiary formation present in the rift zone between Palmdale and Elizabeth Lake. Gazin[46/] named the formation after Anaverde Valley where there are fairly good exposures of the sediments. Correlation of the various units is difficult because most contacts in the rift zone are faults. The basal portion of the series is a pink to reddish arkose in which granitic cobbles are present though not abundant. Gazin[47/] has reported this basal arkose to rest with depositional

46/ Gazin, C. L., unpublished report.

47/ Gazin, C. L., unpublished report.

contact on top of granite with pink feldspar, but this relationship was not observed by the author in the area studied. The red arkose is lenticular in places and grades laterally into the buff colored arkose which commonly overlies it. The thickness of the red arkose appears to be approximately 200 feet in some localities.

Above the red arkose is a buff-colored arkose that is the predominant unit of the formation. It is more conglomeratic than the red arkose and in some places contains boulders up to a foot in diameter although the common sizes range from pebbles of a fraction of an inch in diameter to cobbles having a diameter of 3 or 4 inches. The cobbles are almost all granite and in only a few places were gneissic cobbles found. The top part of this unit has shale and siltstones interbedded with the arkose. The arkose is commonly well indurated and in several localities weathers to form prominent ledges as do the conglomerates of the Cajon and Punch Bowl formations. The maximum thickness of this unit is probably not much more than 800 feet which is approximately the greatest thickness exposed in a single fault block.

The top portion of the Anaverde formation is composed of shales and siltstones. The shale is highly gypsiferous and in the principal body of shale which lies just north of Palmdale reservoir, considerable mining of the gypsum has been carried on in small open pits. In one fault block the shale is approximately 1000 feet thick. In the area mapped it was not ascertained with certainty that this 1000 feet of shale is actually continuous above the arkose and since no fossil material which could be used for correlation has been found in the shale it may actually represent another formation. The shaley portions at the top of a continuous section of Anaverde arkose, however, suggests that the rest of the shale does actually represent the top portion of the formation.

Fossil material thus far found in the Anaverde formation is limited to a flora which was obtained from silty beds near the top of the arkosic portion of the formation. The location of the occurence is in the Palmdale quadrangle in the N.$\frac{1}{2}$, S.W.$\frac{1}{4}$, sec. 29, T.6N., R.12W. It is approximately 1100 feet east of the west edge of the quadrangle and 2200 feet north of the south edge of the quadrangle. Another locality from which a few fragments of leaf impressions were obtained is in sec. 34, T.7N., R.14W., 600 feet east of the west edge and 1100 feet north of the south edge of the section.

Dr. D. I. Axelrod kindly studied the specimens collected by the writer as well as additional material collected by himself and wrote a report which is included for reference at the end of this section.

Axelrod suggested that the Anaverde formation may be intermediate between the Ricardo and Mount Eden floras, or transitional between lower and middle Pliocene.

The arkosic sediments with conglomeratic phases is a typical deposit of a river in a semi-arid climate which possibly had in part alluvial fan characteristics. The shale and siltstone horizons would represent floodplain deposits and the gypsiferous shale portions possibly playa lake deposits.

The source of the sediments is a questionable matter. The granite cobbles of the arkose are almost identical to the granite north of Elizabeth Lake which is also typical of some of the other granites of the Mohave Desert area. As previously stated, Gazin has reported the Anaverde arkose to be resting in depositional contact on granite. The most important though puzzling evidence, however, is of a negative sort; that is, the absence in the Anaverde sediments of Pelona schist and Rosamond volcanic fragments and the scarcity of Vasquez lava detritus, all of which presumably should have contributed to the Anaverde formation.

The absence of Pelona schist detritus might be explained in one of two ways. First, the blocks of Pelona schist may have been faulted upard and exposed to erosion in post-Anaverde times. Second, horizontal displacement along the rift may have been of such an extent as to bring Pelona schist into contact with Anaverde sediments although originally they were widely enough separated so that the sediment did not receive schist detritus.

The likelihood of the first possibility is cancelled or at least greatly lessened by the presence of Rosamond volcanics apparently resting in place on top of the Pelona schist block in Portal Ridge. This fact would indicate that the Pelona schist was exposed in Rosamond times which would suggest that it was also exposed in the later Anaverde times.

The second possibility requires a special original distribution of the rocks. Presuming that the blocks of Pelona schist were exposed in late Miocene times, they would have been separated by a distance of over 25 miles, so that the block north of the rift would lie west of the western end of the Anaverde formation and the block south of the rift would lie east of the eastern end of the strip of Anaverde sediments. Horizontal displacement of over 25 miles would then bring the Pelona schist blocks and the strip of Anaverde sediments into their present relationship.

The scarcity of Rosamond and Vasquez volcanics in the Anaverde formation may also be explained by horizontal displacement. It may also be due to the fact that the area in which the Anaverde sediments were deposited was isolated from drainage which would carry Rosamond or Vasquez material. For example, the Anaverde sediments may have been deposited in a fault trough similar to Leonis Valley and thus have been derived only from immediately adjacent blocks.

That the Anaverde formation was deposited in a fault trough is supported by the fact that essentially all outcrops of Anaverde sediments have been found within the San Andreas rift zone. This, of course, also suggests the presence of the rift in Pliocene times.

Between Elizabeth Lake and Ritter Ranch the Anaverde formation lies entirely within the fault trough and crops out principally in the center trough ridge, lying between the two faults showing recent displacement. From Ritter Ranch east to the Southern Pacific Railroad tracks the outcrops of Anaverde are principally north of the recent fault. In the Pearland quadrangle Gazin[48/] reported that

48/ Gazin, C. L., unpublished report.

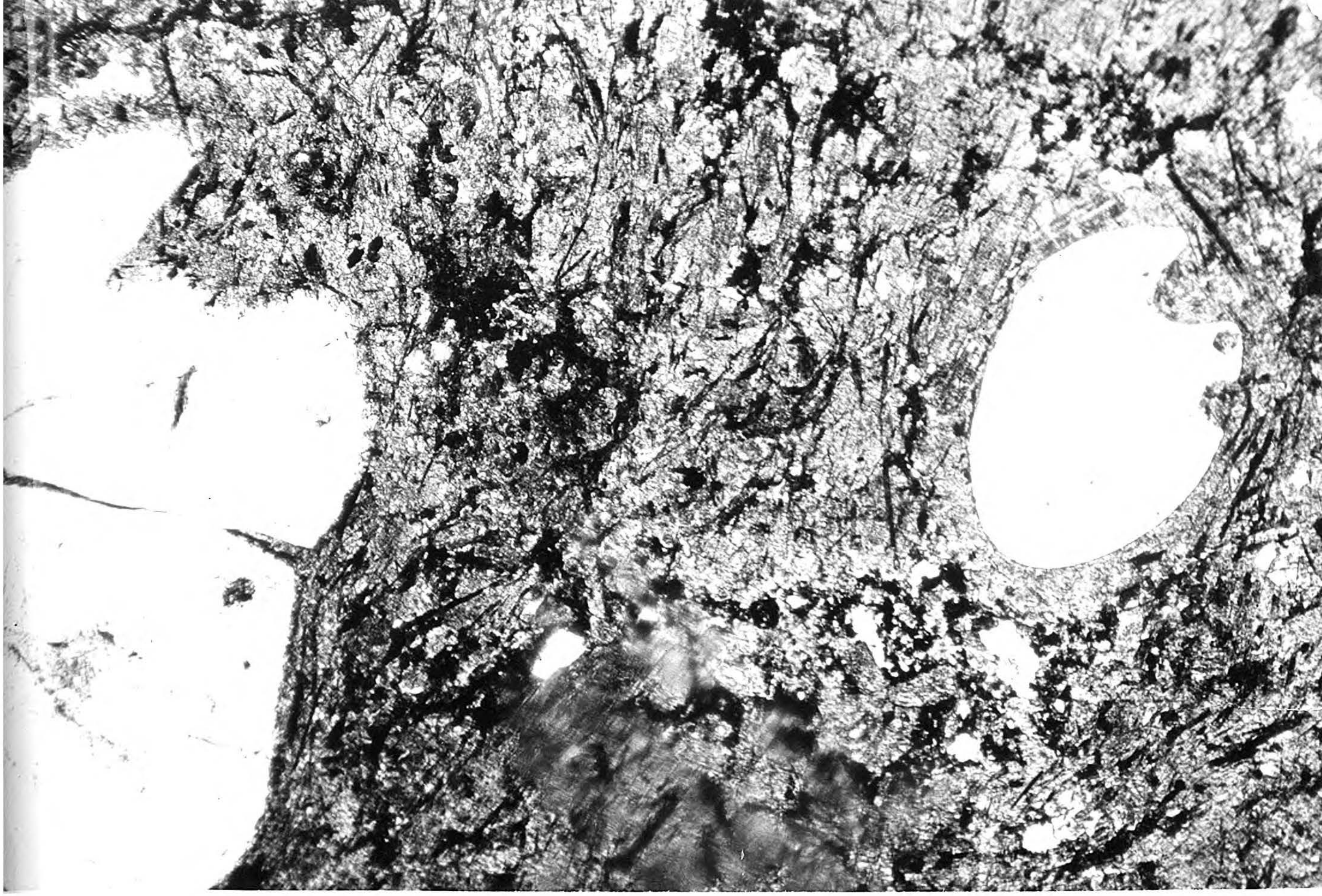
the Anaverde formation is bounded on the south by the rift. All the arkosic sediments south of the line of recent faulting were referred to the Harold beds by Gazin. It is not at all certain that this situation applies to the area studied in this report. In fact, a mile east of Elizabeth Lake school a large body of arkose lies south of the line of recent faulting and appears to be lithologically identical to the arkose of the Anaverde formation north of the fault. At several other points south of the recent fault line arkosic sediments crop out, but are not definitely to be included in the Anaverde formation. In an outcrop just south of the Elizabeth Lake-Pine Canyon road on the road to Ritter Ranch a conglomeratic arkose containing a few gneissic cobbles is present. These cobbles are the only evidence found to suggest that these sediments should not be considered part of the Anaverde formation. In Anaverde Valley other outcrops of arkosic sediments border the south side of a branch fault. They are highly crushed by faulting and are of gouge-like consistency in many places. These sediments may be part of the Harold formation, but inasmuch as no evidence was found in the area studied to indicate that they are different from the Anaverde arkoses, they have been mapped as part of the Anaverde formation.

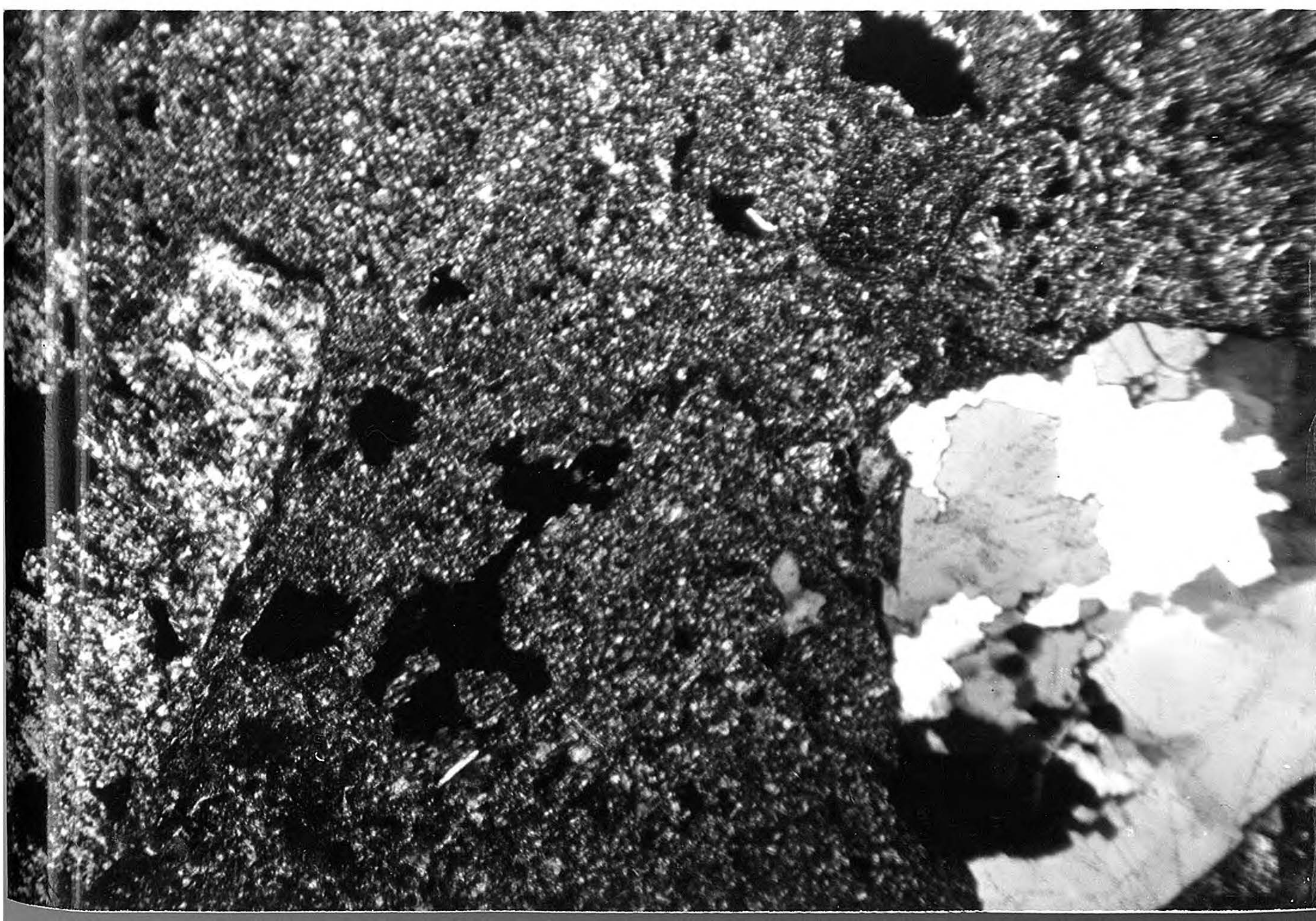
The beds of the Anaverde sediments for the most part are steeply dipping and commonly strike either parallel to the rift, N.65° W., or diagonally to it in approximately an easterly direction.

Plate 10. Photomicrographs of Rosamond rhyolites.

A. Rhyolite from outcrop on top of Pelona schist of Portal Ridge. Note corroded quartz. Uncrossed nicols. X - 60

B. Rhyolite from north of Hitchbrook fault. Note brecciation of rhyolite, possibly flow breccia. Crossed nicols. X - 60





Preliminary report on the Anaverde flora

by

Daniel I. Axelrod

COMPOSITION

A brief study of the Anaverde collection makes possible the provisional identification of the following 19 fossil plants:

Pinaceae
  Pine cone-scale
Palmaceae
  Palm rays ?
Salicaceae
  Populus pliotremuloides Axelrod
  Populus prefremontii Dorf
  Populus sonorensis Axelrod
  Salix wildcatensis Axelrod
Fagaceae
  Quercus cf. dispersa (Lesq.) Axelrod
  Quercus cf. orindensis Dorf
  Quercus wislizenoides Axelrod
  Quercus, new species
Berberidaceae
  Mahonia marginata (Lesq.) Arnold
Lauraceae
  Persea coalingensis (Dorf) Axelrod
Leguminosae
  Robinia californica Axelrod
Sapindaceae
  Dodonaea californica Axelrod
  Sapindus oklahomensis Berry
Anacardiaceae
  Rhus prelaurina Axelrod
Rhamnaceae
  Ceanothus precuneatus Axelrod
  Colubrina, new species
  Rhamnus moragensis Axelrod

The commonest species near the site of deposition, as gauged from some 400 specimens examined, were <u>Persea coalingensis</u>, <u>Populus prefremontii</u>, <u>Quercus wislizenoides</u> and <u>Populus sonorensis</u> in the order listed; they account for fully 85 per cent of all material examined. These dominant species all have heavy-textured leaves; the sediments are generally too coarse to have preserved many of the thin- and medium-textured leaves which belonged to plants near at hand. Owing to this highly selected nature of the material representing the Anaverde flora, it is naturally difficult to give either an exact paleoecological interpretation or to suggest definitely the age of the flora.

PHYSICAL CONDITIONS

The general nature of the vegetation and climate in the Anaverde area may be interpreted from a comparison of the fossil flora with modern vegetation resembling it most closely. Relationships between Anaverde species and living plants are as follows:

Anaverde Species	Similar Living Plants
Ceanothus precuneatus	C. cuneatus Nuttall
Colubrina, new species	C. glabra S. Watson
Dodonaea californica	D. viscosa Linnaeus
Mahonia marginata	M. fremontii (Torrey) Fedde
Palm rays ?	Washingtonia & Sabal spp.
Persea coalingensis	P. pododania Blake
Pine cone-scale	Pinus sabiniana ? Douglas
Populus pliotremuloides	P. tremuloides Michaux
Populus prefremontii	P. fremontii Watson
Populus sonorensis	P. monticola Brandegee
Quercus cf. dispersa	Q. dumosa Nuttall
Quercus cf. orindensis	Q. vaseyana Buckley
Quercus wislizenoides	Q. wislizenii A. DeCandolle
Quercus, new species	Q. amoryi Torrey
Rhamnus moragensis	R. crocea Nuttall
Rhus prelaurina	R. laurina Nuttall
Robinia californica	R. neomexicana Gray
Salix wildcatensis	S. lasiolepis Bentham
Sapindus oklahomensis	S. drummondii Hooker & Arnott

Nearly all of these trees and shrubs most nearly related to the Anaverde fossils live today on the borders of the Sonoran Desert. The majority are found in the transition between pine-oak woodland and chaparral of the upper desert slopes and the desert-border associations of lower levels. Such ecotones are common on desert slopes in southeastern California, southern Baja California, southern Arizona and in west-central Sonora. A study of this related modern vegetation suggests the Anaverde basin was dominated by an oak woodland and savanna, with chapparral on adjacent slopes. Along streams were willows (<u>Salix</u>), cottonwoods (<u>Populus</u>) and avacado (<u>Persea</u>), with chinaberry (<u>Sapindus</u>), locust (<u>Robinia</u>) and perhaps palm in lesser numbers. Shrubs of the thorn forest which had dominated this area in the Miocene apparently had a limited occurrence in the region. Rainfall averages about 15 inches yearly in areas where modern vegetation shows relationship to the Anaverde flora and a good portion of it is received in summer-time. It is suggested that precipitation was not greatly different in Anaverde time; this differs from the present rainfall regime in having about 8 more inches yearly precipitation and summer rains. Modern vegetation on the borders of the Sonoran Desert also lives under a climate having much milder winters than those now prevailing in the Anaverde region.

AGE

The Anaverde flora is clearly younger than the Middle Miocene Tehachapi flora 40 miles northward (Axelrod, 1939) and the late Upper Miocene Mint Canyon flora 20 miles westward (Axelrod, 1940a). The Anaverde has only 2, possibly 3, species representing the Sinaloan Component (thorn forest) which is common in both the Tehachapi and Mint Canyon floras and not now known to be abundant in younger floras of interior southern California. Fossil species of the Oak Woodland Component with descendants now found in areas to southward also are more common in both the Tehachapi and Mint Canyon floras. This also points to the post-Miocene age of the Anaverde for these types of plants were reduced here in numbers following the Miocene.

The Lower Pliocene Ricardo flora, lying 50 miles northward, is smaller than the Anaverde and all of its 5 known species are represented by fossil wood (Webber, 1933). Both floras have an important Oak Woodland Component and most of the Richardo species also find their nearest modern equivalents along the borders of the Sonoran Desert to southward. Three Ricardo plants, the live oak, pine and locust, are related to Anaverde species and the floras do not appear greatly dissimilar from the standpoint of the stage of development of their floristic units insofar as these can be evaluated. We have emphasized elsewhere that stage of floral evolution provides the closest measure of age in late Tertiary time (Axelrod, 1938; 1939; 1940b; 1944a). From the evidence at hand we see every reasn for considering the Anaverde and Ricardo floras as essentially contemporaneous; the absence of Ricardo tuffs in the Anaverde formation may be an indication of its slightly younger age.

There are no known Middle Pliocene floras in the Mohave area with which to compare the Anaverde. However, Middle Pliocene floras providing general floristic data for use in age determination of the Anaverde are in the central and northern Great Basin provinces. Studies there have shown that the dominant Lower Pliocene oak woodland of the central Great Basin and the characteristic montane forest of the northern Great Basin were modified considerably by Middle Pliocene time as the climate became drier (Axelrod, 1940b; 1940c; 1944b). In their place we find that Middle Pliocene vegetation occupying the lowlands over the Great Basin province consisted largely of riparian species in semi-arid open country below the zone of woodland and forest, and resembles that found today at no great distance from the fossil localities (Chaney, 1938; Axelrod, 1944b). It is believed that if the Anaverde were Middle Pliocene in age it would show a greater resemblance to stream-bank and border-woodland vegetation near at hand, and would also have fewer species whose modern equivalents are found today in areas of summer rain to southward. We thus suggest that if the Anaverde is Middle Pliocene it probably belongs to an early part of that stage.

Additional evidence for a late Lower to early Middle Pliocene age for the Anaverde is supplied by the Middle Pliocene Mount Eden flora, situated 80 miles southeastward in interior southern California (Axelrod, 1937). On the basis of new collections made at Mount Eden, only about 6 of its 40-odd species have their nearest equivalents in the southwestern United States and northern Mexico, and none of these is common in the flora; all remaining Mount Eden species closely resemble plants living within a few tens of miles of the fossil locality. Thus it is again reasoned that if the Anaverde were of Mount Eden age it would be expected to have fewer species with equivalents in areas to southward, and to display a greater relationship to modern vegetation in the bordering mountains. The larger representation of these former types in the Anaverde therefore is interpreted as indicating it is older than the Mount Eden flora.

Summary: From the limited and highly selected nature of the plant evidence, we suggest that the Anaverde may be intermediate between the Ricardo and Mount Eden floras in age, or that it is probably transitional Lower to Middle Pliocene. It is emphasized that a more adequate and representative collection might well alter this tentative age assignment.

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Harold beds

South of the rift in the Pearland quadrangle Gazin[49/] has

49/ Gazin, C. L., unpublished report.

found fine gravels, sands, sandy clay, and limey beds which overlie the Cajon formation and contain Pleistocene vertebrate remains. He has called these sediments the Harold beds after the station of that name on the Southern Pacific railway. Gazin reports that south of the rift this formation extends into Leonis Valley. The outcrops which he presumably correlated with the Harold beds have in this report been mapped as Anaverde sediments. Little evidence could be found to distinguish them from the Anaverde sediments, and inasmuch as some Anaverde sediments do crop out near Elizabeth Lake school south of the line of recent faulting, there seemed to be no justification for making a distinction which would carry such strong geologic implications until further evidence was found. It should, however, be kept in mind that some of these sediments in the rift zone are probably correlatives of the Pleistocene Harold beds.

Terrace gravels

Gravels composed almost entirely of Pelona schist detritus have been raised to terrace situations on many fault blocks in the San Andreas rift area. The gravels are characterized by flat pebbles and cobbles of micaceous schists and white milky quartz. Inasmuch as the source of this schist material was almost certainly the block of Pelona schist south of the rift, the eastern limit of which is approximately two miles west of Palmdale reservoir, the present distribution of the gravels with respect to the rift is most significant. South of the rift the gravels spread in broad alluvial fans at the base of Sierra Pelona ridge, and patches of the gravels are present eastward to the vicinity of the Southern Pacific railway tracks. North of the rift, however, Gazin[50/] has found the gravels 5 or 6 miles

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50/ Gazin, C. L., unpublished report

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east of the railroad tracks. Gazin has also pointed out the fact that the most easterly terraces of schist composition are apparently older and are covered by younger granitic gravels. It is hard to escape the implication of these facts; that the north side of the rift has moved a distance of 5 or 6 miles east with respect to the south side, and that the granitic gravels overlying the schist gravels were deposited as the north side of the rift moved past areas south of the rift which were casting granitic debris. This distribution might be explained as fluvial distribution by streams flowing eastward along the trough zone as in Leonis Valley at present. If this had been the case, however, the other blocks east of the Pelona schist should have contributed to the gravel, and the gravels then would not be so predominantly Pelona schist detritus.

The irregular local distribution of Pelona schist gravels supply further indication of disruptions of drainage by repeated faulting. For example, Pelona schist terrace deposits rest on both the ridges bordering the mouth of Anaverde Valley, indicating that the drainage through that pass at one time carried chiefly Pelona schist material, whereas now a great deal of granitic debris is present in the bed of Anaverde Creek.

The terraces capping the center-trough ridge in Leonis Valley are mostly of Pelona schist derived from the Portal Ridge block to the north. The lowest part of the trough in this area therefore, has apparently been for some time, as it is at present, south of the lines of recent faulting.

The Pelona schist gravels are probably of late Pleistocene or early Recent age. They overlie fossiliferous Harold beds of Pleistocene age, but are faulted, tilted and even folded (see pl.19). The purity of the schist gravels suggests a rather sudden uplift of the Pelona schist block as a single unit so that the amount of schist cast into the drainage channels would far exceed any detritus that might be derived from areas of other types of rocks.

In the Bouquet Canyon and Mint Canyon areas south of Sierra Pelona Ridge, similar Pelona schist terraces cap ridges and rest at altitudes several hundred feet above present drainage levels.

Most of the terrace deposits mapped as "undifferentiated" represent detritus from the blocks immediately adjacent to them, and in most cases they are the result of recent rejuvination of drainage.

On the block of diorite and grainite approximately one mile south of Palmdale reservoir, patches of water-worn gravels are present at altitudes over 400 feet higher than that of Palmdale reservoir basin. It would be expected that unconsolidated gravels at that height would be eroded very rapidly so that the uplift which raised them to that altitudo must have been very recent.

Further discussion of terraces may be found in the section on geomorphology.

GEOMORPHOLOGY

Geomorphic divisions and general statement

There are four major geomorphic divisions in the area mapped. On the map (pl. I) they are essentially long narrow zones striking N. 65° W. parallel to the San Andreas rift. The most southerly and highest is the range of mountains broadly known as the Sierra Pelona mountains. This includes Grass Mountain, Mt. McDill and Sierra Pelona Ridge. Mapping was carried south to crest of this range. The next division to the north is the trough zone which marks the trace of the San Andreas rift. North of the trough is a ridge zone made up of Portal Ridge, Ritter Ridge and other smaller, unnamed ridges. The Mohave Desert forms the northernmost zone.

The trough zone and the Mohave Desert are essentially zones of aggradation, whereas the Sierra Pelona Mountains and Portal and Ritter Ridges are zones of degradation.

The drainage of the Sierra Pelona block in general follows the structure of the block so that the major streams tend to flow eastward and northeastward diagonally with respect to the trend of the ridge. In the trough all drainage is parallel to the rift, flowing either N. 65° W. or S. 65° E. Between Elizabeth Lake and the Southern Pacific Railroad the drainage crosses the ridge on the desert side of the rift at only two places, both near the eastern end of the area. A portion of the drainage from the Sierra Pelona Mountains zone has no outlet to the desert area but is ponded in Elizabeth Lake.

A low ridge is present in the center of the trough zone. This ridge as well as sag ponds, terraces, scarplets, disturbed drainage, and other features are the result of repeated faulting along various members of the fault system making up the San Andreas rift.

Terraces and old erosion surfaces are present on top of most of Portal and Ritter Ridges and an old erosion surface is recognizable on Sierra Pelona Ridge.

Wind gaps in the ridges are evidence of disturbance of major drainage patterns.

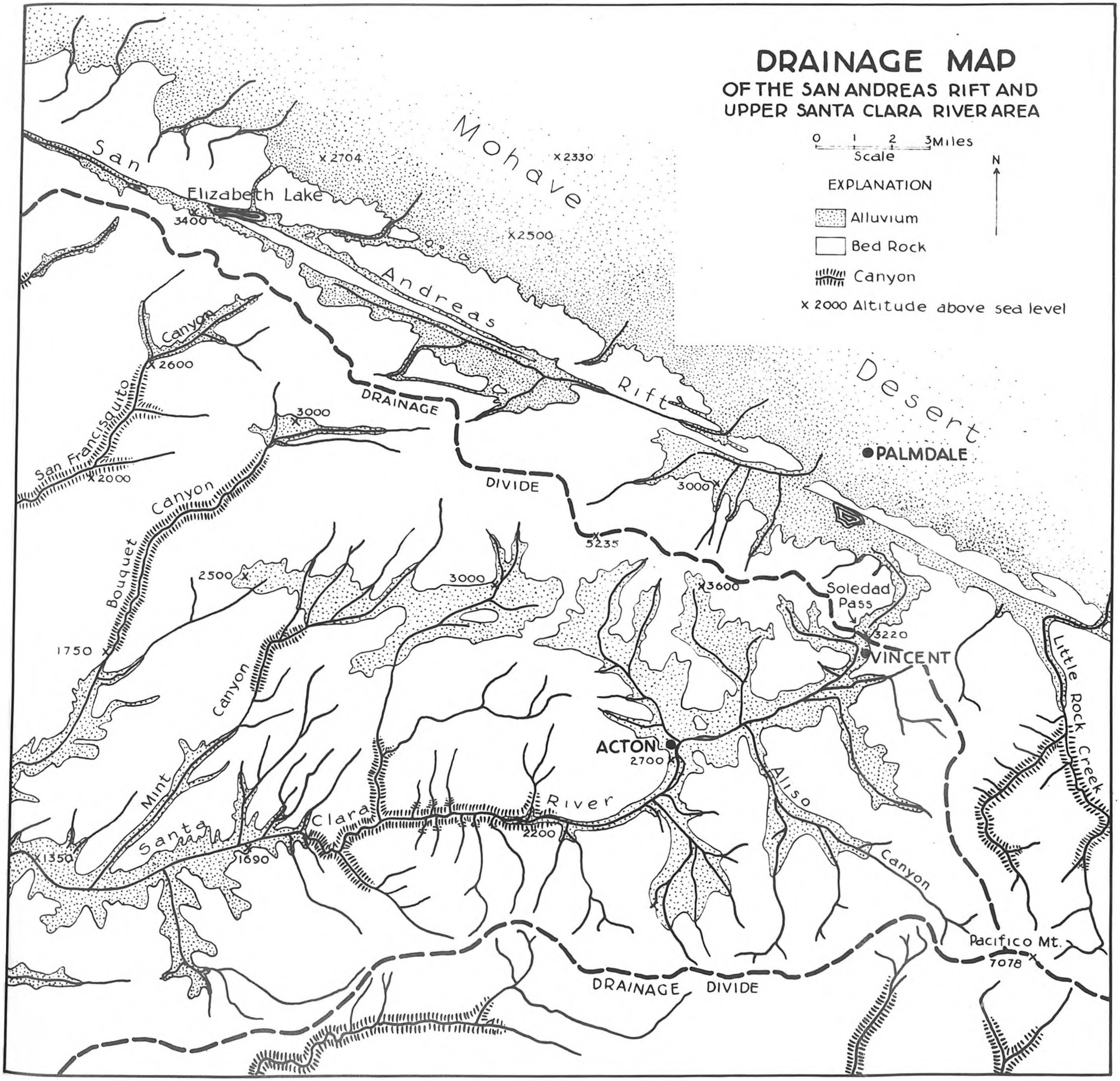
The geomorphic history is very complicated and each individual tectonic block has had, more or less, an individual history.

Drainage pattern in upper Santa Clara River Valley and San Andreas rift area

The history of the drainage in the upper Santa Clara River, San Andreas rift and adjacent portions of the Mohave Desert has been complicated by frequent and repeated shifting of tectonic blocks both vertically and horizontally. The drainage pattern itself gives a clue to some of the most recent tectonic events.

On the drainage map (pl. 11) the most striking geomorphic feature is the San Andreas rift zone which cross cuts all other geomorphic trends. The divide between the Mohave Desert and the Santa Clara River is asymetrical. The presence of this divide so close to the rift is evidence of vertical displacements in the

Plate 11



DRAINAGE MAP
OF THE SAN ANDREAS RIFT AND
UPPER SANTA CLARA RIVER AREA
0 1 2 3 Miles
Scale
N
EXPLANATION
Alluvium
Bed Rock
Canyon
x 2000 Altitude above sea level
Mohave
Desert
San Andreas Rift
Elizabeth Lake
3400
x 2704
x 2330
x 2500
PALMDALE
Canyon
x 2600
San Francisquito
x 2000
3000
DRAINAGE
DIVIDE
3000 x
5235
Bouquet Canyon
2500 x
3000
x 3600
Soledad
Pass
3220
VINCENT
1750 x
Mint Canyon
ACTON
2700
Little Rock Creek
Santa Clara River
x 1350
1690
2200
Aliso Canyon
Pacifico Mt.
7078 x
DRAINAGE DIVIDE

Plate 12. A. View of head of Santa Clara river. Photograph looking southeast over old alluvial surface at head of Santa Clara river. Note ~~mature~~ topography of old surface in middle distance and youthful topography of San Gabriel mountains in distance. Valley in foreground drains into Mohave Desert.

B. View of alluvial slopes of the Mohave Desert at the base of Portal Ridge. Photograph looking southeast with Portal Ridge to the right and the San Gabriel mountains in the distance.

rift zone. This asymetry extends to a point a few miles east of Vincent where the drainage divide swings south away from the Mohave Desert. This, of course, is the result of the uplifting of the San Gabriel block and development of youthful drainage on both north and south flanks.

Another prominent feature shown on the drainage map is the two stages of alluviation separated by a zone of canyon development in the Santa Clara River drainage. The headwaters of the system are in a relatively mature stage of development and as yet are relatively undistrubed by the rejuvenation which has caused the development of canyons in lower parts of the rivers.

Other features of interest include the horizontal offset of stream channels due to horizontal displacement on the San Andreas rift and the reversal of drainage near Vincent as indicated by the acute angle of tributaries pointing upstream and the wind gap of Soledad Pass.

In the eastern part of the area mapped, from Soledad Pass (but excluding the pass itself) west to Bouquet Canyon Pass, broad alluviated valleys are present on the south side of the Mohave Desert-Santa Clara River drainage divide very nearly to the divide itself, but on the north side there are steep canyons. It can be inferred that the divide is migrating southward. This situation of drainage suggests vertical displacement along the rift and a comparison of altitudes of alluviated valleys on either side of the divide suggests that this displacement in recent times may have been of the order of 400-500 feet.

Plate 13. Sag ponds along the San Andreas rift.

A. Palmdale reservoir, in part a natural basin. View looking southeast along recent fault-line scarp which forms north edge of Palmdale reservoir.

B. Elizabeth Lake looking northwest.

West of Bouquet Canyon the major drainage divide is more stationary in position, because Elizabeth Lake Valley and Leonis Valley are not adjusted to the Mohave Desert level but are approximately 400 to 700 feet higher thus providing a temporary base level which isolates the drainage from the main divide from the effects of rejuvenation.

The main recent vertical displacement has taken place along a line obscured by alluvium of the Mohave Desert, but the canyon-like valleys on the north side of Portal and Ritter Ridges are clear evidence of this vertical displacement. The drainage divide at the crests of Portal and Ritter Ridges therefore is moving southwestward.

Near Vincent large tributaries of the Santa Clara River enter the main channel of the river and make an acute angle with the downstream portion of the river. This feature strongly suggests that the headwaters of the Santa Clara at one time flowed northward through Soledad Pass. Indeed, Soledad Pass is broad and alluviated and undoubtedly was formed by a relatively large drainage channel, although now no water flows through the pass. In this regard, it is interesting to note that the U. S. Geological Survey topographic map of the Elizabeth Lake quadrangle mapped in 1915 shows drainage flowing through the pass. The drainage divide at the pass is so low that it is not impossible that the drainage has shifted since the map was made. The reversal of drainage of these two tributaries is due to a combination of uplift along the rift zone, thus shifting the divide northward, and increased gradient of the Santa Clara River which is causing erosion of deep gullies and arroyos in the older alluvium. Where the drainage divide was previously is uncertain, but it possibly followed the approximate location of the ridge on the north side of Aliso Canyon and the ridge on the northwest side of the Santa Clara River approximately 2 miles downstream from Vincent.

The canyons developed along the drainage of San Francisquito Canyon, Bouquet Canyon, Mint Canyon and the Santa Clara River all are in approximately the same relative position on each stream and together form what might be called a canyon zone. This zone trends northwest so that it approaches the rift at the west end and is approximately ten miles south of the rift at the east end.

Uplift which caused the canyon development did not take place along a single fault, but rather along a zone of faulting. The principal faults strike approximately east northeast but are connected by smaller cross faults. The Pelona Fault crosses Bouquet Canyon at the mouth of the canyon section,[51/] and a similar fault crosses Mint Canyon at the mouth of its canyon section. A fault follows the canyon portion of the Santa Clara River several miles.[52/] The rivers have cut into this uplifted zone and

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51/ Simpson, E. C.: Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of the state mineralogist, map, 1934.

52/ Kew, W. S. W.: Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California: U. S. Geol. Survey, Bull. 753, pl. I, 1924.

the canyons are being extended headward. The headwaters of Mint Canyon and the Santa Clara River are just beginning to be affected by the rejuvenation and the older alluvium is being dissected to form terraces. Precluding any further tectonic movement the streams would again become adjusted. It would be possible for the Santa Clara River to cut headward through Soledad Pass and into the Mohave Desert. The uplift causing canyon development probably preceded the uplift along the rift which caused reversal of the headwaters of the Santa Clara River. This is suggested by the more advanced stage to which erosion had progressed in the canyon zone.

Offset streams

The principal evidence of horizontal displacement in the past along the San Andreas rift is the offset channels of streams which flow across the rift. Examples from all sections of the rift length have been described by various investigators. Gazin[53/]

53/ Gazin, C. L., unpublished report.

described the offset of stream channels in the Pearland quadrangle. Little Rock Creek, shown on the drainage map (pl. 11), is one of the best examples of offsetting in the Pearland area and shows a horizontal displacement of over a mile and a half. The displacement is such that the portion of the channel north of the rift is offset to the southwest with respect to the portion of the channel south of the rift. This is the typical situation on all parts of the rift.

The drainage of Anaverde Valley also suggests horizontal displacement. If the drainage pattern is a result of the ridge area on the desert side of the rift moving horizontally, the direction of movement clearly would have been such that the north side moved eastward with respect to the south side, and the amount of offset suggested would be approximately two and a half miles. It is very possible, however, that at least the westernmost of the tributaries of Anaverde Creek (see pl. 1) flowed across what is now a low ridge and out of the desert through the mouth of Leonis Valley. The granitic block north of the rift which lies across the trend of these channels may have been uplifted vertically across the drainage thus shifting the flow to the east. The ridge, however, appears to be a much older feature than the stream channels so that the pattern is more easily explained by lateral movement along the rift.

In the Leonis Valley area drainage from the Sierra Pelona Mountains has been dammed for some time by Portal Ridge so that it has had to flow northwestward or southeastward parallel to the rift. The present mouth of Leonis Valley may represent the mouth of Bouquet Canyon drainage offset to the east. It may on the other hand be the result of a stream cutting southward from the north side of Ritter Ridge and capturing the Leonis Valley drainage much as was the case in the Hitchbrook fault valley, (see p. 64).

Drainage from Portal Ridge into Leonis Valley also suggests horizontal displacements. For a distance of a mile or more west from Leonis school along the center-trough ridge notches in the ridge represent old channels through which drainage from Portal Ridge flowed. From the map (pl. 1) it can be seen that the notches do not match the valleys on Portal Ridge. If the center-trough ridge were shifted east approximately 250 yards the notches and valleys would match much better. It seems very likely that the present situation has been brought about by a horizontal shifting along the rift.

Approximately one and two-thirds miles west of the mouth of Leonis Valley a stream joins Leonis Valley from the south side. It displays a strong suggestion of horizontal shifting of approximately 500 yards, with its mouth being offset that distance east of the rest of its valley. Many other examples, not quite as apparent, might also be mentioned.

Wind gaps and stream capture

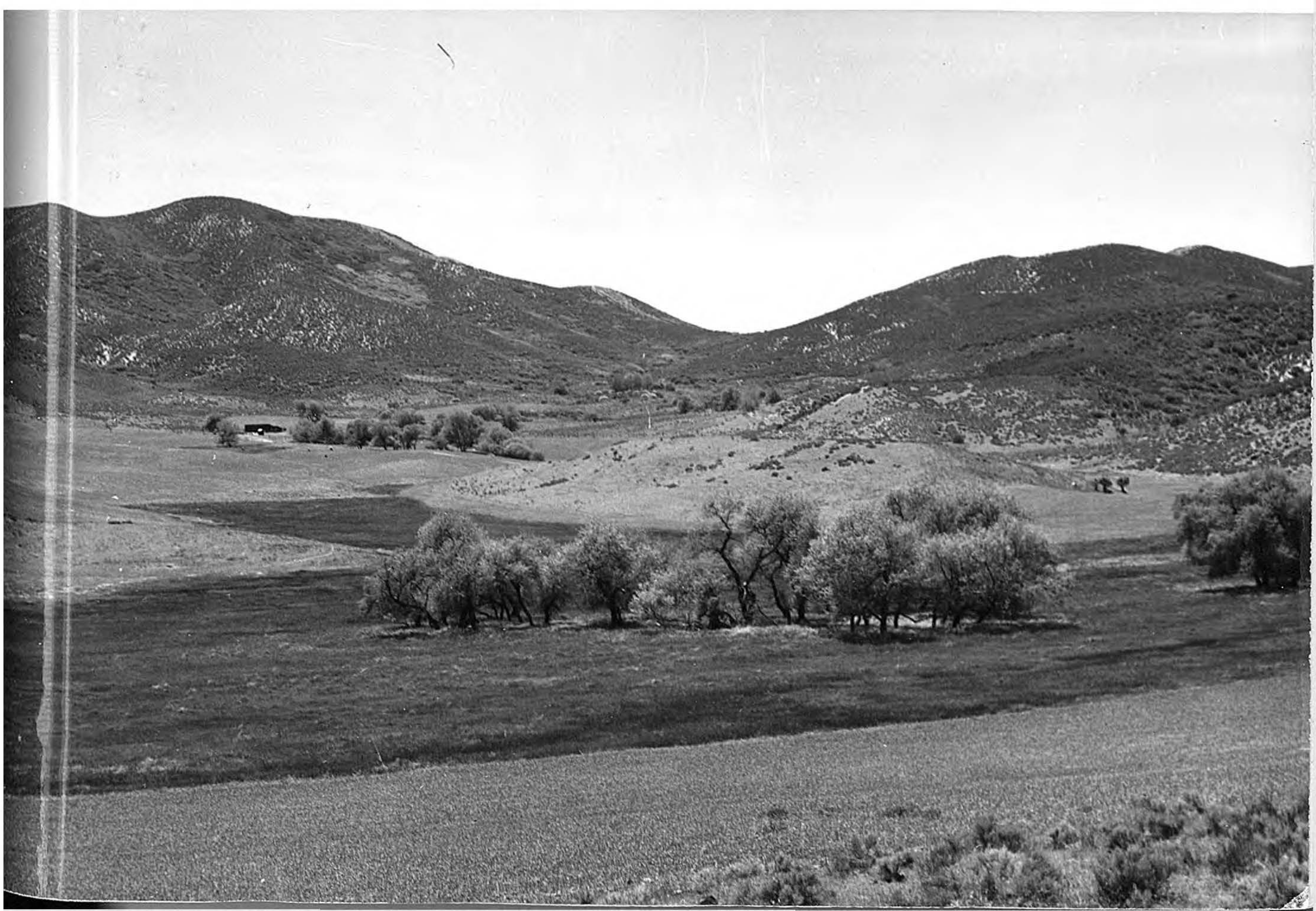
Soledad Pass is a prominent wind gap (see pl. 11) which has been caused by reversal of drainage. Other low saddles in the Mohave Desert-Santa Clara drainage divide may also be due to reversal of drainage. The saddle approximately one and three-quarters miles southeast of the Elizabeth Lake school (see pl. 1) at the head of Dowd Canyon is very low and wide and the stream flowing down the north side of the divide is apparently underfit. This suggests capture of headwaters of the stream by the Dowd Canyon drainage. It may, however, be a feature of mature topography which has been preserved from an earlier cycle. Leonis Valley acts as a temporary base level on the north side, and on the south side the canyon portion of San Francisquito has not yet reached the divide. The divide at the head of San Francisquito Canyon is also low but is probably due to the streams on the north and south sides cutting headward against each other as they both erode the same fault zone. The pass at the head of Bouquet is also a low divide and like that at the head of San Francisquito Canyon is probably due chiefly to erosion along a fault zone.

Between the valley which follows the Hitchbrook fault and the Mohave Desert several broad valleys with underfit streams cut the intervening ridge. It is quite evident that these are the result of stream capture. Originally the stream following the Hitchbrook fault probably flowed more than two and a half miles farther east then at present before entering the Mohave Desert. At that time consequent streams were dissecting the fault line scarp along the north side of Portal Ridge. The first stream west of the mouth of the Hitchbrook fault valley, having less distance to erode southward before intersecting the Hitchbrook fault valley, would be the first to capture the drainage of the fault valley. As erosion proceeded the consequent streams to the west would in turn finally reach the fault valley and capture the drainage of the head of the valley. The present channel followed the drainage probably is a result of at least the fifth capture of the Hitchbrook

Plate 14. Wind gaps in the ridge south of the San Andreas rift.

A. View taken in the broad saddle of Soledad Pass. There is no drainage through this gap at present. Buildings in middle distance constitute the town of Vincent.

B. View looking southwest at a wind gap in Sierra Pelona Ridge a mile southeast of San Francisquito canyon. View is looking across the fault trough and shows the typical topography and vegetation.



fault valley drainage by streams cutting headward from the north side of Portal Ridge.

Apparently the same thing has taken place along the fault which branches from the Bouquet Canyon fault a little more than a mile south of Leonis School. A trough following this fault cuts diagonally to the trend of the range. Probably first the drainage in this trough flowed east to a point near where the Bouquet Canyon road now turns sharply to the north into Leonis Valley. The stream followed by 87th Street first captured the drainage. Finally the valley three miles west of Leonis School was cut headward to the south until it intersected the fault valley drainage and beheaded the stream. Part of the drainage to the east was inverted and part still drains out the 87th Street valley.

The Hitchbrook fault valley will eventually be eroded headward and will intersect the basin of Elizabeth Lake. Elizabeth Lake, however, will probably first be drained by the stream followed by the Elizabeth Lake-Willow Springs road.

<u>Origin of the trough</u>

The trough which marks the trace of the San Andreas rift over much of its length is especially prominent in the area studied. The alluviated bottom of the trough is over a mile wide in places, and the crests of the ridges on either side are of the order of a thousand or more feet above the trough. In that part of the trough known as Leonis Valley a prominent ridge follows the center of the trough for over ten miles. The cause of the trough is probably due to a combination of erosion along the fault zone and downdropping of individual blocks due to local tensional stresses plus the action of gravity. In the area mapped it is suggested that erosion is by far the most important of the two processes.

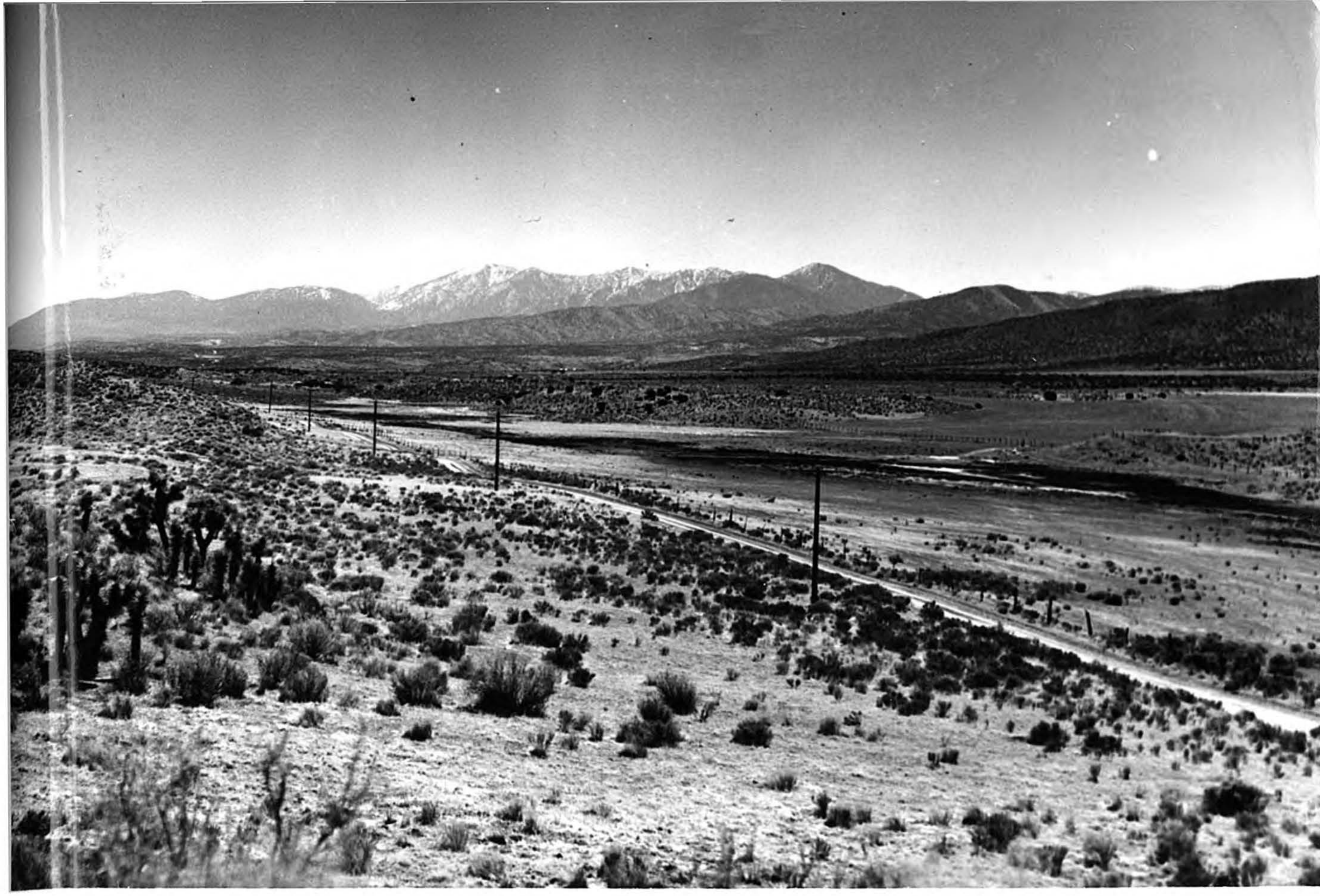
As two large tectonic blocks such as Portal Ridge and the Sierra Pelona Mountains were being forced upward by lateral compressional forces, it would be expected that any narrow band of rocks, such as the rocks of the fault zone, between the blocks would be carried upward along with the larger blocks. The gouge-like portions of the fault zone would also tend to be squeezed upward in the path of least resistance so as to form ridges above the fault zone. The ridge of gouge material near the west end of Palmdale Reservoir could represent an example. The center-trough ridge, as explained elsewhere, is possibly a result of such action.

Contrasting these tendencies toward upward movement of the rocks of the fault zone are the effects of erosion and gravity-slumping of blocks. In the area studied few of the sag ponds present can be definitely ascribed to downdropping of individual blocks. Many appear to be more likely a result of damming by vertical displacements along faults crossing drainage channels. Palmdale Reservoir and Una Lake basins, discounting the effects of man, probably represent good examples of sag ponds due to downdropping of a fault block, and yet the Palmdale Reservoir basin would drain into the Mohave Desert if the ridge between the reservoir and the desert were not present. The block underlying Elizabeth Lake also represents a good example of a downdropped

Plate 15. Views of the trough of the San Andreas rift.

A. View looking southeast along Anaverde Valley. Note the series of scarplets following the middle of the valley.

B. View looking northwest along the lower portion of Leonis Valley. The mouth of Leonis Valley is in the lower right hand corner. Note the fault line scarp along the ridge at the right.



block, or at least a block which has been elevated less than the surrounding tectonic blocks. The basin forming Elizabeth Lake is actually over 500 feet above nearby portions of the Mohave Desert. The pond three and a half miles southeast of Elizabeth Lake school (see pl. 1) is undoubtedly due to damming of the drainage from Portal Ridge by the uplifting of the center-trough ridge.

Erosion proceeds relatively rapidly in the fault zone where fault gouge is present. Such ease of erosion along faults is displayed by many fault valleys in the area. Approximately half a mile south of the mouth of Leonis Valley two recently formed valleys are being cut eastward and westward along the fault instead of south into the uplifted basin of Anaverde Valley as might be expected. Faults such as the Hitchbrook fault and the Bouquet Canyon fault and branches have localized the development of prominent valleys which almost certainly are due principally to erosion.

Precluding any differential resistance to erosion, all the scarplets developed on recent faults cause drainage to flow parallel to them and that together with uplifting of the zone as a whole tends to entrench the streams in the fault zone. Streams forming on an initial slope seek out any irregularity that might be present. Certainly a fault such as the Bouquet Canyon fault would cause a prominent irregularity even on an uneven slope. Streams would tend to follow such an irregularity even if the rocks and fault zone all offered equal resistance of erosion.

Therefore, with little real evidence of true down-dropped fault blocks and with many suggestions of differential erosion and entrenchment along the fault, it is believed that erosion is the more important of the two trough-forming agencies.

Origin of the center-trough ridge

The ridge which is present in the center of the fault trough zone for a distance of over ten miles is obviously an upthrown block bordered by two faults of the San Andreas system. In one place one of the faults is exposed in a stream cut-bank (see p. 86 and pl. 21) so that it could be seen that the block forming the ridge is definitely faulted upward. The upthrowing of a block in the center of a physiographically low zone suggests that the faults along which the upthrow has taken place represent merely components of the major fault zone and that the upthrow of the block is of a secondary character in relation to the major displacement.

A possible cause of the "center-trough ridge", as it may be called, is diagrammed in plate 16. The sequence of events would be as follows:

Beginning as shown in plate 16 A, a wide zone of fractured rock and essentially fault gouge could be eroded away, the edge of the adjoining blocks beveled off, and deposition of sediments on the floor of the valley to form a situation as pictured in plate 16 B. Lateral compressional components of any later forces exerted would cause the material of the gouge zone, acting in a plastic-like manner, to be squeezed upward in the direction

Plate 16. Diagrammatic sketch of trough zone and center-trough ridge. Refer to text (page 68) for explanation.

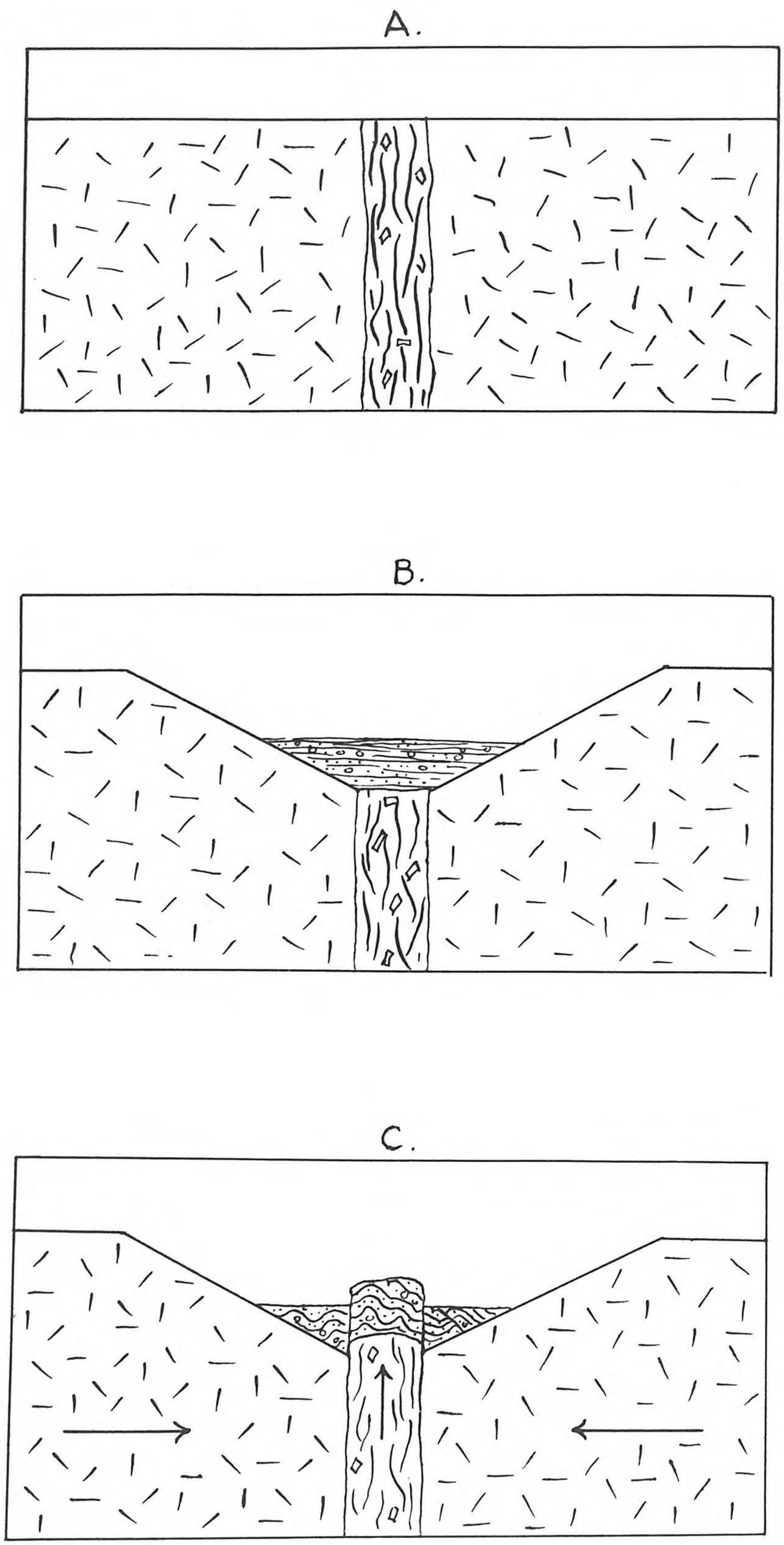
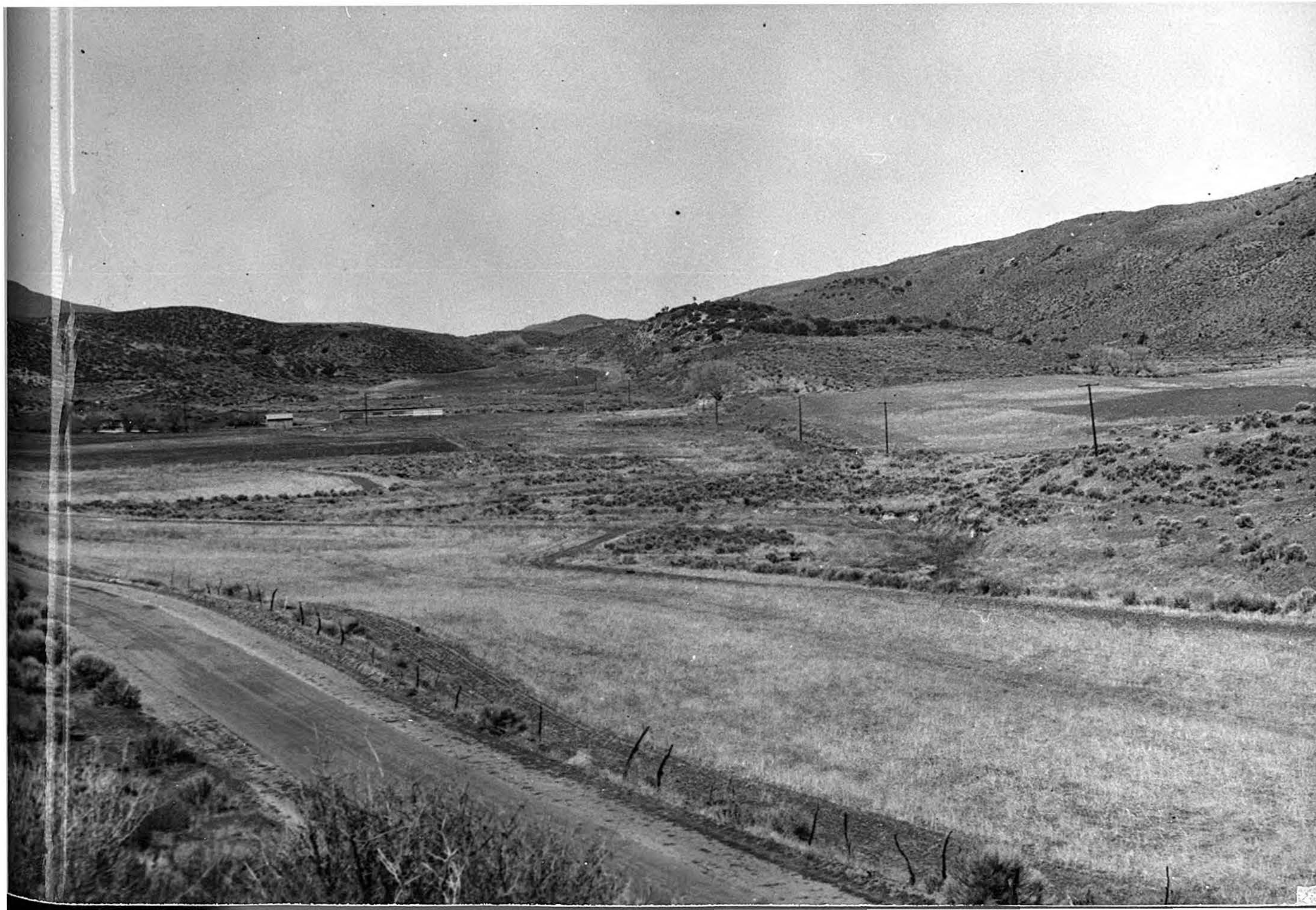

A.
B.
C.

Plate 17. Views of recent scarps along the San Andreas rift.

A. View looking southeast from a point 4 miles southeast of Elizabeth Lake showing typical recent fault scarp and sag pond.

B. View looking northwest from a point near Ritter Ranch showing recent fault scarp and typical topography along fault trough.



of least resistance. This would cause the central part of the sedimentary band above the gouge zone to be faulted upward as is shown in plate 16 C. Over a long period of time erosion would cut down the trough and center-trough ridge more rapidly than would the gouge material be forced upward, so that the trough feature would predominate over the ridge feature. At any given instant, however, the center-trough ridge might be present due to the recency of uplift above the gouge zone, but it would lie within the trough, and, in the normal case, its crest would be much lower than the crests of the two blocks on either side. The fact that the sediments deposited in the trough would be wider than the actual fault zone might account for the broad valleys that are commonly present between the center-trough ridge and the blocks on either side. There would not then necessarily be any faults along the edges of the valleys to account for the width of the valley floor, although commonly that is the case. It would also be expected that at some time the overlying sediments would be removed and that gouge would be exposed in the ridge. What appears to be an example of just this is present west of Palmdale reservoir.

When the fault gouge is squeezed upward the two blocks on either side naturally move toward each other. This would cause buckling and thrust faulting in the sediments of the trough. The tendency of the gouge zone to become narrower and narrower due to the two blocks being forced together would be compensated for by addition of gouge material from the opposing faces of the two blocks during periods of strike-slip displacements. Inasmuch as the strike-slip component of motion is the principal one, the gouge zone would be adjusted to a width that would accommodate that movement.

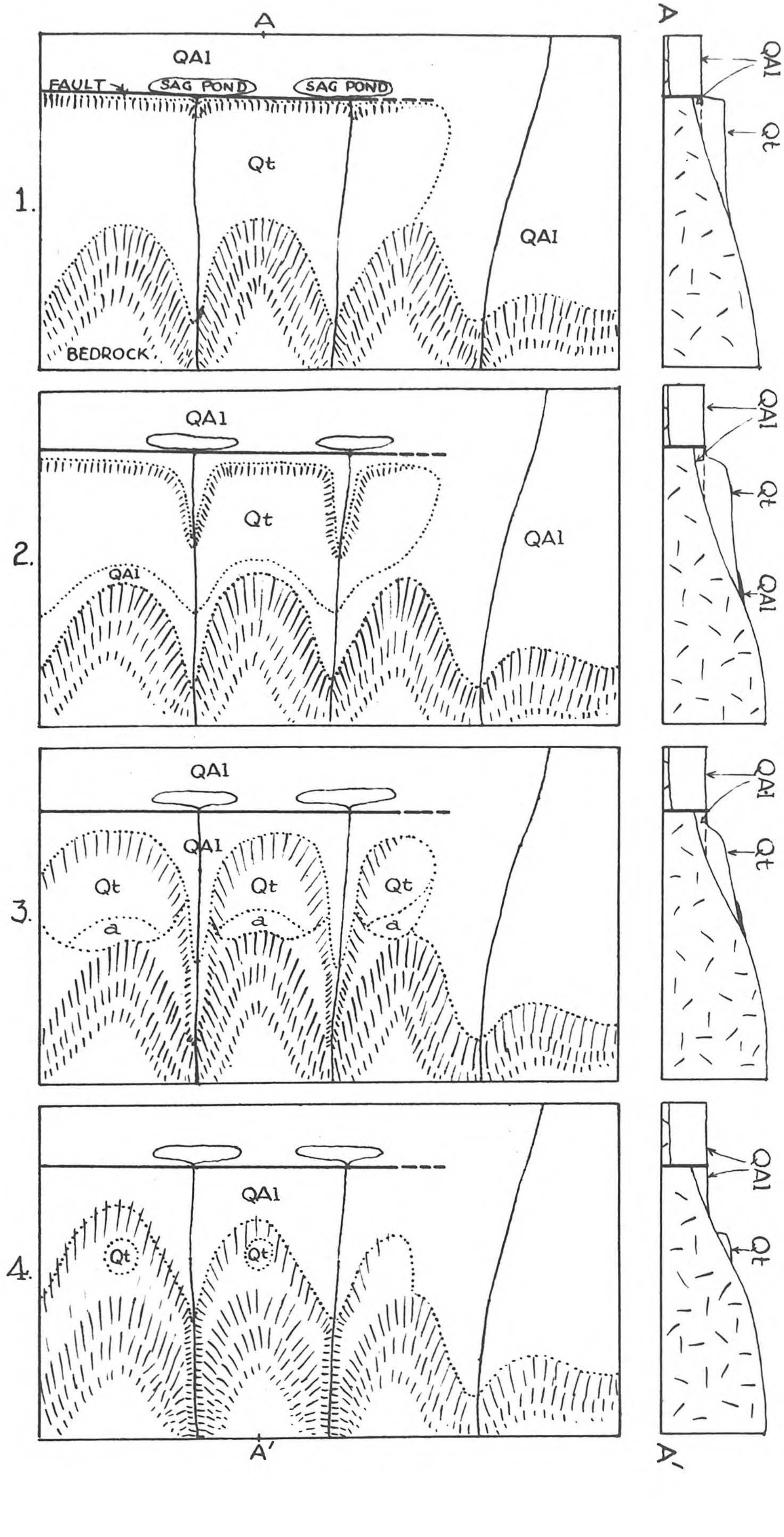
The diagrams (pl. 16A, B and C) illustrating the possible mode of formation of the center-trough ridge suggest that the sediments in the trough would be derived from the blocks on either side. It is significant then to note that no fragments of Pelona schist which borders the trough in most of the area investigated were found in any of the exposures of Anaverde sediments between Elizabeth Lake and Palmdale reservoir. This problem is discussed in another section of the paper (p. 101).

Terrace deposits defined

The broadest definition of a terrace might be, as Webster defines it, merely "a raised level or platform of earth". For geological purposes a more specific definition is necessary. Indeed, it is at once apparent that many types of geologic features are included under the general term "terrace", and that subdivisions of the broad term must be defined. There are apparently two major geologic uses of the term that are essentially different and must be separated before further limits are applied to specific types. One use has been made in referring to a "terrace surface" which is two dimensional in nature, such as an erosion surace. The second use is made in speaking of a "terrace deposit".

The requirements in setting up limits of various subdivisions

Plate 18. Diagrammatic sketches showing origin of terrace deposits. Refer to text (page 71) for explanation.


A
QAl
FAULT
SAG POND
SAG POND
Qt
QAl
BEDROCK
1.
2.
3.
4.
Qt
a
A'
A
QAl
Qt
QAl
Qt
QAl
QAl
Qt
QAl
Qt
A'

of the two dimensional feature are quite different from the types of limits that can be applied to deposits. The subject of classification of the first type has been discussed in many papers, but apparently the problem of determining the essential qualifications of a mapible unit that can be called "terrace deposit" has not received much attention. Inasmuch as the "platform" or surface is the essential characteristic of a terrace, a terrace deposit qualifies for inclusion under the term "terrace" only because it is commonly related to a "terrace surface".

The essential qualities which distinguish an individual terrace deposit from other deposits are first; the elevated nature of its surface above the original level. This subjects all the material raised above the original plane to erosion. Secondly; inasmuch as the deposit is to be considered a geologic formation, the material deposited must represent a specific period of time. The end of that period of time is marked by the change which places the deposit in a terrace category.

In plate 18 an attempt has been made to diagram the sequence of events that take place after alluvial material has been uplifted along a fault and placed in a terrace situation. Plate 18, 2 is a diagrammatic sketch of a situation in Anaverde Valley which was one case observed in the area mapped that raised the problem as to what constitutes the boundaries of a terrace deposit.

In plate 18, 1 the area south of the fault has been raised and the north side depressed. All the alluvial material from the fault south to the bedrock outcrop and east to the drainage divide between the easternmost two streams is placed in a different situation than the remaining alluvial material in that it is raised and therefore, is subject to erosion.

In the cross-section only the material above the plane to which erosion will cut as a result of the uplifting can be considered terrace material. The portion below that plane will never be in a terrace situation as a result of the one movement along the fault.

In plate 18, 2 the fault scarp has been eroded back from the fault and the streams have cut headward into the terrace. The disturbance of grade has not yet been felt in the headwaters of the stream and alluvium is still being shed by the mountain slopes and deposited as an "apron" (plate 18, 3 "a") on top of the terrace deposit. Because this alluvium is more recent than the uplifting of the terrace, it cannot actually be classed as part of the terrace deposit. Geologically this is a short period feature, but in an area such as that mapped, faulting is so frequent that the situations being mapped are short period features, and to be able to interpret the history correctly, distinction of such features are sometimes necessary.

In plate 18, 3 the streams have cut headward so that the original alluvium has been removed from the valley and redeposited in the new lower area of deposition. The alluvium deposited after faulting (plate 18, 3, "a") is also eroded and reworked. When erosion begins to act on this post-faulting alluvium its situation is changed so that it then fulfills the requirements of a terrace deposit. If the situation is such that the distinction between the pre- and post-faulting accumulations of material must be recorded, they may be mapped separately, otherwise for convenience they may best be grouped and mapped as a unit.

As illustrated in plate 18, 3 the old alluvium-bedrock contact has turned from making an angle with the vertex pointing upstream to an angle with the vertex pointing downstream. In the field this feature can be used to distinguish alluvial material as being terrace deposit when other features were not obvious.

Plate 17, 4 shows the terrace material completely isolated from the other alluvial material. This is probably the most characteristic situation for a terrace deposit and no difficulty is encountered in establishing boundaries. In the earlier stages of terrace formation, however, theoretical contacts may have to be drawn if the terraces are to be mapped. In summary then, the tests which may be applied to determine the existence and boundaries of a terrace deposit are:

1. Is the surface of the deposit essentially a raised platform?
2. What portion, both in area and depth, is subject to erosion?
3. What portion of the sediment predates the change which caused the terrace?

Examples of terrace deposits

Putting these tests into practice brings out the fact that in an area of as frequent tectonic activity as that around the San Andreas rift, a great deal of the alluviated areas can actually be classed as terraces. If certain features shown by the terraces are to be emphasized on a map, not all of the terraces can be shown without introducing an involved and cumbersome system of subdivisions. Some terraces must necessarily be mapped as alluvium and others grouped into a few classes of terrace deposits. The tests can be then applied to determine where the boundaries of those few should be drawn.

A half mile east of Goode Hill Road on Ritter Ridge is a terrace deposit which is perched several hundred feet above a level that would be at grade with respect to the Mohave Desert. In the upper portions of this drainage the effects of rejuvenation are not yet apparent and the topography is in a mature stage of erosion. The lower parts are being rapidly cut into gullies and there is a break between the lowest terrace material and the highest point to which the alluvium of the present cycle has extended up the valley. It is apparent that within a relatively short time this material will be eroded away, clearly showing the recency of the uplift which last elevated Ritter Ridge.

A broad alluviated valley following the rift and draining northwestward joins Leonis Valley a few hundred yards from its mouth. The eastern end of the valley is truncated by erosion proceeding along streams draining into Anaverde Valley. The alluvium of the present cycle in the lower parts of the valley grades imperceptibly into deposits at the head which must be classed as terraces. A theoretical contact must necessarily be drawn if the terrace deposit is to be distinguished on a map from the alluvium. East of the present head of this valley isolated terrace deposits are present for a distance of nearly a mile, attesting to the fact that alluvium once was continuous over that area. These terraces are also indicative of uplift of the block north of the rift.

A similar situation where alluvium grades imperceptibly into deposits having a terrace situation is present approximately a mile and a half west of Leonis School on and adjacent to the center-trough ridge. At this locality a hill composed of Anaverde arkose on the center-trough ridge is surrounded by alluviu. West of the hill the alluvium is broken by the San Andreas rift so that the alluvium north of the rift is actually in a terrace situation with respect to the alluvium south of the rift. East of the hill the displacement is not apparent so that the two zones of alluvium grade imperceptibly into one another. On the map no terrace is distinguished, but if a distinction were made, the location of a theoretical boundary would have to be determined by the tests set forth in the preceding section.

Deposits of older alluvium are in a terrace situation in many places along the borders of Leonis Valley, and were mapped as "undifferentiated terrace deposits". The highest terrace is at the west end at an altitude of approximately 3500 feet above sea level. The altitudes of the terraces grade to approximately 3000 feet above sea level near Ritter Ranch in the eastern portion of Leonis Valley. The rather even gradation in altitudes suggests that the terraces are a result of uplift of the valley area as a whole resulting in dissection of the old alluvial deposits. At present even later rejuvenation of the Leonis Valley drainage is causing the streams to cut headward and dissect the more recent deposits of alluvium in the valley.

Erosion surfaces

Surfaces representing former periods of erosion are present on most of the mountain and ridge blocks. On the ridge area north of the rift a series of erosion surfaces and terrace deposits are present. On the west end above Elizabeth Lake the old surface is well preserved (pl. 19 B) and shows the advanced stage to which the cycle of erosion had progressed. The altitude of the surface in this area is approximately 3700-4000 feet above sea level or more than 1000 feet above nearby portions of the Mohave Desert.

Between Elizabeth Lake School and Goode Hill Road the erosion surface on Portal Ridge is also at an altitude of about 3700-4000 feet but is not as well preserved or extensive as west of Elizabeth Lake School. East of Goode Hill Road on Ritter Ridge the surface is at an altitude of approximately 3300 feet. Farther east at the east end of the area mapped an erosion surface is present on the block of Anaverde shale a mile south of Palmdale. The altitude of this surface is only 100-200 feet above the Mohave

Plate 19. Views of Portal Ridge from Grass Mountain lookout.

A. View looking northeast showing fault trough and Portal Ridge in the distance.

B. View looking northwest showing dissected nature of the Grass Mountain block and the fault trough and Portal Ridge in the middle distance. Note erosion surface on the crest of Portal Ridge. The Tehachapi Mountains are in the distance.

Desert. Patches of terrace deposits composed of Pelona schist detritus are present on both sides of the mouth of Anaverde Creek and probably represent the level at which aggradation was taking place while the ridges were being eroded to produce the present flat tops. These erosion surfaces and terrace deposits indicate that recent elevation of the west end of the ridge zone has been greater than the east end, possibly amounting to as much as 1,000 feet in the western part and 200 feet in the eastern part. The shape of this erosion surface suggests that the present ridge area was also a ridge during the erosion period which produced the surface so that the ridge drained both into the Mohave Desert and Leonis Valley.

Erosion surfaces in the mountains south of the rift are not as prominent as on the ridges north of the rift. West of Bouquet Canyon only a few flat tops are present on the mountains to suggest an earlier period of subdued relief. The crest of Grass Mountain is one good example. The topography of this block is in a late youth or early maturity stage of development. The situation is quite different east of Bouquet Canyon in that Sierra Pelona ridge has a relatively flat top and on the north side an even slope is preserved. This slope, however, now is being dissected by recent rejuvenation of the drainage. The topography of this block represents a recent cycle of erosion which is still in early youth superimposed upon an older cycle of erosion which was in an advanced stage before the recent elevation.

Although the stage of dissection by drainage would suggest that the Grass Mountain block has been subjected to more recent elevation than the Sierra Pelona block, the Sierra Pelona block is actually higher. This suggests that at an earlier time the Sierra Pelona block was elevated to a much greater height than the Grass Mountain block, so that now even after erosion has proceeded for some time, it still is higher than the elevation to which Grass Mountain has been recently raised. This suggestion together with the indication that the recent uplifts of the two blocks has been different in amount and possibly different in time indicates alternate uplifting of the two blocks. Such situations apparently are common in and adjacent to the rift zone.

STRUCTURAL GEOLOGY

General Statement

The most striking feature of the area mapped is the San Andreas rift and the manner in which it cross-cuts the structural trend of the bands of older rocks. Movement along the rift, at least in recent times, has been such that the southwest side moved northwest with respect to the northeast side. In the rift zone itself a long narrow stringer of sediments is bordered by faults which show evidence of recent displacements. These lines of recent movement strike approximately N. 65° W. Faults branching from the rift or being cut by the rift, as the case may be, strike approximately east and bound most of the blocks bordering the rift. Several reverse faults and thrusts are present and most of them dip into the rift. Most of the folds strike east approximately parallel to the bands of older rocks. The tectonic blocks in and adjacent to the rift are tilted, distorted, and often brecciated.

Recent faults

Faults so recent that their scarps are essentially undissected are confined almost entirely to the topographic trough marking the San Andreas rift. Many of the associated faults such as those branching away from the trough zone and those bordering the Mohave Desert are also relatively recent, but in very few cases are such faults marked by actual displacements in recent alluvium as are those in the trough zone. Commonly, however, these branch faults are followed by drainage lines. This would result in more rapid erosion of any topographic expression of recent faulting that might occur than would be the case in many sections of the trough zone. In some places these faults showing very recent activity are bordered on both sides by the same lithologic type of rock suggesting no great magnitude of displacement. In general, however, these lines of recent movement appear also to represent much older lines of faulting along which repeated displacements have taken place. In a zone of faulting of this magnitude the most recent of the faults, and, therefore, the most easily traced topographically, would not necessarily represent the major break which is actually a composite of innumerable fractures along each of which movement has taken place at various times.

At the easternmost edge of the area mapped the most prominent recent fault scarp crosses the Southern Pacific Railroad tracks at a point approximately two miles south of Palmdale. In this area the scarp forms the northern border of Palmdale reservoir. The north side of the fault is upthrown so that the escarpment formed, which is approximately 40 feet high, faces south. Anaverde arkose is exposed in the eroded scarp. One of the few places in which recent faulting is actually exposed as a contact between two rock formations is in the road-cut along the Sierra Highway near the northeast corner of Palmdale reservoir (see pl. 20). The movement along this fault is apparently slightly older than that along the fault which forms the scarp just to the south inasmuch as almost all of the topographic expression of the fault has been removed by erosion. The fault

Plate 20. Roadcut near Una Lake showing fault cutting Pelona schist terrace gravels and Anaverde conglomeratic arkose.

A. View showing overall relationship of beds. Note drage of Anaverde beds. Vertical displacement of 20 feet can be seen although little topographic expression of this remains above this relatively recent fault.

B. Detail view of fault. Note nature of Anaverde sediments and Pelona schist gravels.

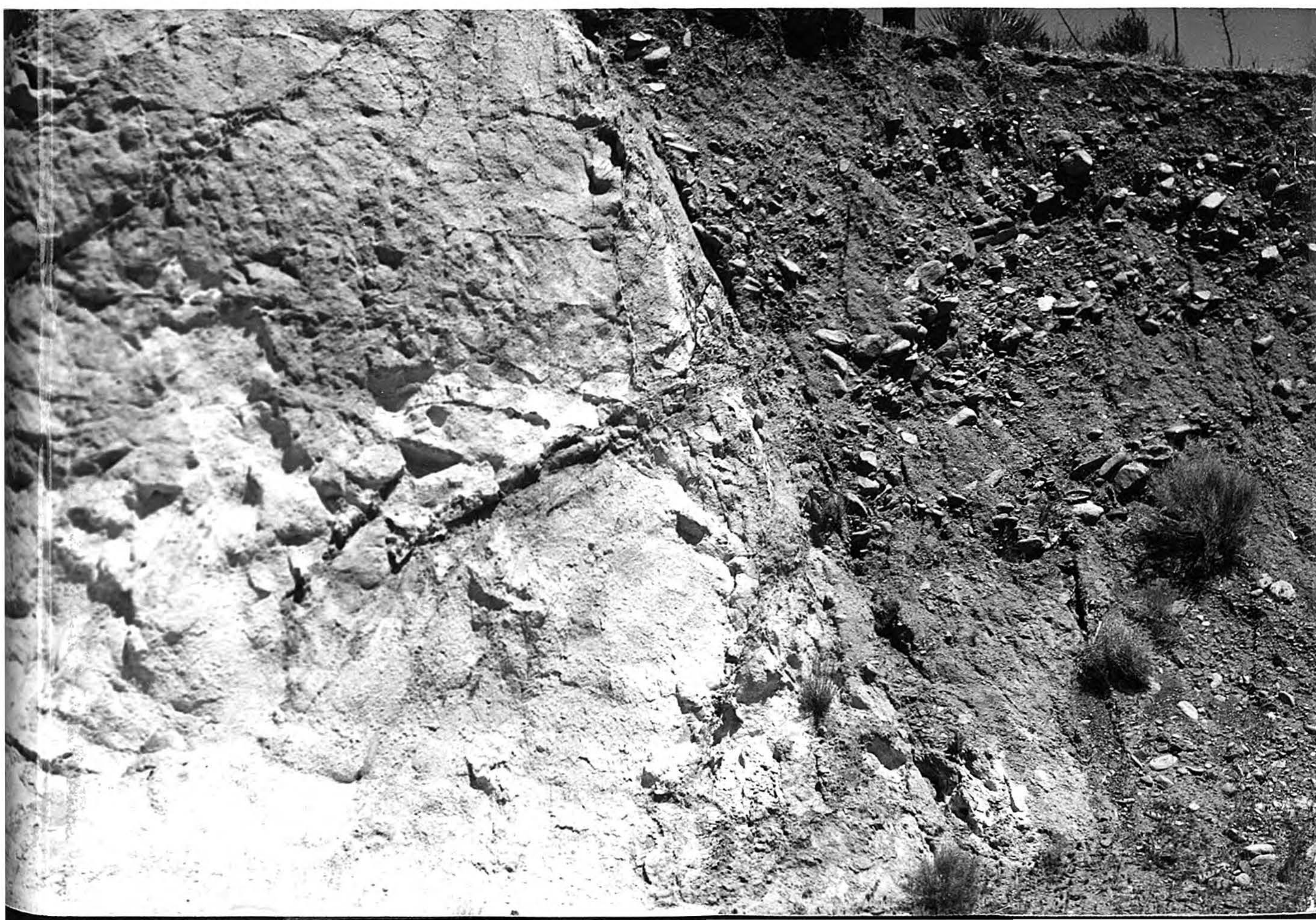
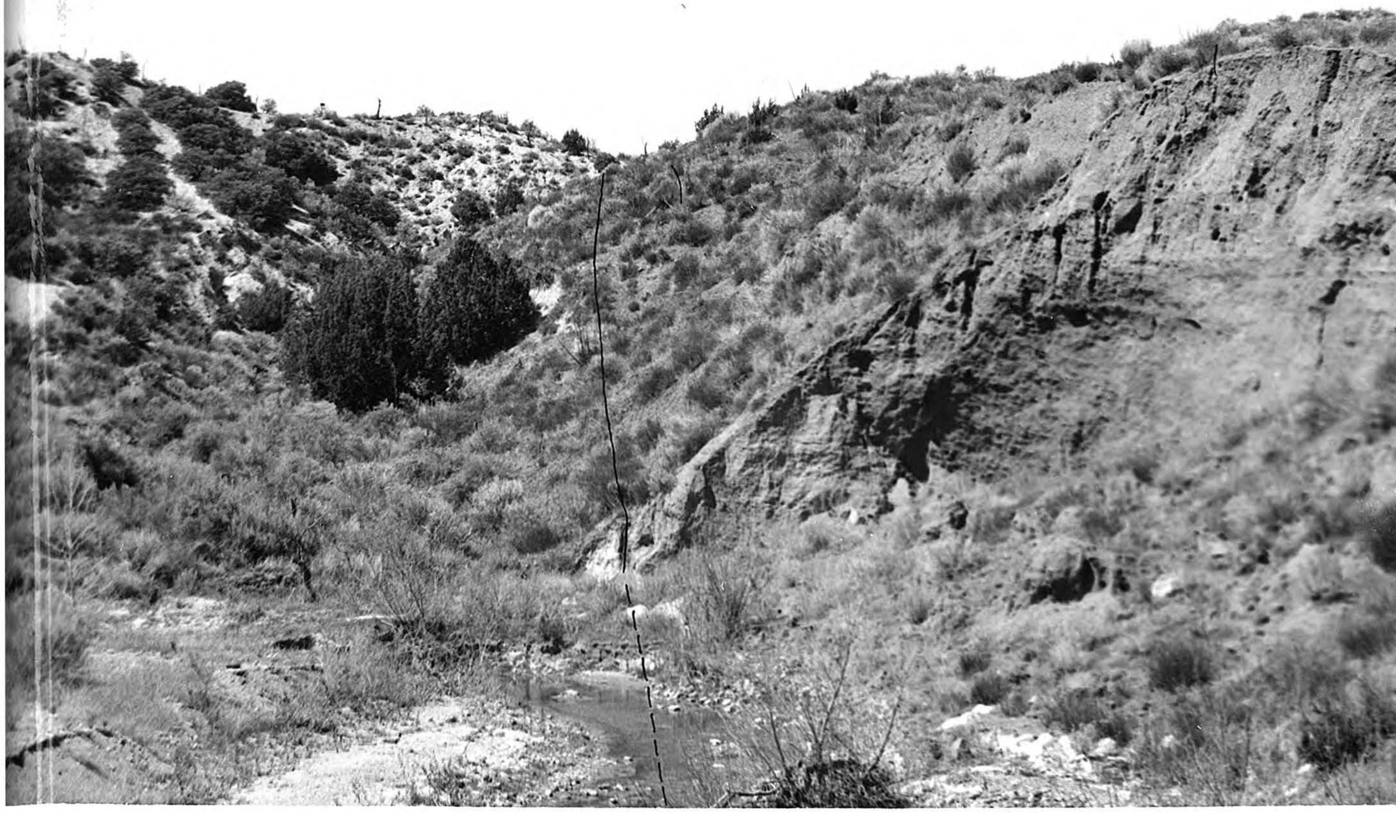


Plate 21. Views of recent fault on north border of center-trough ridge near Ritter Ranch.

A. General view of recent fault showing Anaverde arkose, on left, faulted into contact with Pelona schist terrace gravels on right. Line marks trace of fault. Fifty or more feet of vertical displacement are represented.

B. Close-up view of fault showing gouge zone. Anaverde arkose on left, terrace gravel on right.



brings Pelona schist terrace deposits and Anaverde arkose into contact. The minimum vertical displacement is approximately twenty feet as can be seen in plate 20. The fault is normal, and the north side is the upthrown block.

Approximately one mile northwest from the Southern Pacific tracks the most recent movement appears to have taken place along two branching faults spaced a few hundreds of feet apart. In a few places the ridge can be seen to be composed of fault gouge, and compressional forces possibly caused this plastic gouge materiial to be squeezed upward to form a ridge. Any adjustment taking place would most likely be made throughout the whole body of gouge, over a width of several hundred feet.

At a point approximately one-third mile north of Lakeview where this line of recent displacements forms the south border of Anaverde Valley, the fault scarp faces north. This scarp is considerably more dissected by erosion than the one bordering Palmdale Reservoir and perhaps was formed during an earlier movement along the fault. Anaverde arkose is exposed in this dissected scarp as in the scarp at Palmdale Reservoir. The presence of an upthrown block first on one side and then on the other side of a single fault line is typical in the San Andreas rift.

Continuing to the northwest the fault is hidden by the alluvium of Anaverde Valley, but branching off from the main fault is a fault trace trending more westerly. The scarp along this fault persists for approximately a mile and a half to a point in Anaverde Valley where it finally dies out. This scarp faces north and several sag ponds have been formed along its base, presumably due to subsidence of the block on the north side. During periods of heavy rains these ponds become filled, overflow, and the drainage becomes integrated so that the water flows out Anaverde Valley to the Mohave Desert. For the most part the scarp is formed in gravels derived from the Pelona schist block. Excellent examples of terraces caused by faulting have been formed.

West of the point where the main fault crosses Anaverde Valley, it trends diagonally at a very low angle across a ridge area. It is there marked by small sag ponds, pressure ridges, and valleys differentially eroded in gouge and shattered zones. The south side of the fault in this area was apparently upthrown so that the northern edge of the upper parts of Anaverde Valley was tilted to the south. This has caused a greatly decreased gradient in the streams draining from Sierra Pelona ridge into this portion of Anaverde Valley, and has caused the lower sections of these valleys to be aggraded and "drowned" with alluvium.

In the area where Amargosa Creek flows through a narrow canyon and where the two major blocks of Pelona schist are nearest together, the trace of the recent movement is indistinct, but apparently is represented by a slight break in slope in the terraces underlain by Pelona schist south of the creek, as well as by the valley of Amargosa Creek itself. Anaverde arkose crops out on the south bank of Amargosa Creek in the western part of this constriction of Leonis Valley. From the west end of this narrow part of the valley to and beyond Elizabeth Lake there are two lines along which evidence of recent movement is present. These two fault lines branch from each other and are then separated by distances of from a few hundred feet to approximately one-third of a mile. The portions between the two lines is for the most part a ridge, but in many places where it crosses alluvial areas no relief of the center block is visible. In such places the fault traces can commonly be seen on airplane photographs due to differences in color of the ground along the fault. This difference in color is due to variations of such features as moisture content of the soil and differences in vegetation. In the field alignments of such features are not easily seen.

Approximately half a mile north of Ritter Ranch the northernmost of the two fault lines is exposed in the outbank of Amargosa Creek (see pl. 21). The gouge zone along the fault is 8 - 10 inches wide and the fault is essentially vertical, with Anaverde arkose on the south side and Pelona schist terrace on the north side. This situation is present over the entire vertical range in which the fault is exposed so that a minimum vertical displacement can be estimated at 50 feet. The south side is the upthrown side of the fault. This does not appear to be a case of apparent vertical displacement due to strike-slip movement, which must always be considered in dealing with the San Andreas rift.

At this location and again approximately half a mile west along the fault it can be seen that the Anaverde arkose is probably in contact with Pelona schist. In all other places alluvium or terrace material obscures any possible contact between Pelona schist and rocks of the center-trough ridge. Even at the two localities mentioned a thin veneer of alluvium covers the actual contact. The fact that along this fault recent movement has been such that the center-trough ridge is the upthrown block seems anomalous when it is also realized that Portal Ridge is topographically much higher and apparently a block that is horst-like in nature, and should, therefore, be the upthrown side. Evidence seems to indicate that the center-trough ridge and its bounding faults are essentially secondary features of the rift. The formation of the center-trough ridge is discussed in the section on geomorphology (see pp. 68-70).

For a distance of approximately three miles east of Elizabeth Lake school house the southern of the two recent faults extends diagonally across the center-trough ridge. The fault is bounded on both sides by Anaverde arkose except for a short section just south of Elizabeth Lake school. Here a small wedge of what appears to be Pelona schist is present south of the fault. The Anaverde arkose south of the fault does not extend west of San Francisquito Canyon. This absence of Tertiary sediments and the narrow width of Quaternary sediments south of the fault at the base of Grass Mountain suggests that this block west of the San Francisquito fault and south of the San Andreas rift has been uplifted with respect to the rift trough and the block to the east.

From Elizabeth Lake school to Munz Ranch at the west end of Elizabeth Lake the southern of the two recent faults is marked by scarplets and sag ponds so fresh and undissected as to suggest that the last movement was within historic times, and certainly more recently than on any other portion of the fault in the area mapped. At least some of this may be due to the displacements during the 1857 earthquake. The northern of the two faults is also marked by scarplets though not as clearly as the southern. West of Elizabeth Lake the trace of the rift is confined to a relatively narrow valley and is bordered on both sides by granite. West of the area mapped at the head of Pine Canyon the fault trace crosses a relatively high mountain mass where the floor of the fault trough approaches an altitude of 4,000 feet above sea level.

The principal features of the lines of recent movement may be summarized as follows:

1. In this area the recent faults are marked principally by relatively undissected scarplets, pressure ridges, small sag ponds, dissected gouge zones, and variations in soil and vegetation.
2. Lines showing very recent displacements are confined almost entirely to the trough zone.
3. The lines along which recent displacements show at the surface are in many aspects superficial, and are only representative of the general path of the rift as a whole.
4. Vertical displacements along these lines of recent movement are not indicative of the general dis-

placements along the rift zone.

5. Little evidence was displayed along the lines of recent movement to indicate the nature of the strike-slip displacements. In the few places where outcrops were present on opposite sides of the recent faults, the rocks were of similar types so that no suggestion of the amounts of displacements along these lines of recent movement could be obtained.

Older structures in the rift trough

In addition to the lines of recent displacement there are older faults in the trough zone which parallel the strike of the rift and are probably genetically as much a part of it as are the faults showing recent displacements.

The south side of the granitic ridge approximately 2 miles west of Palmdale is bounded by a fault which has not been active in recent times. It roughly parallels the line of recent movement and is nearly vertical along the western and central portions of the ridge, but along the eastern part the fault dips approximately 75° to the south. South of this section of the fault is a zone of white rock that appears to be gouge-like material derived from a granitic mass. The zone is over four hundred feet wide at its widest part, and its south side is also a fault boundary. Faults striking northeast have offset both of these older faults. If these older faults paralleling the main rift zone ever had strike-slip movement, that movement preceded the cross faulting. Such a situation would then cause later strike-slip displacements to take place along another line of fracturing. Southeast of the mouth of Anaverde Valley the northern of the two old faults skirts the north edge of a ridge composed of Anaverde shale. The Anaverde shale of this block is folded and the axes of the folds strike approximately east diagonally to the trend of the ridge and major faults.

Clark[54/] has shown that this would be the expected orientation of folds associated with a shear couple which would cause strike slip movement of the type displayed along the San Andreas. The compressional components of force which caused the folding would be oriented north and south. It must be pointed out, however, that features as small as these folds may be local phenomena and do not necessarily indicate the nature of the principal forces causing the San Andreas rift.

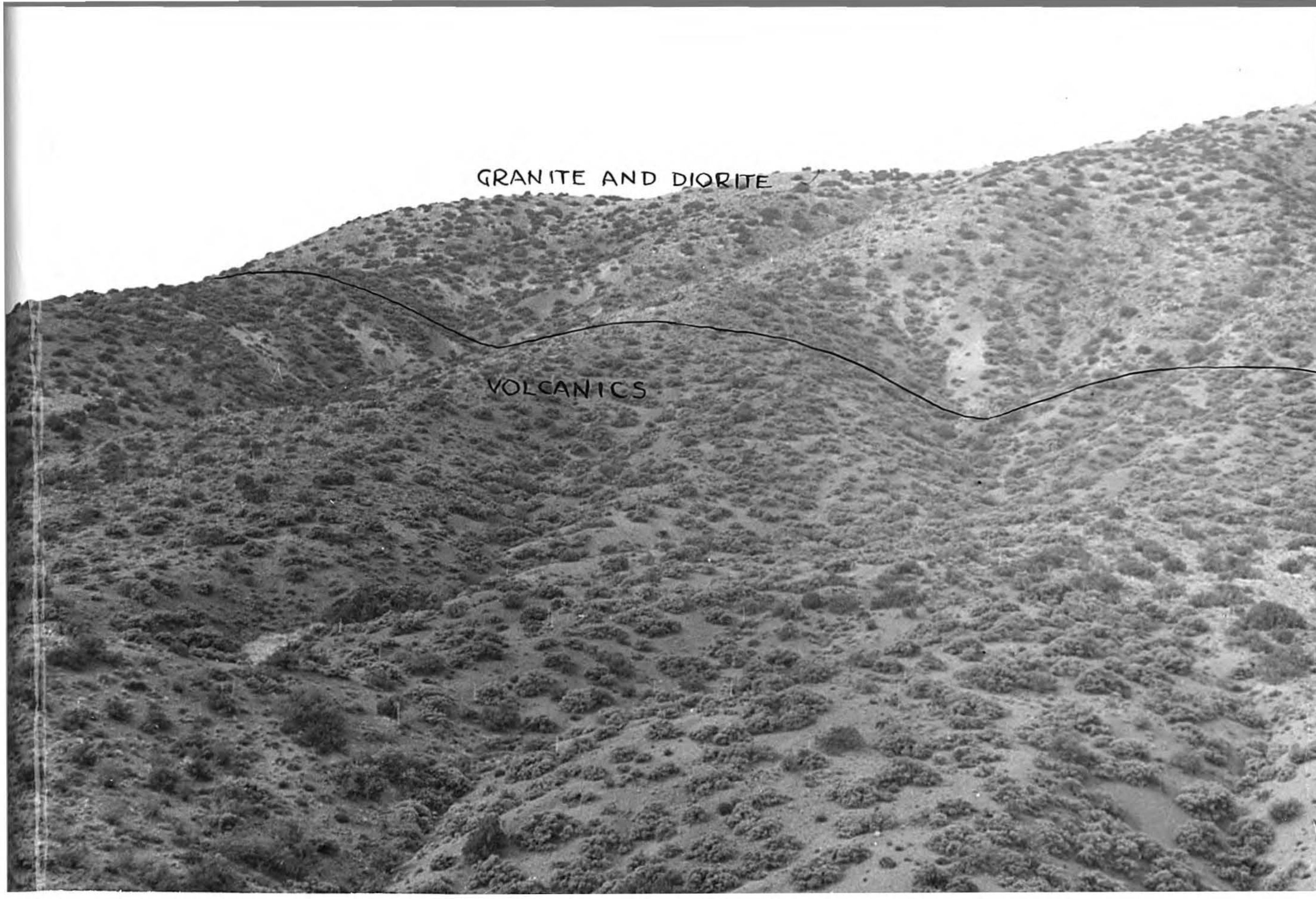
Granite is exposed in the tips of the spurs extending from the ridge toward the desert showing that a band of granite borders the ridge on the north and extends parallel to the rift zone. Between the granite and the shale a thin zone of red arkose is present. The northern contact of the granite ribbon is most likely a fault, inasmuch as the northern contact of the granite in the ridge west of the mouth of Anaverde Valley is a fault contact bringing Anaverde arkose into contact with the granite. All

54/ Clark, B. L., Tectonics of the Coast Ranges of Middle California: Bull. Geol. Soc. Amer., vol. 41, p. 824, 1930.

Plate 22. Views of granite block thrust over Vasquez volcanics.

A. View looking west from a point 2 miles south of Palmdale reservoir showing overthrust plate of granite underlain by Vasquez basalts and andesites. Line marks fault trace.

B. View continuing to left of "A" showing typical outcrops of Vasquez volcanics.


GRANITE AND DIORITE
VOLCANICS

contacts of this body of Anaverde arkose exposed are faults against granite. The Anaverde arkose beds are folded and one syncline is overturned so that the axial plane dips south as though the granite were being thrust northward against the sediments.

Just west of the mouth of Anaverde Valley and approximately one-tenth of a mile north of the line of recent displacement is another old fault striking approximately N. 60° W. It is situated between the red conglomeratic phase of the Anaverde arkose and the buff-colored Anaverde arkose. A cross fault trending northeast also cuts this fault.

Approximately half a mile north of Ritter Ranch, Amargosa Creek cuts across the center-trough ridge exposing a cross section of it. This is one of the few such exposures in the area. The principal rock exposed is pinkish to buff-colored Anaverde arkose which is folded into an asymetrical syncline parallelling the strike of the rift. The dips on the north flank of the syncline are between 10° and 20° to the south and on the south flank of the syncline dips are between 45° and 55° to the north. A mass of Anaverde shale is thrust over the south flank of the syncline in the arkose causing drag in the beds near the thrust plane.

On the north side of the center-trough ridge from a point approximately one mile east to a point approximately five miles west of Leona School the old arkose is thrust over Anaverde arkose and in several places the thrust plane is nearly horizontal.

These features of folding and thrusting described above are all indicative of compressional forces within the center-trough ridge.

The traces of several other faults can be identified in the fault-trough zone south of the principal line of recent movement. Many portions of these can be seen more easily on aerial photographs of the region than from the ground. One fault extends from just south of the Elizabeth Lake-Pine Canyon road approximately half a mile west of the Bouquet Canyon road to the vicinity of Ritter Ranch. It is not very distinct over most of its trace as observed from the ground, but on aerial photographs there is no question as to its location. Another fault trace is present approximately half a mile south of the Elizabeth Lake-Pine Canyon road between 87th Street West and 95th Street West. This fault line was identified only by means of aerial photographs. In line with this fault, and possibly representing a western extension of it, a fault is probably present but covered with alluvium. No trace of a fault was observed, but the elongated nature of the block of granite, parallelling the rift near the central part of Leonis Valley strongly suggests that a fault lies between it and the Sierra Pelona ridge to the south. The western portion of Leonis Valley is also bordered by different types of rocks, and the same fault zone probably extends west to a point near San Francisquito Canyon.

During the mapping of this area of the San Andreas, the feeling was constantly present that for every fault being observed and mapped, there were many more that were buried by alluvium or otherwise concealed or made indistinct, and that the group of faults mapped represented at best merely a sample of the faults actually present. It also seemed quite certain that the principal displacements of the past were by no means confined to the lines which were mapped as individual faults. The broad trough area itself represents more nearly an accurate trace of the San Andreas rift than does any single fault line that may be traced within the trough.

Other faults associated with the rift

There are many structures in the mountain blocks on either side of the trough zone, some of which are almost certainly associated with the rift structures and others which may represent older structures formed at a different time and by different stresses.

In the area of the Vasquez volcanics just west of Soledad Pass and approximately one mile south of Palmdale reservoir several reverse faults are present which dip toward the line of recent displacement along the San Andreas rift. The northern boundary of the Vasquez volcanics is a fault contact along which a dioritic and granitic block has been thrust to the south up and over the volcanics (see pl.22). For a distance of approximately two miles the falt strikes nearly east and varies in dip between 60° to the north and vertical. At its west end the fault swings in a sharp right angle turn to a south strike and has a west dip of approximately 45°. The north-south portion of the fault might actually be considered a separate fault. Slickensides in the thrust-fault zone indicate that the movement was parallel to the dip. The

Plate 23. Views of valleys controlled by faults.

A. View looking east along Hitchbrook fault valley from divide near Elizabeth Lake. Drainage has been captured by stream in first valley on the left.

B. View of San Francisquito Canyon from divide above Elizabeth Lake at head of San Francisquito Canyon.

character of this fault, being a high angle reverse fault in its east-west portion and a low-angle thrust fault in its north-south portion, is the result that could be expected from a force oriented slightly north of west. If the active force were directed from the southeast the thrust would be considered an underthrust. Another east-west trending fault is entirely within the Vasquez volcanics and also has the north side upthrown. Between these two parallel faults the Vasquez volcanics are folded into an asymetrical syncline with its axial plane inclined toward the north and striking east. The fold is probably genetically associated with the thrust fault. The volcanics near the north-south striking thrust are also dragged and tilted to the east.

The south boundary of the Vasquez volcanics is also a fault contact having nearly vertical dip. Presumably the granite which is present to the south of the fault has been faulted upward inasmuch as it is probably older than the volcanics. The Vasquez volcanics are broken along several other faults although none of these is very distinct as there is no contrast of rock types on either side to mark their traces. One fault can be traced over a distance of about a mile and trends N. 30° W. The northeast side appears to be the down-thrown side if the tuff beds exposed in the two blocks represent the same horizon. Just east of the central portion of this fault is a body of basalt which rests on top of vertically dipping, truncated beds of other volcanics. Whether the body represents a flow on an erosion surface or a low-angle thrust could not be ascertained. In view of the facts that the rocks are all apparently of the Vasquez formation and that faults are so numerous, it seems more likely that the situation is a result of faulting.

On the north side of the line of recent movement in the west end of the granitic ridge two to three miles due west of Palmdale another reverse fault is present. There is one good exposure of the fault plane and slickensides indicate that the south side has been forced upward with respect to the north side. The plane of the fault dips approximately 60° to the southwest. There is no indication that it has been active in recent times. It may continue northwest along the southern edge of Ritter Ridge as there is evidence in the Pelona schist of a fault of similar orientation. Slickensides are present on many rock faces of Pelona schist and the truncated spurs facing Leonis Valley suggest faulting. Evidence supplied by slickensides must be used with caution because they are common throughout most of the rocks, even where no distinct faulting has taken place. Practically all of the structural blocks have been so thoroughly shattered that joint planes along which slight movement has taken place are everywhere present.

The Bouquet Canyon fault is the principal fracture branching off on the south side of the rift. It forms the northern boundary of the block of Pelona schist situated south of the rift. At Lincoln Crest, the divide at the head of Bouquet Canyon, the fault trace is marked by a distinct saddle. Half a mile to a mile east of this divide it can be seen that the fault brings the

Pelona schist block and the granitic block into contact. A broad zone of shattered rock and gouge represents the fault. Undoubtedly the fault has determined the location of the upper portion of Bouquet Canyon and the valley east of Lincoln Crest. To the east where the fault follows the north base of the Pelona schist block it lies for the most part under alluvium. At one place a sharp break in slope of a spur of the Pelona schist block probably marks at least a branch of the fault. In the vicinity of Ritter Ranch the trace is covered by Quaternary terrace material and east of that point traces of several faults are present where the Bouquet Canyon fault would join the main zone of recent movement along the San Andreas rift. In this portion the Bouquet Canyon fault trends east or slightly south of east. Approximately two miles from the San Andreas trough zone the Bouquet Canyon fault swings so that its trend is slightly north of east, and at the head of Bouquet Canyon the strike of the fault is approximately N. 70° E. This swing in strike is conceivable due to drag along the San Andreas rift. The junction represents a rather sharp intersection of the two faults which may suggest that the San Andreas is truncating the Bouquet Canyon fault, rather than that the Bouquet Canyon fault is a branch of the rift.

As far as could be determined, the dip of the fault is nearly vertical. The Pelona schist block has apparently received greater elevation, as shown by topographic relief, than the granitic block. As discussed under geomorphology (see p. 77) there probably has been reversal of movement along the fault.

Approximately a mile west of Ritter Ranch a fault branches off the Bouquet Canyon fault and strikes N. 75° W. West of the area mapped Simpson[55] has found that several faults branch from

55/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of the State Mineralogist, California State Mining Bureau, map, 1934.

the Bouquet Canyon fault, the principal one being the Bee Canyon fault.

As has been pointed out by Simpson the age of the displacement is suggested by the age of the rocks in which Pelona schist first appears. Pelona schist detritus is not present in the Vasquez (referred to by Simpson as Escondido) or older formations, but schist fragments are found in the Miocene Mint Canyon formation. The Anaverde formation, presumably Pliocene in age, however, does not contain any Pelona schist. Perhaps the schist fragments present in the Mint Canyon formation were derived from an area not contributing to the Anaverde sediments. Gazin[56] does not report any Pelona schist detritus in the Harold beds of Pleistocene age, but terrace deposits on all sides of the Pelona schist block are composed almost entirely of schist fragments. There is therefore a strong suggestion that the principal uplift along the Bouquet Canyon and other faults bounding the Pelona schist block took place in late Pleistocene or Recent times.

56/ Gazin, C. L., unpublished report.

The other large fault branching at a low angle from the San

Andreas rift approaches and probably joins the rift just west of Elizabeth Lake school. It is marked by a prominent valley and strikes across Portal Ridge at approximately N. 80° E. passing under Hitchbrook ranch. This fault, will, therefore, be referred to as the Hitchbrook fault. As with the Bouquet Canyon fault, Pelona schist forms the block on the south and granite the block to the north. On the north side of Portal Ridge the fault swings more nearly parallel to the strike of the rift. Here it brings rhyolites of the Rosamond formation as well as granite into contact with Pelona schist. At the contact of the rhyolite and the schist the fault appears to dip steeply to the north. The north dip of this part of the fault suggests that it may represent an example of the tertiary thrust as described by Willis.[57/] The uplift of Portal Ridge has apparently taken place principally along a fault located north of the ridge but now covered by alluvium (see discussion under "possible faults"). The age of the fault and the amount of displacement along it are uncertain. Patches of Rosamond volcanics appear to be in place on top of the Pelona schist of Portal Ridge suggesting that the ridge was uplifted and eroded prior to Rosamond times, and yet Pelona schist is not present in the later Pliocene Anaverde formation adjacent to the block. This introduces the possibility that the volcanics resting on top of Portal Ridge were carried there along a thrust. No other evidence

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57/ Willis, Bailey: San Andreas Rift, California: Jr. Geol., vol. XLVI, p. 802, 1938.

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indicates this to be the case, however. No evidence of displacements as recent as those in the trough is preserved along the trace of the Hitchbrook fault.

A third fault is present in San Francisquito Canyon. It is not, however, an extension of the San Francisquito fault in lower San Francisquito Canyon which Simpson 58/ describes as being a low-

58/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of the State Mineralogist, California State Mining Bureau, p. 405, 1934.

angle thrust. In the area mapped the fault is traced entirely by geomorphic evidence, principally valleys and saddles.

Possible faults

Many faults almost certainly are present in the area studied that have not been included on the geologic map. As has been stated previously in this report, the faults showing recent movement are probably representative of the complex system of faults which make up the rift zone. For example, in the report on dam sites of this region by Hill 59/ the area around Elizabeth Lake was

59/ Hill, R. T., Report on the Geology of the Proposed Bouquet Canyon, Elizabeth Lake and Antelope Valley Dam and Reservoir Sites: unpublished manuscript, map after page 74, 1928.

mapped on a reconnaissance scale, and a great many more faults are mapped as recognizable than on the present map. The probable and possible faults, are, of course, extremely important in consideration of dam sites and it would be wrong from a practical standpoint to overlook even the slightest suggestion of the presence of a fault. In the present study, however, the principal interest was in obtaining a structural picture and history of the rift, and so for the most part only relatively certain faults whose traces could be determined with some degree of accuracy were mapped. It was felt that a more accurate sample could be obtained in this way, inasmuch as the complete picture could not be obtained.

The principal line of uplift which has not been mapped as a specific fault lies probably a mile or more north of Portal Ridge and approximately parallels the trend of the ridge. As is described in the section on geomorphology, Portal Ridge has been uplifted with respect to the Mohave Desert floor. There is no physiographic expression to indicate the exact location of the fault, except on one aerial photograph taken in the vicinity of Palmdale there appears to be an alignment of vague spots which may represent the trace of this fault. This line crosses Sierra Highway approximately 1000 feet south of the junction of Avenue R and the highway.

The borders of the gneissic block a few miles southwest of Palmdale reservoir may be fault contacts. No fault zone was observed, no geomorphic evidence of faulting was found, and little other than that the strike of the contacts is parallel to the large branch faults suggested that the contacts are faults. In fact, one road cut near the south contact of the gneissic body exposed numerous granitic dikes intruded into the gneiss thus suggesting that the contact is an intrusive contact.

At the mouth of Leonis Valley the south slope of the Pelona schist block of Ritter Ridge is oversteepened and may represent a fault scarp dipping steeply to the south. Hanging valleys are present above the scarp-like portion of the slope. It may represent a continuation of the reverse fault which is present in the granite block on the southeast side of the mouth of Leonis Valley. The possibility of a fault striking out Leonis Valley into the Mohave Desert as has been mapped by Simpson 60/ is lessened by the presence of Pelona schist on the

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60/ Simpson, E. C., Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California: 13th report of the State Mineralogist, California State Mining Bureau, map, 1934.

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east side of the mouth of Leonis Valley. The granite is apparently in intrusive contact with the schist at this point. The lower portion of Leonis Valley is probably underlain by a gouge zone and a network of faults. This group of faults is represented on the map as a single fault indicated as "location uncertain".

In the block situated between Bouquet Canyon and San Francisquito Canyon several valleys are present which suggest control by faults. Two valleys in the eastern half of this block cross the block at about N. 20° - 30° E. and their bottoms are filled with alluvium. The breadth of these valleys suggests that they may have been formed in an easily eroded zone such as a fault zone. Other possibilities are discussed under "geomorphology". A third valley whose mouth is about 4 miles northwest of the mouth of

Bouquet Canyon is unusually straight, strikes approximately N. 60° E., and strongly suggests fault control. The fourth valley is similar to the third mentioned in having a northeast strike. It is in a line with and north of the upper part of Dowd Canyon which drains southwestward into San Francisquito Canyon. Other features of this valley are described in the section on "geomorphology".

Another valley which suggests fault control is the one followed by the Elizabeth Lake - Willow Springs road where it crosses Portal Ridge just northeast of Elizabeth Lake.

To summarize the situation regarding the other faults associated with the lines of recent displacements the following may be said:

The two principal faults which branch from the San Andreas rift, the Bouquet Canyon and the Hitchbrook fault, show no indication of strike-slip movement, though little evidence to the contrary was found either. The Hitchbrook fault curves in a fashion that would be difficult to accommodate strike-slip movements. Relatively recent uplift of the Portal Ridge block is indicated by terraces on its crest and the youthful nature of dissection on its flanks, especially the north flank. This uplift probably took place along a fault which is now covered by the alluvium of the Mohave Desert. None of these faults show any effects of very recent displacements such as fault scarplets, sag ponds, and pressure ridges. However, the frequency and amount of displacements along such subsidiary faults, if they are genetically associated with the rift, would not be expected to be as great as along the main rift zone.

The situation in this area, therefore, is possibly similar to that described by Taliaferro in the area north of Parkfield in that the branch faults show no recent scarps and have had essentially vertical displacements. The situation, however, certainly is not clear enough to state emphatically that these branch faults are of an earlier period of faulting and are not genetically related to the rift.

Structure of metamorphic rocks

The schistosity of the Pelona schist parallels the bedding of the original sediments. The rocks, ranging from metamorphosed limestones and quartzites to mica schists, have been thrown into relatively open folds. In detail the beds or planes of schistosity, are in a complicated system of small crenulations and drag folds. The axes of the folds in Portal Ridge strike approximately N. 80° W. A cross section of one of these folds can be seen on the Goode Hill Road which crosses Portal Ridge. The axial plane of this large syncline dips to the north. The schistosity on the north side of the syncline dips approximately 70° or 80° to the south, whereas the dips on the south side are approximately 30° to 40° to the north.

In Sierra Pelona Ridge the schistosity strikes more nearly N. 70-80° E., as does the gneissic structure in the block south of the Pelona schist.

Problem of displacement along the San Andreas rift

Since the recognition of the strike-slip displacement which took place at the time of the San Francisco earthquake of April 18, 1906, investigators have reported several strike-slip displacements along other portions of the San Andreas rift. An excellent example of such displacement accompanied the earthquake of May 18, 1940 and has been described by F. P. Ulrich.[61] Displacements at

61/ Ulrich, F. P., The Imperial Valley Earthquake of 1940: Bull. Seis. Soc. Amer., vol. 31, pp. 13-31, 1941.

that time were as great as 14 feet. Gutenberg[62] has shown that

62/ Gutenberg, Beno, Mechanism of Faulting in Southern California Indicated by Seismograms: Bull. Seis. Soc. of Amer., vol. 31, no. 4, pp. 263-302, 1941.

seismographic evidence indicates a similar type of displacement is common on many faults in southern California. Gutenberg's investigation was principally a test of the rebound theory, but the evidence obtained in support of that theory also showed the tendency of other faults in southern California to have strike-slip displacements with movements like the San Andreas.

It is certain, therefore, that at least at present the displacement along the San Andreas rift is such that the southwest side moves northwest with respect to the northeast side. Recorded displacements give some idea of the rate at which movement is taking place along the line of the San Andreas rift. During the San Francisco earthquake of 1906 accurately measured strike-slip displacement varied in amount between 2 and 15 feet[63/] (maximum of

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63/ Lawson, A. C. and others, The California Earthquake of April 18, 1906: Carnegie Inst. of Wash., Pub. no. 87, p. 133, 1908.

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21 feet was reported from one locality) over a distance of approximately 190 miles. In 1857 in the Tejon Pass region displacements of over 30 feet took place and the effects of the quake were visible for a distance of over 200 miles along the rift. In the earthquake of 1868 in the San Francisco area strike-slip displacements ranged up to 10 feet.[64/] In the recent earthquake of 1940 in the

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64/ Lawson, A. C. and others, The California Earthquake of April 18, 1906: Carnegie Inst. of Wash., Pub. no. 87, p. 133, 1908.

Imperial Valley area, displacements averaged approximately 3 or 4 feet over a strike length of 40 miles. From these few cases a suggestion of the order of magnitude of displacement and rate of displacement may be possible. A conservative estimate might be to assume an average of 5 feet displacement over a 100 mile length of the fault each 50 years. With that frequency and amount of displacement one could expect the rocks on opposite sides of the approximately 700 mile length of fault in California would be offset 5 feet in 350 years. A mile displacement would, therefore, accumulate in a period of about 400,000 years. If the rift has been active since mid-Tertiary times or about 30,000,000 years, then approximately 75 miles offset could result. Extrapolation to such a degree, of course, is dangerous reasoning, but even so, it vividly indicates the amount of displacement that is possible. It also suggests the extreme effects that might be produced in only a relatively short lifetime of fault activity, so that the severity of disarrangement along the rift does not necessarily indicate great age.

Gazin[65/] has described the distribution of terrace deposits which suggest displacement of 5 - 6 miles since late Pleistocene times. Offset of streams in the area just east of that mapped show approximately a mile and a half displacement. These displacements are of approximately the same order of magnitude per unit of time as estimated above; in fact, the estimate would appear to be slightly too conservative.

There are many suggestions of great horizontal displacements, but other than offset of streams and the terrace deposits described by Gazin, practically no direct evidence has been observed to show the exact amount since any specific instance in geologic time. This very lack of structures or rock types that can be matched on either side of the rift to show offset is in itself a strong argument in favor of great displacement. In the area studied for this report a "shoe string" of Pliocene Anaverde sediments over 20 miles long is present in the fault-trough zone. The material of the sediments is chiefly detritus from a granitic mass, whereas the rock masses bordering the "shoe string" of

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65/ Gazin, C. L., unpublished report.

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sediment and from which the sediments would be expected to be derived are schists and gneisses. This situation is present over a distance of more than twenty miles. There are apparently only two possible ways that this might come about. First, the blocks on either side may have had such a structure and have been involved in vertical movements ofsuch a nature as to expose schist and gneiss at present where in Pliocene times granite was exposed. This is a difficult situation to imagine, and contradicting this, on the Pelona schist of Portal Ridge Rosamond volcanics are apparently in place on an erosion surface, suggesting that as early as Miocene times Pelona schist was exposed. The alternative is that horizontal displacements have carried these sediments along the rift for a distance of more than 20 miles. The granite of the west end of Portal Ridge and of the Pine Canyon district is petrologically similar to the granite material of the Anaverde conglomerate and arkose and may represent the source of the sedimentary material. It is difficult, however, to understand the mechanics of a displacement that could carry such a long narrow string of sediments a distance of over 20 miles and still leave it essentially a single unit.

Noble's[66/] suggestion of a correlation of sediments in the

66/ Noble, L. F., The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California: Bull. Seis. Soc. Amer. vol. 17, pp. 25-39, 1927.

Cajon Pass area with beds of the Punch Bowl formation indicating a horizontal displacement of approximately 24 miles has been somewhat weakened by the finding of vertebrate remains which indicate a different age for the two sedimentary blocks. On the basis of equine material obtained from the two areas the Cajon beds can be considered no younger than upper Miocene, but the Punch Bowl beds appear to be at least lower Pliocene in age.[67/] The beds probably

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67/ Stock, Chester, oral communications.

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were formed under similar conditions of environment and, therefore, are of similar lithologic nature.

As has been stated previously in the report, Taliaferro[68/] has

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68/ Taliaferro, N. L., Geologic History and Structure of the Central Coast Ranges of California: California Division of Mines, Bull. 118, pp. 159-161, 1943.

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described a region in central California where offset of structure limits the possible horizontal displacement along the rift to under one mile, whereas Gazin has shown good evidence in the area east of Palmdale that displacements are at least 5 or 6 miles. In the area studied Anaverde sediments are found on both sides of the most prominent line of recent displacement. Certainly no enormous displacement has taken place along this extremely recent line or the patches of Anaverde would be separated. As has been pointed out previously, however, these lines of extremely recent displacement appear to be relatively superficial features as compared to the whole rift zone, that is the quarter to half a mile width of brecciated material, gouge, and faults within the general trough zone.

In the area studied an anomalous situation is present in that the east end of Portal Ridge bordering the San Andreas rift is composed of Pelona schist. The west edge of the mass of Pelona schist bordering the rift on the south side is 9 miles east of the west edge of the Pelona schist block in Portal Ridge. The orientation of the structures in the two blocks is essentially the same. These facts introduce the possibility of reversed direction of strike-slip displacement at an earlier time in geologic history. It is, however, probably incorrect to compare the edges of the blocks only at the rift zone. Actually the western limit of the Pelona schist block south of the rift is over ten miles west of the western tip of the Pelona schist block north of the rift. As has already been shown the exposure of Pelona schist as it essentially is today came about in late geologic time, probably as late as Pleistocene times and no earlier than Miocene time. The present areal distribution is, therefore, not an old feature and is probably mostly a result of vertical uplifting of the schist blocks with subsequent stripping and not of horizontal displacement along the rift. Considering these facts, it is not hard to imagein that the distribution represents more apparent displacement than it is indicative of actual reversed displacement.

It is highly possible that vertical displacements have obliterated any relatively old patterns of aerial distribution of rocks which might have afforded a key to the horizontal displacements.

Another situation suggesting an anomalous displacement is the distribution of Anaverde sediments with respect to the line of recent movement. The westernmost occurrence of Anaverde sediments on the south side of the principal fault showing recent displacement is approximately two and a third miles east of the westernmost outcrop of Anaverde sediments from its northern edge.

This amount of contradictory evidence introduces the possibility of different histories along various parts of the rift, but when the continuity of the rift is considered, it seems as though the whole rift would be the result of a single cause and that the history of all portions, therefore, would be essentially the same. In contradiction of this idea Clark[70/] has made the following comment:

70/ Clark, B. L., Tectonics of the Coast Ranges of Middle California: Bull. Geol. Soc. Amer. vol. 41, p. 819, 1930.

"The writer is convinced that there is no continuous north-south fault-zone along which a general movement of the earth's crust has taken place, such as has been postulated for the San Andreas fault-zone by different writers, but that horizontal movements are the result of the shifting of individual blocks, and the resulting stresses are taken up in other adjoining blocks either by folding or by shearing."

The problem of the amount of strike-slip displacement along the San Andreas rift is certainly far from being solved. The principal suggestions may be summarized as follows:

1. All investigators are apparently in agreement that relatively recent movement has caused strike-slip displacements of as much as a mile. This is shown principally by

offset of stream channels. The southwest side of the rift has moved northwestward with respect to the northeast side.

2. Taliaferro and others believe offsets are no more than one mile in the area north of Parkfield.

3. Noble and others have suggested offsets of the order of several tens of miles.

4. Gazin has found evidence of strike-slip displacements of 5 or 6 miles in the Pearland quadrangle.

Evidence from the area studied for this report includes the following:

1. The thin stringer of Anaverde sediments, over 20 miles long and a fraction of a mile wide, has possibly been dragged some 20 or more miles, because over that distance the rocks bordering the sediments are different than the material in the sediments.

2. The distribution of Pelona schist suggests horizontal displacements of 9 miles in the opposite direction to that expected. This offset is possibly only apparent and a result of vertical movement.

3. The western edges of the blocks of Anaverde sediments on the north and south sides of the most recent fault also suggest displacements of the south side to the east, but again this distribution very likely is due to vertical movements and subsequent erosion.

4. In this area is situated the only visible source of

the Pelona schist detritus which Gazin found 6 miles to the east in Quaternary terrace deposits.

The antiquity of the rift

The age of the San Andreas rift is not known with any certainty. Suggestions made by various investigators range from pre-Tertiary to late Pleistocene as a maximum age of the rift. Willis[71/] and Noble[72/] among others have postulated that the rift

71/ Willis, Bailey, San Andreas, Rift, California: Jr. Geol., vol. XLVI, no. 6, p. 810, 1938.

72/ Noble, L. F., The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California: Bull. Seis. Soc. of Amer., vol. 17, pp. 25-39, 1927.

was in existence as early as Eocene times. The chief difficulty, as Taliaferro[73/] has pointed out is in distinguishing the San Andreas

73/ Taliaferro, N. L., Geologic History and Structure of the Central Coast Ranges of California: California Division of Mines, Bull. 118, pp. 159, 1943.

rift and separating it from other faults. Taliaferro has essentially limited his definition of the San Andreas fault system to include only those faults which show recent displacement and have strike-slip movement. He recognizes a slightly earlier period of diastrophism, probably late Pliocene to mid-Pleistocene in age, when compression and thrusting typified the conditions of movement along the fault. Besides both of these periods of activity, Taliaferro points out that a normal fault of large displacement followed essentially the same line as the present strike-slip movement.

This concept of age, then, is not so extremely different from that of Willis' and Noble's who merely suggested diastrophism along the line of the rift at an early time, but offered no proof of its being of a strike-slip nature. It becomes essentially a matter of definition, as to what portion of the events that have occurred along the line of the San Andreas rift should be included under the heading of, let us say, the San Andreas phenomenon. If study is centered on the phenomenon of strike-slip displacement alone then attention must spread to include the strike-slip movements of other faults. Buwalda[74/] has recognized strike-slip move-

74/ Buwalda, J. P., Recent Horizontal Shearing in the Coastal Mountains of California: Proceeding Geol. Soc. Amer. p. 341, 1936.

ments on several other faults in California. Seismic evidence also indicates that such displacements are common in the southern California region.[75/] On the other hand, if there has been a prominent

75/ Gutenberg, Beno, Mechanism of Faulting in Southern California Indicated by Seismograms: Bull. Seis. Soc. of Amer., Vol. 31, p. 299, 1941.

line of demarcation essentially in the position of the line of the San Andreas rift for a long period of geologic time, there may have been a variety of movements take place along it, but the individual events would be merely subsidiary to the underlying cause of the presence of the feature itself. The ancient displacements along the line of the rift, then, even if of a different type than those of recent times constitutes a feature of antiquity of the rift zone, and the age of the strike-slip type of movement may then be considered a separate problem.

In the area studied the strike-slip movement may or may not be old. No evidence was observed to prove one case or the other. The associated faults, although showing little physiographic evidence of recent displacements, were probably active in mid-Pleistocene at which time the block of Pelona schist was apparently elevated.

There is a suggestion that the branch faults have even greater age. In the gneissic mass bordering the Pelona schist block on the south a mafic zone trends northeast approximately parallel to the contacts of the gneissic body and the general strike of the branch faults. This mafic zone probably represents the metamorhic phase of a dike of basic composition, and since it is parallel to the branch faults, suggests that the orientation of this structural trend was determined prior to its intrusion. Inasmuch as the dike rock is now completely metamorphosed, considerable age, probably Mesozoic or earlier, is suggested.

To summarize:

The problem of antiquity involves a specific definition of the San Andreas rift. There probably have been old periods of diastrophism along this general line, but they probably did not all display strike-slip movements. The strike-slip movements may have had a relatively recent beginning.

Mechanics of the rift and its relation to earth structure

Considering the present lack of agreement of interpretations of the time and space relationships of various structural features of the rift, an analysis of the mechanics of the forces causing the features seems somewhat premature.

On the assumption that the faults, and structures trending at an angle to the rift are a result of the same forces causing the rift, Bailey Willis[76/] has analyzed the nature of the mechanics which could possibly give this structural relationship. Willis postulates essentially north-south rotational stresses which result in a shear couple causing the strike-slip displacements on the rift as well as compressional stresses which cause reverse faults and folds having an east-west orientation at right angles to the directions of the primary forces. Clark[77/] has also described and diagrammed somewhat the same relationship of folds and cross structures to the strike-slip shear.

Such an interpretation presents a relatively simple picture. If, on the other hand, the cross structures are older and of dif-

76/ Willis, Bailey, San Andreas Rift in Southern California: Jr. of Geol., vol. XLVI, no. 8, pp. 1017-1056, 1938.

77/ Clark, B. L., Tectonics of the Coast Ranges of Middle California, Bull. Geol. Soc. Amer., Vol. 41, pp. 748-828, 1930.

ferent genesis than the rift itself, as Taliaferro[78] suggested,

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78/ Taliaferro, N. L., Geologic History and Structure of the Central Coast Ranges of California: State of California Division of Mines, Bull. 118, pp. 159-161, 1943.

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a much more complex history of tectonic forces must be represented by these structures.

One basic concept which Willis apparently assumed in his analysis, and which many other writers have also assumed, is that the forces originate in rather restricted zones and are applied essentially to the edge of a surface plate which then transmits the stresses to the affected areas. Such statements of Willis as the following suggest this concept:

> "---if there were any irregularity of development, we would anticipate that the one nearest the application of the pressure would show the maximum effect; ---"

and:

> "The rift --- appears to have developed in the zone where their opposed bodies acted like the jaws of a vise."

Presuming rocks had strength enough to transmit stresses over great horizontal distances, and several investigators have indicated that rocks have not such strength, it would be expected that stresses would be relieved along a single large break. Instead of that being the case in southern California, Buwalda[79] has des-

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79/ Buwalda, J. P., Recent Horizontal Shearing in the Coastal Mountains of California: Proceedings Geologic Society of America, p. 341, 1936.

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cribed faults in widely separated areas which show strike slip displacements similar to that found along the San Andreas rift. Gutenberg[80/] has described seismographic evidence which indicates

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80/ Gutenberg, Beno, Mechanism of Faulting in Southern California Indicated by Seismograms: Bull. Seis. Soc. Amer., vol. 31, no. 4, pp. 263-302, 1941.

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that many shocks from various points in southern California apparently accompanied displacements having movements similar to that displayed at the surface along the rift.

Such a wide distribution of faults having essentially the same type of displacement would suggest that stresses were applied sub-equally throughout a wide area. This could be accomplished from below the crustal block, possibly by drag on the base by subcrustal flowage. Griggs[81/] has postulated such subcrustal cur-

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81/ Griggs, David, A Theory of Mountain-Building: Amer. Jr. of Sci., Vol. 237, no. 9, pp. 611-650, 1939.

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rents and has described a possible interpretation of wedge-like mountain masses by such a process. He dealt principally with situations in which two crustal blocks would be dragged toward each other. Strike-slip displacements might be the result of a streamlike current which had different velocities at different points across its width. This would create local stresses at various points in the overlying plate which would all be capable of producing strike-slip displacements. A line of sudden change in velocity would create a "master fault" such as the San Andreas. A "rip line" as in water currents, where two currents of different speeds and direction of motions meet, might be the nature of the line of change which would cause the San Andreas rift. Possibly a single current might be flowing past a relatively stable mass. In the present case the Sierra Nevada Mountains might act as the relatively stable mass, inasmuch as seismographic[82/] evidence indicates that the Sierra Nevada Mountains have "roots" which extend to greater depths than the adjacent crustal units in California. The earthquake foci along the rift average approximately ten miles[83/] depth which is normal for the origins of shocks in the southern California area. In relation to the present activity of various faults in southern California, it is interesting to note that the San Andreas rift is the locus of very few earthquake shocks at present.[84/] Perhaps this is due to the recency of relief of stresses along the rift which took place during the 1857 and later displacements.

82/ Gutenberg, Beno, Seismological Evidence for the Roots of Mountains: Bull. Geol. Soc. Amer., vol. 54, pp. 473-498, 1943.

83/ Gutenberg, Beno, oral communication.

84/ Gutenberg, Beno, oral communication.

Wallace, Robert E.
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CONTRIBUTIONS TO PALEONTOLOGY

VI

A Miocene Mammalian Fauna from Beatty Buttes, Oregon

Robert E. Wallace

With six plates and one text figure

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ROBERT E. WALLACE

With six plates and one text figure

[ISSUED JANUARY 25, 1946]

CONTENTS

A Miocene Mammalian Fauna from Beatty Buttes, Oregon

Introduction

Fossil mammalian remains were first discovered in tuff beds of the Beatty Buttes area in 1938 by Dr. Warren D. Smith and Lloyd Ruff, of the University of Oregon. Shortly thereafter, the occurrence was brought to the attention of Dr. Chester Stock by Dr. Smith. During the summer field seasons of 1940 and 1941 collecting parties from the California Institute of Technology examined the region and obtained much additional material.

The original locality at Beatty Buttes lies approximately 22 miles southwest of Blitzen, Oregon, and nearly 100 miles south of Burns, Oregon (see map, fig. 1). Here the tuff beds in which the fossil mammals are found border the north side of the volcanic cone of Beatty Buttes. Most of the material was collected in an area lying approximately 5 miles from the highest point of the cone and nearly due north of it. At a second locality, here designated Corral Buttes, occur fossiliferous deposits that are unquestionably like those exposed at Beatty Buttes. Fossils were discovered in these beds by K. A. Richey and J. C. Stock in 1941. Corral Buttes lies approximately 20 miles northwest of Beatty Buttes.

The author is indebted to Dr. Chester Stock not only for suggesting the problem, but also for valuable advice and criticism during the progress of the study. The field party of 1940 was under the supervision of Robert Leard, and that of the following year was led by K. A. Richey. The assistance and advice kindly given by E. L. Furlong and K. A. Richey are deeply appreciated. Dr. Robert W. Wilson furnished information which aided in the identification of some of the fossil rodents. Dr. W. D. Smith, who is familiar with the geology of the region, made many helpful suggestions. The illustrations were brought to finished form by David P. Willoughby.

Previous Work in Region

Geological investigation in southeastern Oregon has been for the most part of a reconnaissance type. Only a few areas have been mapped in detail geologically. In many instances even base maps are difficult to obtain.

Following an account in 1927 of the geology of Steens Mountain by W. D. Smith, Fuller in 1931 published the results of a study of the sequence of volcanic rocks in this region and included information regarding the geologic relations in the surrounding area. A paper by Piper, Robinson, and Park (1939) is concerned with the water resources of Harney Basin and sets forth the geology of the region about Malheur Lake, north of Beatty Buttes. In a much earlier paper, Waring (1908) considered the geology and water resources of an area

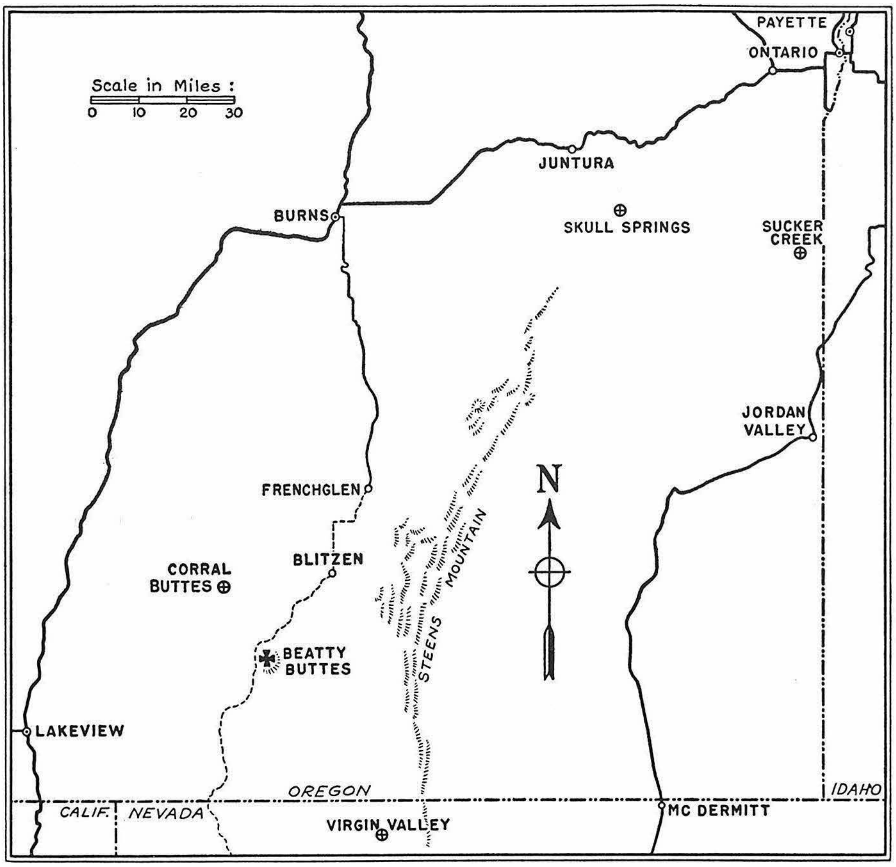

FIG. 1. Map showing the location of Beatty Buttes and Corral Buttes in relation to known fossil vertebrate localities in southeastern Oregon and in Nevada.

adjacent to Lake Abert and west of Beatty Buttes. Russell (1928) reported on the geology of the Warner Range in northeastern California.

Vertebrate remains of Miocene age were recorded from Sucker Creek, Oregon, by Scharf (1935); from Skull Springs, Oregon, by Gazin (1932); from the Mascall formation, Oregon, by Merriam (1907), and from Virgin Valley, Nevada, by Merriam (1911); from the Payette formation, Idaho, by Buwalda (1924); and from the Upper Cedarville formation, California, by Russell (1928).

Fossil floras are known from the Alvord Creek formation (Fuller, 1931), Upper Cedarville formation (Russell, 1928), Payette formation (Chaney, 1922), and Mascall formation (Chaney, 1925).

GEOGRAPHICAL AND GEOLOGICAL RELATIONS

Beatty Buttes is a volcanic cone rising to a height of 7916 feet above sea level. It stands several thousand feet above a broad alluvial plain which is bordered on the east by the high Steens Mountain and on the west by the Hart Mountains. The climate of the area is arid and most of the vegetation is of a grassland and brush type. One of the largest of the few remaining herds of pronghorn antelope roams these plains. Other characteristic members of the animal community are the coyote, jack rabbit, and rattlesnake.

The fossil specimens were found in a series of acidic tuffs which form small buttes of the order of 100 to 150 feet in height surrounding the base of the main volcanic cone. Alluvial terraces composed of obsidian cobbles commonly cap these buttes, though near the volcanic cone itself basic flows cap the tuff beds. These flows apparently were extruded from the cone. The glass and pumice fragments of which the tuff is predominantly composed has an index of refraction ranging between 1.48 and 1.50. This would indicate a silica content of approximately 70 per cent (George, 1924).

The tuff beds show only slight deformation. Southerly dips of 5 to 8 degrees were the greatest divergence from the horizontal observed by the author. Elevation of the strata since the obsidian terraces were deposited has resulted in dissection of the tuff beds, forming the badlands in which the fossil material is exposed.

On the basis of a flora obtained from the Alvord Creek beds in Steens Mountain, Chaney (Fuller, 1931) believed that a correlation between these deposits and the Mascall formation was possible. This would likewise suggest a correlation with the Beatty Buttes horizon, since the fauna from the latter is nearly related to the Mascall assemblage. The Alvord Creek beds, however, lie below the Steens Mountain basalt, whereas the Beatty Buttes tuffs appear to rest on these basalts. This relation may be explained on the assumption that the resemblance between the floras of Alvord Creek and Mascall reflects in the main similar ecologic conditions without necessarily indicating an exact time equivalence. On the other hand, the extrusion of the basalt series may not have required a long time. Perhaps the fossiliferous deposits at Beatty Buttes are to be correlated with a higher part of the Mascall formation rather than with the plant-bearing Alvord Creek beds.[1] Russell (1928) described the Upper Cedarville formation from Warner Valley to the west of Beatty Buttes and stated that a fossil flora from it was regarded by Chaney as comparable in age to that of the Mascall. Thus the Upper Cedarville formation may be closely related in time to the Beatty Buttes horizon. Fossil vertebrates are known from the Upper Cedarville formation near Alturas, California, but no list of mammals has been published.

The stratification of the tuff beds does not suggest extensive fluviatile deposition, but rather an accumulation of the sediments in relatively quiet water or subaerially, or possibly under both conditions. The fossil remains suggest exposure to the weather before burial, not only by their fragmentary state of

[1] Since the above was written, Axelrod (in Chaney, Condit, and Axelrod, Pliocene Floras of California and Oregon, Carnegie Inst. Wash. Pub. 553, 1944) concludes that the flora from the Alvord Creek formation is Lower Pliocene. The deposits would, therefore, be distinctly younger than those at Beatty Buttes, and this difference in age would imply a somewhat different interpretation of the geologic history of the region between the two localities.

preservation, but also by the fact that a number of bones show the gnaw marks of rodents. Many of the fragments have their edges completely rounded by this type of attrition. Although evidence of rodent gnawing is often seen in fossil materials, the frequency of occurrence of this type of marking at Beatty Buttes suggests some specific cause. Absence of mineral salts in a region where accumulation of volcanic glass was widespread may have forced creatures to seek such materials in the scattered organic remains that were lying on the ground before they were buried. Moreover, the rather common occurrence of gnaw marks gives the impression that many rodents were present. Indeed, certain structures observed in the tuff beds may be the remains of rodent burrows that were subsequently filled with volcanic ash.

Lithology

The following is a measured section of the rocks exposed at Beatty Buttes:

	Thickness (feet)
1. Basalt flows (estimated thickness)	35+
2. Stratigraphic distance between bottom of basalt and top of uppermost tuff bed exposed (estimated thickness)	25–30
3. Brown to gray-brown, tuffaceous silt. Top of the section not exposed	50
4. Brown, tuffaceous silt. Forms badland cliffs	10
5. Tuffaceous silt grading from gray at bottom to cream or buff at top. Many fossils occur in this unit. Usually exposed in badland slopes between cliff-forming units	32
6. Light-tan to brown tuffaceous silt containing many pumiceous fragments. Many fossils are preserved in this unit, especially toward the base. Forms badland cliffs	10
7. Brown to buff, tuffaceous silt	40
8. Coarse, greenish lapilli, or scoriaceous tuff. Base of section not exposed	70
Total	272–277+

Comparative Lists of Miocene Faunas from Southeastern Oregon

Beatty Buttes	Sucker Creek	Skull Springs
	Insectivora	
Insectivore, possibly erinaceid		
	Carnivora	
Amphicyon frendens Matthew		Amphicyon cf. frendens Matthew
		Amphicyon sinapius Matthew or cf. Pliocyon medius Matthew
		Tomarctus cf. brevirostris Cope
		Euoplocyon (?) sp.
Canid (?) sp.	Canid (?) sp.	Canid (?) sp.
		Hemicyon, n. sp.
		Martes (Tomictis) gazini Hall

Beatty Buttes	Sucker Creek	Skull Springs
	Rodentia	
Sciurus sp.	Sciurus (?) sp.	Sciurus malheurensis Gazin
		Sciurus tephrus Gazin
		Citellus ridgwayi Gazin
Liodontia cf. alexandrae (Furlong)		Liodontia alexandrae (Furlong)
Mylagaulus cf. laevis Matthew	Mylagaulus cf. laevis Matthew	Mylagaulus cf. laevis Matthew
Diprionomys (?) sp.		Diprionomys (?) oregonensis Gazin
	Chalicomyid sp.	
	Lagomorpha	
Oreolagus (?), n. sp.		
	Proboscidea	
	Mastodont sp.	Mastodont sp.
	Perissodactyla	
Archaeohippus cf. ultimus (Cope)		
Hypohippus near osborni Gidley	Hypohippus near osborni Gidley	Hypohippus sp.
Parahippus cf. avus (Marsh)	Parahippus avus (Marsh)	Parahippus near coloradensis Gidley
Merychippus isonesus (Cope)	Merychippus isonesus (Cope)	Merychippus isonesus (Cope)
Merychippus cf. campestris Gidley	Merychippus brevidontus Bode	
Merychippus sp.		
Aphelops sp.	Rhinocerotid sp.	Rhinocerotid sp.
	Moropus sp.	Chalicothere (?) sp.
		Tapirid sp.
	Artiodactyla	
Oreodontid (?) sp.		
	Prosthennops (?) sp.	Platygonus (?) sp.
	Ticholeptus sp.	Ticholeptus (?) sp.
Dromomeryx borealis (Cope)	Dromomeryx near borealis (Cope)	Dromomeryx near borealis (Cope)
Merycodus, possibly n. sp.	Merycodus cf. nevadensis Merriam	Merycodus ? sp. *a*
Merycodus sp. (?)		Merycodus ? sp. *b*
Camelid (?) sp.	Camelid (?) sp. *a*	
	Camelid (?) sp. *b*	

Age of Fauna

The fossil vertebrate assemblage found at Beatty Buttes has much in common with those collected in the Miocene deposits of Sucker Creek and Skull Springs, Oregon. The similarity is so close that the three faunas appear to represent nearly identical horizons. The genus *Archaeohippus* and an insectivore are the only important members of the fauna from Beatty Buttes that do not occur in the assemblages from Sucker Creek and Skull Springs. The fauna from Beatty

Buttes is likewise comparable to that from the Mascall formation, Oregon, and that from the Virgin Valley formation, Nevada. *Merychippus isonesus, Dromomeryx borealis,* and *Mylagaulus* are conspicuously present in all these five faunas. However, the assemblages from Beatty Buttes, Sucker Creek, and Skull Springs show greater resemblance to that from Virgin Valley than they do to the Mascall fauna.

Several fossil mammals found at Beatty Buttes are known from the Sheep Creek beds of western Nebraska, and still others are present in the Lower Snake Creek beds, which overlie the Sheep Creek horizon. For example, *Archaeohippus* and *Amphicyon frendens* are described from the Sheep Creek horizon, and *Mylagaulus laevis* and *Hypohippus osborni* are present in the Lower Snake Creek fauna. The presence of these forms suggests at least a broad time relationship between the Oregon fauna and the two assemblages from the Great Plains. On the other hand, of the merychippine forms, only *M. primus* is recorded by Matthew (1924) from the Sheep Creek beds, whereas at Beatty Buttes occur several more advanced merychippines, suggesting an age slightly younger than that of the Sheep Creek fauna.

A slight resemblance appears to exist between the Oregon fauna and that from the Pawnee Creek of Colorado. In the latter occur *Merychippus campestris, Hypohippus osborni,* and *Aphelops megalodus.* These mammals are tentatively recorded from Beatty Buttes. The typical Pawnee Creek fauna is regarded by Osborn (1918) as slightly more progressive than the Mascall. Simpson (1933) considers the Pawnee Creek assemblage late Miocene in age.

Dougherty (1940) suggested an age for the Caliente fauna of California intermediate between the Mascall and the Sheep Creek, and further correlated the Caliente with the upper Temblor in the marine section of the California Coast Ranges. *Merychippus isonesus* is certainly more advanced than *M. carrizoensis* and indicates a slightly younger age for the fauna from Oregon.

Bode (1934) considered the Merychippus zone of the North Coalinga district to be intermediate between the Mascall and the Barstow. It was likewise correlated by Bode with the *Valvulineria californica* zone or basal Monterey of the California marine section.

Inasmuch as some of the fossil mammals from Beatty Buttes are like those from the Merychippus zone, a correlation of the former horizon with the marine Tertiary section of the California Coast Ranges is suggested. Thus, the assemblage from Beatty Buttes appears to represent a stage comparable in position to at least a lower part of the *Valvulineria californica* zone of the Middle Miocene as defined by micropaleontologists in the California marine section.

A discrepancy in these time relations becomes apparent, however, in that the fauna from Beatty Buttes is nearly identical in age with the Sucker Creek and Skull Springs faunas. These approximate in age the Mascall and Virgin Valley faunas, and would therefore represent a stage in the upper part of the Miocene, or Barstovian age, as defined by the committee of the Vertebrate Section of the Paleontological Society of America (Wood et al., 1941).

Environment of Fauna

The assemblage of fossil vertebrates represented at Beatty Buttes is not of sufficient size and variety to warrant definite statements as to the environmental conditions which prevailed during its period of existence and accumulation. Nevertheless, several suggestions seem worthy of mention.

The prevalence in a fossil fauna of grazing horses like *Merychippus* has often been regarded as evidence suggesting the presence of grassland country. Caution is necessary in the use of a criterion of this kind in determining what the particular kinds of environmental conditions were like during the past, for, as Bode (1934) points out, horses with hypsodont dentitions live today in open woodland country in certain parts of the world. Supporting the view that grasslands were in existence in the region of Beatty Buttes is the presence of *Merycodus,* a grazing type of antelope. On the other hand, the mylagaulid rodents and the genus *Liodontia* are often regarded as indicative of wooded areas, and so are the brachyodont, browsing types of ungulates, such as *Hypohippus* and *Dromomeryx.* Living rhinoceroses are found in regions which apparently include both grassland and open woodland, and the extinct *Aphelops* may have occupied a similar environment. A combination of faunal elements such as that comprising the assemblage from Beatty Buttes suggests, therefore, variable ecologic conditions in which open woodlands may have existed adjacent to plains.

The Payette formation of Idaho is tentatively correlated with the Sucker Creek horizon, and the latter in turn with Beatty Buttes. Although a Payette flora has been described (Chaney, 1922) from localities approximately 200 miles to the east of Beatty Buttes, what is known of the geological history of the intervening areas does not invalidate the view that essentially similar climatic conditions prevailed in southeastern Oregon and southwestern Idaho in mid-Tertiary time. Chaney concludes from a study of the Payette flora that the humidity was lower than that indicated by the Mascall flora. A similar climate may have prevailed during the period of deposition at Beatty Buttes. The relatively fine-grained character of the tuffs in which the fossil vertebrates are found suggests no great relief in adjacent areas. Similar topographic conditions are suggested by the Payette flora.

Description of Fossil Material

Insectivore, possibly erinaceid

(Plate 3, figure 9)

A part of a right mandible with M_1–M_3, no. 3068, may represent an erinaceid in the fauna from Beatty Buttes. Unfortunately, the specimen was lost before a complete description was made. One photograph of a lateral view and the following notes are available as a record of this jaw fragment.

The cusps in the teeth in the Oregon specimen appear to be less prominent than in *Domnina gradata* Cope, described by Patterson and McGrew (1937). They are not so high in proportion to the anteroposterior and transverse diameters of the teeth as in *D. gradata.* M_3 is less reduced than in the latter form. These two features, low cusps and lack of reduction of M_3, suggest that the specimen from Beatty Buttes represents a more generalized type, and possesses to less extent the distinctive characters of soricids. This is significant since *D. gradata* is found in the Oligocene, whereas the Beatty Buttes form belongs to the later Miocene. No. 3068 certainly does not show the pronounced features seen in *Limnoecus tricuspis* Stirton from the Barstow Miocene of California.

In the following table the measurements of the Beatty Buttes specimen are compared with those of the holotype of *Domnina gradata* as given by Patterson and McGrew.

Comparative measurements (in millimeters)

	No. 3068 C.I.T.	*D. gradata*, no. 5353 F.M.N.H.
Anteroposterior diameter:		
M_1	*a*2.0	2.2
M_2	*a*2.0	2.1
M_3	*a*1.6	1.6
Depth of ramus under M_1	*a*2.0	2.4

a, approximate.

Amphicyon frendens Matthew

(Plate 4)

A fragment of a right ramus with P_4, M_1, M_2, and the alveoli for P_3 and M_3, no. 3192, Calif. Inst. Tech. Vert. Pale. Coll., is referred to *Amphicyon frendens* Matthew.

M_1 in this specimen is larger than that of the cotype of *Amphicyon sinapius,* no. 9357, Amer. Mus. Nat. Hist., from the Middle Miocene Pawnee Creek beds of Colorado. The teeth of no. 3192 are also considerably larger than comparable teeth of *A.* ref. to *sinapius,* no. 18258 A.M.N.H. (Matthew, 1924). A distinct difference between the Beatty Buttes specimen and no. 18258 is seen in the relation of depth of mandible to height of crown (protoconid) of M_1. In no. 3192 this depth immediately below M_1 is approximately three times the height of the crown of the tooth.

In size of teeth and in depth of mandible, no. 3192 is more like the type of *Amphicyon frendens,* no. 18913 A.M.N.H. The teeth in the Oregon specimen are actually slightly smaller than in no. 18913, and the hypoconid of M_1 is considerably smaller in proportion to the protoconid in the former than in the latter. The protoconid-paraconid blade tapers forward more than in the American Museum specimen, and is directed slightly more toward the inner side. M_1 in no. 3192 approximates in transverse diameter the comparable tooth in no. 376 C.I.T. of *A.* cf. *frendens,* from Skull Springs, but has a higher shearing blade. M_2 resembles in size and proportions the comparable tooth in no. 18913, but the notch between protoconid and hypoconid is more shallow. The mandible in no. 3192 is slightly longer than in the type specimen of *A. frendens,* although shorter than in *A.* ref. to *sinapius,* no. 18258 A.M.N.H. The convexity of the lower margin below the posterior end of M_2 is much more pronounced in the type than in the specimen from Beatty Buttes.

Comparative measurements (in millimeters)

	No. 3192 C.I.T. Beatty Buttes, Oregon	No. 376 C.I.T. Skull Springs, Oregon	*A. frendens*, type, no. 18913 A.M.N.H.	*A.* ref. to *sinapius*, no. 18258 A.M.N.H.	*A. sinapius*, cotype, no. 9357 A.M.N.H.
M_1, length from base of metaconid to anterior end of tooth	26.0	25.5	25.7	23.4	23.5
M_1, anteroposterior diameter..	37.0	....	....	*a*34.0	....
M_1, transverse diameter at posterior base of metaconid.	17.0	17.5	20.4	*a*17.4	15.0
M_1, transverse diameter across notch between paraconid and protoconid............	15.5	17.0	15.7	14.6	14.3
M_1, height of protoconid......	24.0	22.0	27.0	*a*21.0	....
M_2, anteroposterior diameter..	27.0	....	30.0	*a*28.0	....
M_2, transverse diameter at notch between hypoconid and protoconid............	17.5	....	19.6	.....	....
Length, anterior end of P_4 to posterior end of M_2........	85.5	....	....	.....	....
Depth of mandible below protoconid of M_1.............	50.0	*a*45.0	....	*a*83.0	....

a, approximate.

Canid (?) sp.

A fragmentary jaw, no. 3067 Calif. Inst. Tech. Vert. Pale. Coll., with only a part of P_4 remaining of the dentition, is referred tentatively to the Canidae. The specimen approaches in size the jaw of the present-day *Vulpes macrotis.*

Comparative measurements (in millimeters)

	Canid (?) sp., no. 3067 C.I.T.	*Vulpes macrotis* Merriam
Length, anterior end of alveolus for P_3 to posterior end of alveolus for M_3..............................	34.0	34.8
P_4, anteroposterior diameter.........................	8.0	7.8
Depth of jaw below M_1............................	10.8	9.9

Sciurus sp.

(Plate 3, figures 5, 6)

Several isolated upper teeth, nos. 3077A and 3077B, and two fragments of maxillaries with teeth, nos. 3076 and 3078, Calif. Inst. Tech. Vert. Pale. Coll., unquestionably represent the genus *Sciurus,* but incomplete preservation of the material prevents specific identification.

The characters of the upper cheek teeth are well displayed in nos. 3077A and 3077B, for the crowns of these specimens are practically unworn. The teeth are quadrate in shape and have four transverse lophs. The two outer lophs are less prominently developed than the two inner ones. The inner lophs terminate externally in pronounced cusps. In size the teeth are comparable to those in *S. malheurensis,* no. 129 C.I.T., described by Gazin (1932) from Skull Springs, Oregon. The material from Beatty Buttes may represent that species. The teeth of *Sciurus griseus,* a modern tree squirrel, are slightly larger than those of the Oregon fossil.

Comparative measurements (in millimeters)

	Sciurus sp., no. 3077A C.I.T.	*S. malheurensis,* no. 129 C.I.T.	*S. griseus,* no. 9601 C.I.T.
M^1, anteroposterior diameter.....	2.2	2.4	2.9
M^1, transverse diameter.........	2.7	2.7	3.3

Liodontia cf. **alexandrae** (Furlong)

(Plate 3, figures 7, 8)

A maxillary fragment, no. 3083, Calif. Inst. Tech. Vert. Pale. Coll., including P^3, P^4, M^1, and a part of M^2, seems referable to *Liodontia alexandrae.* Two lower premolars, nos. 3082A and 3082B, and several upper molars, nos. 3084A and 3084B, are also present. An anterior part of a skull with two incisors, no. 3087, is tentatively referred to this species.

Miller and Gidley (1918) established the genus *Liodontia* on the basis of the characters displayed by *Aplodontia alexandrae* Furlong from the Thousand Creek and Virgin Valley formations of Nevada. Gazin (1932) recognized specific differences between the type specimen from the Virgin Valley Miocene and the cotype from the Thousand Creek Pliocene, and proposed for the latter the name *Liodontia furlongi.*

P^4 in no. 3083 from Beatty Buttes is comparable in size and in acuteness of mesostyle to the corresponding tooth in the type specimen of *Liodontia alexandrae,* no. 11325, Univ. Calif. Vert. Pale. Coll., from Virgin Valley. A noticeable difference, however, is the presence of seven enamel lakes on the occlusal surface of no. 3083, whereas not more than four lakes are noted in individuals of *Liodontia alexandrae* described from other Miocene localities. The teeth in no. 3083 are only slightly worn, however, and this may account for the difference in number of lakes. The three additional lakes are arranged along a line which passes approximately through the mesostyle, dividing the tooth in half transversely.

The two lower fourth premolars, nos. 3082A and 3082B, have conspicuous anteroexternal folds, a feature which is considered characteristic of *Liodontia alexandrae,* when seen in teeth of moderate wear.

Mylagaulus cf. **laevis** Matthew

(Plate 3, figures 1–1*d*, 2–2*d*)

Mylagaulus is represented in the collections from Beatty Buttes by approximately 25 isolated teeth. The majority of these specimens are enlarged fourth premolars. The teeth from the Oregon locality are comparable in size to those of *M. sesquipedalis* and *M. laevis.* The form from Beatty Buttes, however, shows distinct external flattening of the upper premolars, a feature typical of *M. laevis,* whereas in *M. sesquipedalis* the teeth are described as having a "regularly oval" occlusal surface. The teeth from Beatty Buttes are also similar to those from Skull Springs which have been referred to *M. laevis* (Gazin, 1932).

Features common to the specimens of P^4 from Beatty Buttes and Skull Springs include the anteroexternal and anterointernal grooves, concave curvature of external face along vertical axis, and presence of five to eight enamel lakes depending on stage of wear of crown. The lakes are elongated and are oriented roughly parallel to the anteroposterior axis of the tooth. In several specimens the teeth taper anteriorly.

The lower premolars from Beatty Buttes, no. 3070, Calif. Inst. Tech. Vert. Pale. Coll., are more extended anteroposteriorly than the upper premolars. Usually six lakes are present, and the number is apparently more persistent with further wear of the tooth than is the case with the number of lakes in the upper premolars. The lakes occur in two rows of three each, one row having a position along the external border and the other along the internal border. The rows are oriented parallel to the anteroposterior axis of the tooth, but the elongation of individual lakes is transverse to this axis and the trends are anteroexternal.

Several isolated second upper molars, nos. 3072 and 3073, are in the collection. Two upper molars of *Mylagaulus* have nearly equal transverse and anteroposterior diameters. In diameter these teeth approximate half the size of the upper fourth premolars. Five enamel lakes are present. The four large lakes are located at the corners of a square. The fifth or smaller lake lies halfway between the two outer lakes and closer to the outer wall. The individual lakes are extended in a direction parallel to the anteroposterior axis of the tooth. Two molars, tentatively regarded as of the lower dentition, have a circular outline of the occlusal surface, with lakes numbering four in one and five in the other.

Several fragments of teeth and skeletal elements from Corral Buttes represent *Mylagaulus*. So far as can be determined from the scant material available, this form is identical with that recorded from Beatty Buttes.

Measurements (in millimeters) of teeth of Mylagaulus cf. laevis

Specimen no.	Transverse diameter	Anteroposterior diameter
3069A, P^4	7.9	9.8
3069B, P^4	6.1	9.0
3069C, P^4	7.1	9.7
3069D, P^4	5.4	9.0
3070A, P_4	5.2	10.0
3070B, P_4	5.6	10.2
3070C, P_4	5.1	11.9
3070D, P_4	4.8	*a*10.4
3070E, P_4	5.0	9.4
3073A, M^2	4.4	4.6
3073B, M^2	4.0	3.8

a, approximate.

Diprionomys (?) sp.

A badly broken cheek tooth suggests a rodent similar to *Diprionomys* (?) *oregonensis,* described by Gazin from the Skull Springs Miocene.

Oreolagus (?) n. sp.

(Plate 3, figures 3, 4)

A left maxillary with P^3–M^2, no. 3074, Calif. Inst. Tech. Vert. Pale. Coll., and a right ramus with M_1–M_2, no. 3088, may represent the Ochotonidae. No. 3088 is similar to *Oreolagus nevadensis,* described and illustrated by Dice (1917) from the Virgin Valley Miocene, and to *Sylvilagus* ? sp., recorded by Hall (1930) from the Fish Lake Valley beds of Nevada, and may represent a similar form. No. 3088 is apparently an ochotonid rather than a leporid, for the anterior and posterior columns of the teeth are joined by narrow connections and are not closely fused. In the upper cheek teeth of no. 3074, however, the two columns are broadly united. The form from Beatty Buttes is considerably larger than either *Oreolagus nevadensis* or *Sylvilagus* ? sp., but is smaller than *Hypolagus vetus.*

Descriptions of ochotonid material from the North American Tertiary are rare. The specimens from Beatty Buttes probably belong to an undescribed species.

Measurements (in millimeters) of specimens of Oreolagus (?), n. sp.

Length of tooth row, P^3–M^2, no. 3074	6.4
Greatest transverse diameter of M^1, no. 3074	3.0
Length of tooth row, M_1–M_2, no. 3088	4.3
Greatest transverse diameter of M_1, no. 3088	1.9

Archaeohippus cf. **ultimus** (Cope)

(Plate 2, figures 4, 5)

A single upper tooth, no. 3061 Calif. Inst. Tech. Vert. Pale. Coll., lacks the outer wall. It is referred to the genus *Archaeohippus* and is compared with *A. ultimus* and *A. mourningi.* The specimen appears to fall within the size range of teeth of *A. ultimus* from the Mascall. It likewise resembles teeth of *A. mourningi* from the Barstow Miocene, as well as teeth referred to this species and described by Bode (1933) from the north Coalinga district, California.

In no. 3061 the protocone is not so distinctly separated from the protoconule as in the unworn tooth of the type of *A. mourningi,* probably because of greater wear in the former. In other respects the two teeth are almost identical. The hypostyle is well developed, and cement is lacking. Protocone and hypocone are enlarged and conical in shape, thereby constricting somewhat the lingual entrance to the valley between protoloph and metaloph. No crochet is present.

Fragments of two superior cheek teeth, nos. 3204 and 3203 C.I.T., were found in the deposits at Corral Buttes and represent *Archaeohippus.* No. 3204, apparently P^2, is slightly larger than the tooth from Beatty Buttes. No. 3203 represents, as nearly as can be determined, the same form as no. 3061.

Measurements (in millimeters) of upper cheek tooth of Archaeohippus cf. ultimus, no. 3061 C.I.T.

Anteroposterior diameter	13.5
Approximate transverse diameter	13.0
Approximate height	11.0

Hypohippus near **osborni** Gidley

(Plate 2, figures 1, 1*a*, 2, 2*a*)

An unworn P^3, no. 3199, Calif. Inst. Tech. Vert. Pale. Coll., and a slightly worn M_3, no. 3063 C.I.T., represent the genus *Hypohippus* in the collection. No. 3199 is similar to P_3 in the type specimen of *Hypohippus osborni* from the Middle Miocene, Pawnee Creek formation. The only noteworthy differences are the presence in no.

3199 of a well developed cingulum at the base of the protocone, and a slightly smaller anteroposterior diameter. No. 3063 is comparable in size and in character of crown to a specimen from Virgin Valley, described by Merriam as near *H. osborni*. In no. 3063 the hypoconid ridge is distinct from the metastylid, and an external cingulum is only slightly developed. Specimens from Skull Springs and Virgin Valley identified as *Hypohippus* are likewise similar to the tooth from Beatty Buttes.

A fragment of a ramus, no. 3198 C.I.T., with part of a lower premolar, collected at Corral Buttes, represents apparently the same form as that found at Beatty Buttes. The external cingulum in no. 3198 appears to be slightly heavier than in the latter.

Measurements (in millimeters) of teeth of Hypohippus near osborni

	P^3 no. 3199 C.I.T.	M_3 no. 3063 C.I.T.
Greatest anteroposterior diameter	20.0	24.4
Greatest transverse diameter	27.5	15.6
Height of paracone	16.7	...
Height of metaconid	...	11.0

Parahippus cf. avus (Marsh)

(Plate 2, figures 3, 3*a*)

Referred to *Parahippus* is a fragmentary and unworn M_1 or P_4, no. 3064, Calif. Inst. Tech. Vert. Pale. Coll. This specimen is similar to P_4, no. 442 C.I.T., from the Sucker Creek Miocene, which was identified as *Parahippus avus* by Scharf (1935). It resembles also no. 19403, Univ. Calif. Vert. Pale. Coll., from Virgin Valley, identified as *P. avus* by Merriam. In no. 3064 the metaconid-metastylid pillar is prominent and higher than the protoconid or hypoconid. An external cingulum is present. Cement is entirely lacking. The comparatively large size and subhypsodont character of the tooth suggest a slightly more advanced parahippine stage than that of *P. avus*.

Measurements (in millimeters) of M_1 ? of Parahippus cf. avus

Greatest transverse diameter	16.9
Height of metaconid	14.4

Merychippus isonesus (Cope)

(Plate 2, figures 6, 6*a*, 7, 7*a*, 8, 8*a*)

Most of the equine material from Beatty Buttes is referred to this species. It is represented by a fragment of ramus, no. 3057, Calif. Inst. Tech. Vert. Pale. Coll., with M_1–M_3 inclusive, approximately 14 separate and fairly well preserved teeth, and many tarsal and carpal elements.

The upper teeth have medium high crowns. The radius of curvature of the external side approximates 1 to 2 inches. Cementation is variable, but is fairly heavy in several specimens. The anteroposterior and transverse diameters of the crown are often nearly equal. The fossettes are open internally in some instances, especially in early stages of wear. The protocone and hypocone are of subequal or equal size, with the hypocone usually slightly smaller and more flattened than the protocone. In all specimens the protocone is distinct from the protoloph, but the pli protoconule is usually present. The hypocone in all but one specimen is joined to the metaloph, although in P^2 this union is established by only a narrow isthmus.

Specimen no. 3052 is similar to P^2 in the type of *M. isonesus,* no. 8175, Amer. Mus. Nat. Hist. The fossettes are open and have practically no plications. Hypocone and protocone are entirely separate from protoloph and metaloph in at least the upper part of the tooth.

Specimens 3049 and 3050 from Beatty Buttes are similar to M^1 of the type, no. 8175 A.M.N.H. In no. 3049 the crochet does not quite reach the protoloph and the prefossette remains open toward the inner side by a narrow channel. The plications on the border of the postfossette are not so complex as in the type specimen. A plication or style is present on the external enamel wall in the region of the hypostyle. This feature is likewise prominent in no. 3047. The only appreciable difference between no. 3050 and the type of *M. isonesus* is the presence in the former of a slightly smaller number of plications on the anterior border of the postfossette.

A superior milk tooth, no. 3096 C.I.T., is brachyodont and lacks cement. This specimen resembles a comparable tooth, no. 440 C.I.T., described by Scharf (1935, p. 108), and a Dp^4 and P^3, no. 1500 C.I.T., described and figured by Bode (1934, p. 63). In no. 3096 the protocone and hypocone each have a conical shape, a character which Bode points out is distinctive of *Merychippus isonesus.*

The deposit of cement in the permanent teeth is apparently considerably less in specimens from Beatty Buttes than in those from Skull Springs, Sucker Creek, or Virgin Valley. Teeth in the present collection appear to be slightly larger than those from Sucker Creek, and approximate more nearly in size those referred to *M. isonesus* from Skull Springs and Virgin Valley.

Unfortunately, the lower dentition is represented only by the well worn teeth in the fragmentary ramus, and by three practically unworn specimens. Two of the latter are possibly milk teeth.

The species *Merychippus isonesus* is known from the deposits at Corral Buttes by several separate teeth, including a fragment of a milk tooth, and also by isolated carpal and tarsal elements. The teeth resemble those collected at Beatty Buttes in stage of development.

Measurements (in millimeters) of teeth of Merychippus isonesus

Specimen no.	Anteroposterior diameter	Greatest transverse diameter	Approximate height of crown
3047, P^4	21.8	20.5	30
3049, M^1	21.3	20.0	29
3050, M^1	20.7	20.5	21
3051, P^2	25.0	16.5	28
3052, P^2	23.0	16.0	23
3056, M_3	25.0	9.8	16
3057, M_1	17.0	....	10
3057, M_2	17.3	11.0	9
3057, M_3	24.0	12.0	10
3091, M^2	21.0	20.0	30.5
3092, M^2	20.8	17.0	27
3093, M^1	22.0	21.0	31
3094, M^1	22.0	....	34
3095, P^2	25.0	15.0	23
3096, Dp^4	20.0	19.0	15

Merychippus cf. **campestris** Gidley

(Plate 1, figures 1, 1*a*, 2, 2*a*, 3, 3*a*, 4, 4*a*)

A single P^4, no. 3084, Calif. Inst. Tech. Vert. Pale. Coll., and two lower cheek teeth, nos. 3055 and 3062 C.I.T., P_3 and M_1 respectively, differ from comparable teeth of *M. isonesus* but resemble those of *Merychippus campestris* and *M. sejunctus* from the Middle Miocene, Pawnee Creek beds. No. 3084 is larger than P^4 in the type of *M. sejunctus,* no. 8291, Amer. Mus. Nat. Hist., and is smaller than the comparable tooth in the type of *M. campestris,* no. 9096 A.M.N.H.

Comparative measurements (in millimeters)

Specimen no.	Anteroposterior diameter	Transverse diameter	Approximate height
3084, P^4	21.0	24.0	24
3055, P_3	20.8	13.0	22
3062, M_1	21.1	11.1	20

	No. 3207 C.I.T.	*M. campestris,* type, no. 9096 A.M.N.H.	*M. sejunctus,* type, no. 8291 A.M.N.H.
Anteroposterior diameter:			
P^1	14.0	....	....
P^2	25.3	27.8	23.9
P^3	22.6	23.3	19.0
P^4	20.2	23.3	18.9
M^1	19.8	20.8	17.0
M^2	20.2	22.0	18.0
M^3	20.1	21.4	20.6
Length, P^2–M^3	131.0	135.4	117.0
Anteroposterior diameter:			
P_2	25.0	26.3	24.2
P_3	20.0	21.1	17.0
P_4	19.1	19.0	16.8
M_1	20.8	23.0	18.5
M_2	21.8	22.8	18.5
M_3	22.5	22.8	18.8
Length, P_2–M_3	131.0	134.0	113.5

In no. 3084 the protocone and hypocone are joined and there is a small enamel lake at the inner end of the postprotoconal valley. The fossettes have simple borders, and a moderate deposit of cement is present. A pli caballin is present in the specimen from Beatty Buttes and in the type of *M. campestris,* but is absent from the type of *M. sejunctus.* In *M. campestris* and *M. sejunctus* the metastyle and parastyle are directed more anteriorly than in the specimen from Beatty Buttes. In the latter these styles project at nearly right angles to the anteroposterior axis of the tooth crown.

Two lower teeth are tentatively assigned to *M. campestris.* P_3, no. 3055, is similar to a comparable tooth, no. 8273 A.M.N.H., that has been referred to *M. sejunctus* (Cope). M_1, no. 3062, resembles M_1, no. 8273 A.M.N.H. The two teeth in the collection of the American Museum are more heavily cemented than any of the merychippine specimens in the collection from Beatty Buttes. Likewise the transverse diameter exceeds that in lower teeth of *Merychippus* from this locality.

Remains of a single individual of *Merychippus*, no. 3207 C.I.T., which include a fragmentary skull with complete set of worn teeth, a left ramus with cheek teeth, and scattered skeletal elements, were collected at the Corral Buttes locality. The upper cheek teeth in no. 3207 are similar in enamel pattern to the type of *M. sejunctus*, no. 8291 A.M.N.H., but the tooth row is somewhat longer. No. 3207 approaches *M. campestris*, no. 9096 A.M.N.H., in size. The lower cheek teeth in no. 3207 are similar to those of the type of *M. campestris*.

In the stage of wear seen in no. 3207, protocone and hypocone are joined to metaloph and protoloph. The plications on the fossette borders are also greatly simplified. A hypostyle is present in M^2 and M^3 of no. 3207, but is absent from the remaining teeth. These characters have probably been acquired through wear of the occlusal surface. A small accessory style, immediately anterior to the protocone, is present in M^1 of no. 3207.

Merychippus sp.

(Plate 1, figures 5, 5*a*)

An unworn M_3, no. 3054, Calif. Inst. Tech. Vert. Pale. Coll., has a considerably longer crown than do the merychippine teeth already described from Beatty Buttes. The specimen may belong to a distinct species. No. 3054 compares in height of crown with *M. paniensis*, no. 8255, Amer. Mus. Nat. Hist., from the Pawnee Creek.

An unworn M_3, no. 3202 C.I.T., from Corral Buttes undoubtedly represents the same species as no. 3054 from Beatty Buttes.

Measurements (in millimeters) of M_3 of Merychippus sp.

Specimen no.	Anteroposterior diameter	Transverse diameter	Approximate height
3054	24.0	9.1	31
3202	24.0	10.2	34

Aphelops sp.

(Plate 5, figures 1, 2, 2*a*)

Two slightly worn lower teeth, nos. 3085 and 3207, Calif. Inst. Tech. Vert. Pale. Coll., are referred to the genus *Aphelops*. In size and in degree of brachyodonty these specimens resemble *Aphelops megalodus* from the Snake Creek beds of Nebraska and the Pawnee Creek beds of Colorado.

According to Matthew, the three genera of rhinoceroses of the Middle Miocene, namely *Aphelops, Peraceras,* and *Teleoceras*, are not readily distinguished. The dentition of *Teleoceras* is slightly more hypsodont than that of *Aphelops*, and in this character the material from Beatty Buttes is more like the latter genus.

A single upper cheek tooth of *Aphelops*, no. 3206 C.I.T., and scattered skeletal fragments referred to this form were obtained at the Corral Buttes locality. The tooth is well worn, but appears to have been moderately short-crowned. The antecrochet is usually the only accessory crest in molars of *A. megalodus*, and in this specimen shows slight development. The posterior valley on the tooth crown is closed and thus suggests a form more advanced than *A. megalodus*. This feature, however, may be due to the advanced stage of wear.

Measurements (in millimeters) of teeth of Aphelops sp.

Specimen no.	Anteroposterior diameter	Transverse diameter	Greatest height
3206, P^4?	49	58	25
3207, M_1?	51	33	30
3085, M_1?	49	28	33

Oreodontid (?) sp.

No fossil remains of oreodons are certainly identified in the collection. An enamel fragment from Beatty Buttes may belong to this group of artiodactyls.

Dromomeryx borealis (Cope)

(Plate 6)

The only fairly well preserved skull of a fossil mammal from Beatty Buttes belongs to *Dromomeryx*. This specimen, no. 3060, Calif. Inst. Tech. Vert. Pale. Coll., includes enough of the cheek-tooth series to permit satisfactory comparisons. The skull is considerably crushed and distorted, and only the basal parts of the horns are preserved. A single M_3, no. 3065 C.I.T., is also present in the collection.

Measurements (in millimeters) of Dromomeryx borealis

Specimen no.	Anteroposterior diameter	Transverse diameter	Approximate height	Tooth wear
3060, M^3	23	24	11	Worn
3060, M^2	21	23	9	Worn
3060, M^1	18	*a*21	8	Worn
3060, P^4	14.5	17	7.5	Worn
3060, P^3	17	16	7	Much worn
3060, P^2	....	12.5	3	Much worn
3065, M_3	32.5	15	13.5	Only slightly worn

Dimensions (no. 3060)	Approximate measurement
Length of preserved part of skull	397
Width measured at outer surface of M^2	86
Length of upper cheek-tooth series	104
Length of upper premolar series	44
Length of upper molar series	60

a, approximate.

Skull. The description of the skull of *Dromomeryx borealis* as given by Douglass (1909) applies well to the present specimen. In brief, the skull of *Dromomeryx* from Beatty Buttes is characterized by a rather long, narrow facial part. The mid-point between the extreme anterior end and posterior end of the skull coincides approximately with the anterior border of the orbit and the posterior end of the molar series. Anterior to the orbits are prominent fossae or pits in the facial part of the maxillary. These are not present in no. 827, Carnegie Mus. Coll., nor in the type, no. 8132, Amer. Mus. Nat. Hist. These depressions on either side of the snout are apparently not due to crushing of the specimen.

Dentition. The molar teeth are well worn, but are similar in size and pattern to specimens no. 827 and no. 1542 Carnegie Mus., described by Douglass. In no. 3060 from Oregon the teeth lack the accessory style or pillar between the two principal inner cusps. Lacking also is the spur which in no. 1542 extends from the inner posterior crescent into the valley between the posterior internal and external crescents. However, both this spur and a similar one branching from the anterior internal crescent are absent from no. 827. In their slightly complex enamel pattern, the crescents of the premolars in the Oregon specimen are more like those in no. 1542 than those in no. 827.

The single third lower molar, no. 3065 C.I.T., agrees well in pattern with the specimen of *Dromomeryx borealis* figured by Douglass (1909), but it is approximately 10 per cent larger than the latter.

Merycodus, possibly n. sp.

(Plate 5, figures 3, 4)

A fragment of a right ramus, no. 3066, Calif. Inst. Tech. Vert. Pale. Coll., with P_4–M_2 poorly preserved, is larger than that in *Merycodus loxocerus,* but is not quite so large as that in *M. hookwayi.* It is larger than *M. nevadensis,* described by Merriam (1911) from the Virgin Valley beds, northwestern Nevada. In P_4 the anterior and posterior lobes that project inward are particularly well developed. The posterior lobe has an enclosed enamel lake. At the inner posterior side of the middle lobe, an extension of the enamel wall of this lobe projects backward. Because of this there is no open valley, but only a V-shaped incision between the middle and posterior lobes. The anterior valley between middle and anterior lobes is also not so broadly open toward the lingual face as in *M. loxocerus.*

The molar teeth are not so long-crowned as in *M. hookwayi.* In these teeth the outer crescents are rounded, not acutely ridged. An intercrescent columnette is present in M_2 of no. 3066. The depth of the ramus below the molars is slightly greater in no. 3066 than in either the type or the paratype of *M. loxocerus* from the Tonopah Miocene, but this feature is apparently variable in the Nevadan specimens. Comparison with merycodont material from Sucker Creek and from Skull Springs is difficult because of incomplete preservation of the latter. No noticeable differences are seen.

A horn-core fragment, no. 3194 C.I.T., approximates *M. loxocerus* in its diameter. This measurement is slightly larger than that in *Merycodus nevadensis* from Virgin Valley.

Two horn-core fragments, nos. 3196 and 3197 C.I.T., are also known from Corral Buttes.

Measurements (in millimeters) of Merycodus, possibly n. sp.

Length of preserved part of cheek-tooth series, measured at level of occlusal surface, no. 3060	24.6
Depth of jaw below M1, no. 3060	15.5
Diameter of horn core above burr, no. 3194	12.3

Merycodus sp. (?)

A fragment of an inferior molar, no. 3195, Calif. Inst. Tech. Vert. Pale. Coll., is considerably larger than *M. loxocerus,* both in height and in anteroposterior diameter. It approaches *M. hookwayi* more nearly in size.

Camelid (?) sp.

Fragments of a tooth suggest the presence of the camel family in the Beatty Buttes fauna, but no generic designation is possible on the basis of these scanty remains.

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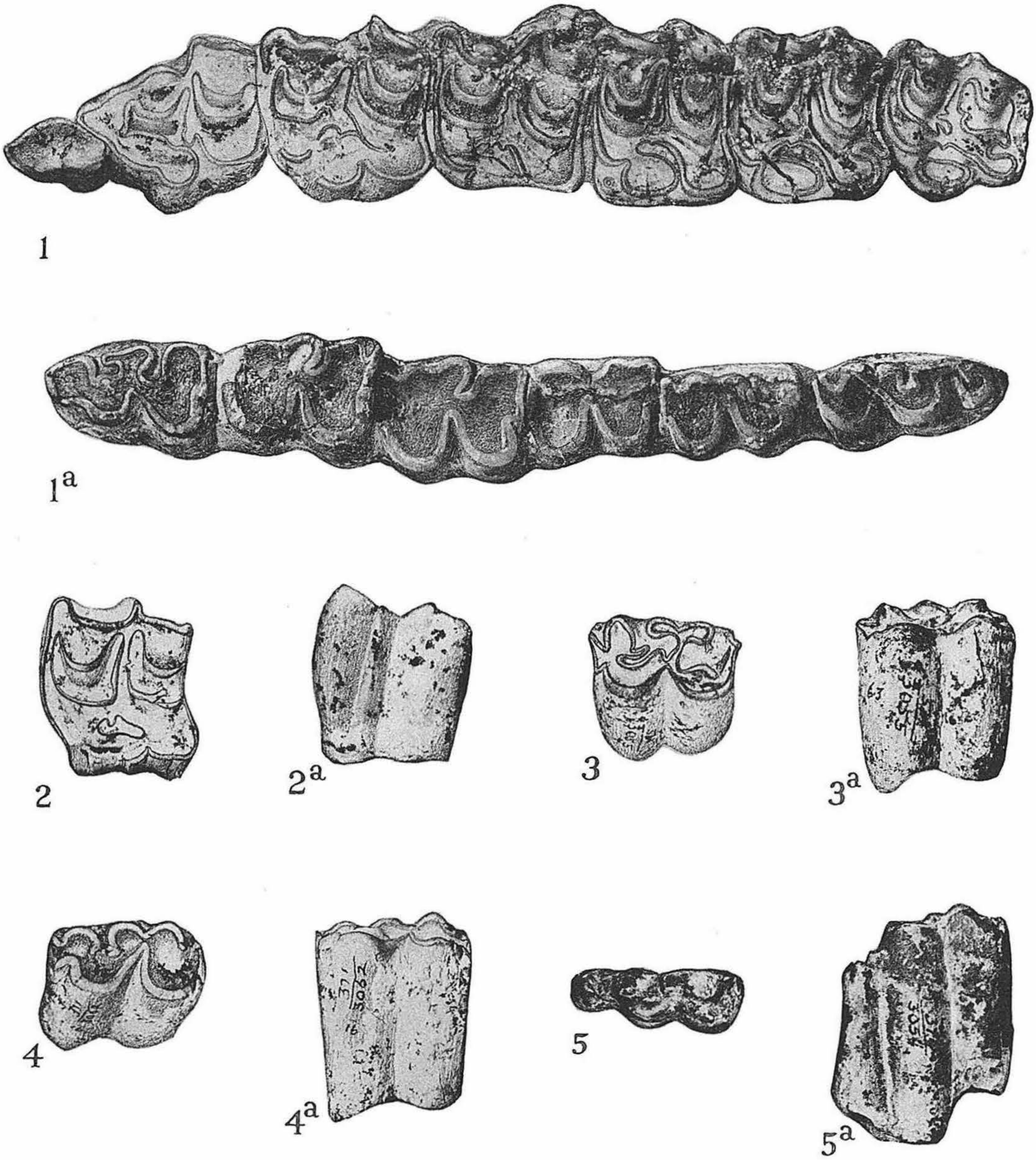
PLATES



FIGS. 1, 1*a*. *Merychippus* cf. *campestris* Gidley. No. 3207, upper and lower cheek-tooth series, occlusal views.

FIGS. 2, 2*a*. *Merychippus* cf. *campestris* Gidley. No. 3084, P^4, occlusal and lateral views.

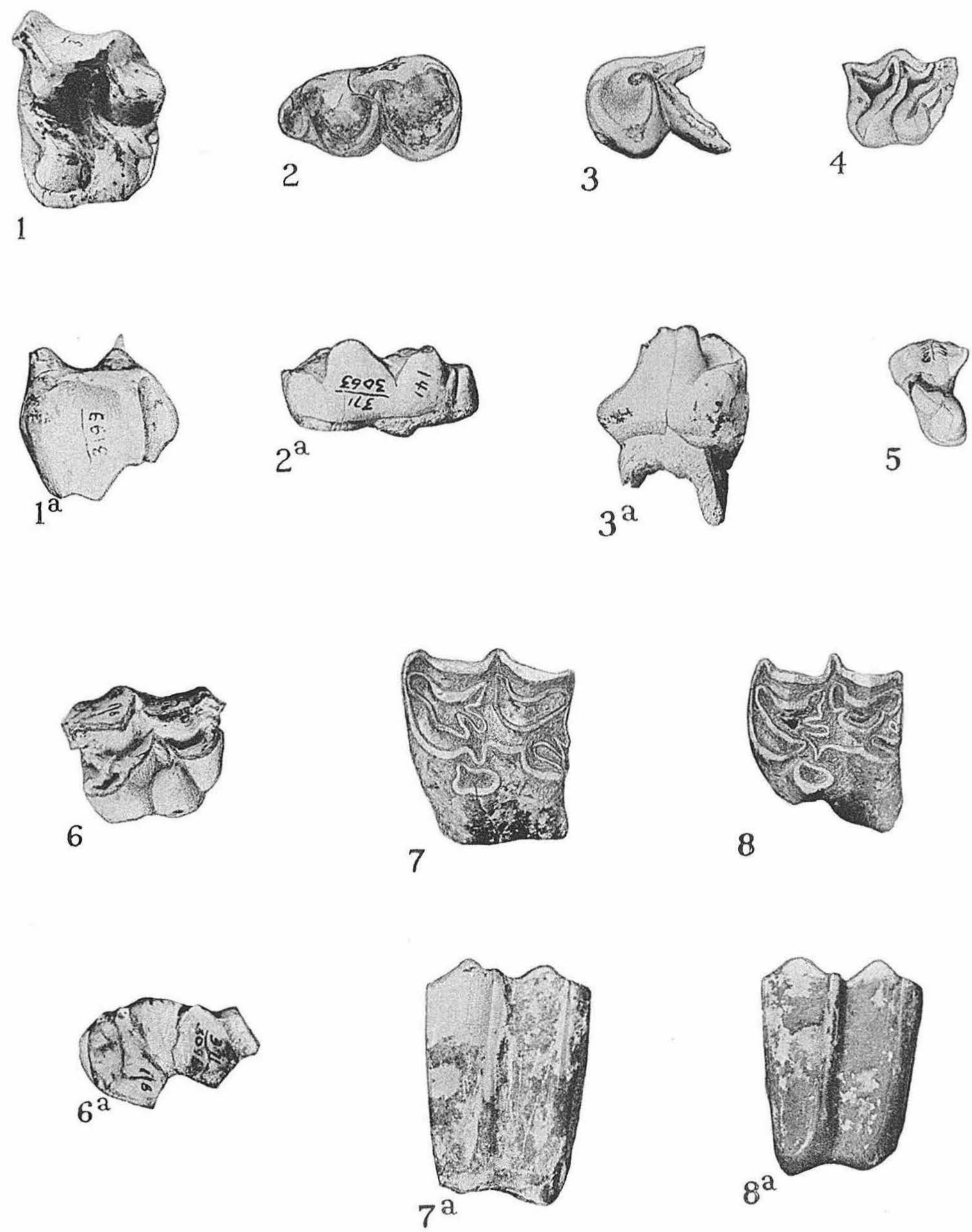
FIGS. 3, 3*a*. *Merychippus* cf. *campestris* Gidley. No. 3055, P_3, occlusal and lateral views.

FIGS. 4, 4*a*. *Merychippus* cf. *campestris* Gidley. No. 3062, M_1, occlusal and lateral views.

FIGS. 5, 5*a*. *Merychippus* sp. No. 3054, M_3, occlusal and lateral views.

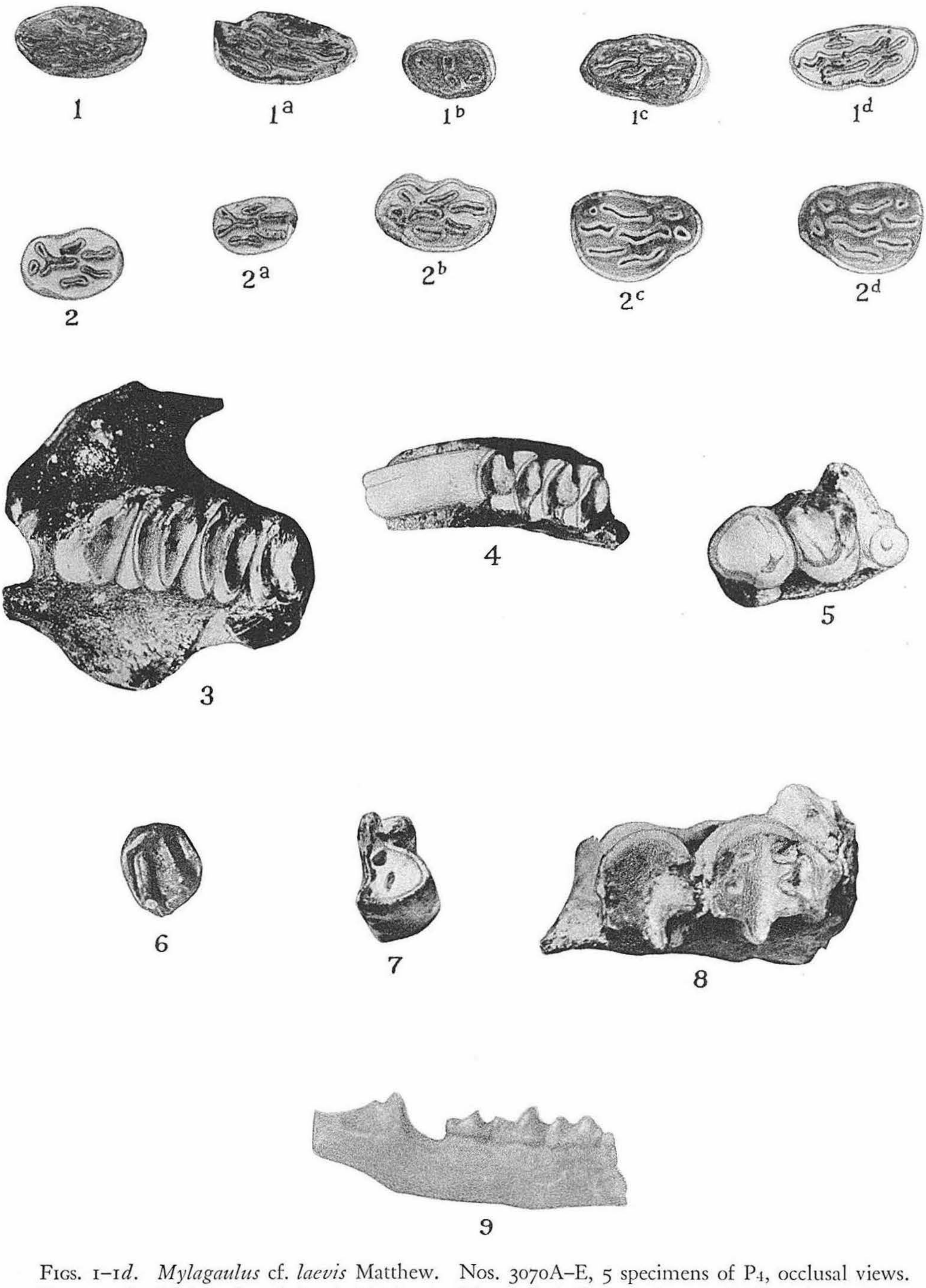
Calif. Inst. Tech. Vert. Pale. Coll. × 1

Beatty Buttes Miocene, Oregon



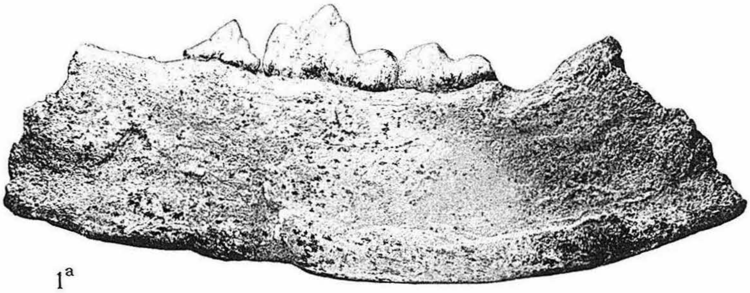
Figs. 1, 1*a*. *Hypohippus* near *osborni* Gidley. No. 3199, P^3, occlusal and lateral views.
Figs. 2, 2*a*. *Hypohippus* near *osborni* Gidley. No. 3063, M_3, occlusal and lateral views.
Figs. 3, 3*a*. *Parahippus* cf. *avus* (Marsh). No. 3064, M_1?, occlusal and lateral views.
Fig. 4. *Archaeohippus* cf. *ultimus* (Cope). No. 3061, upper cheek tooth, occlusal view.
Fig. 5. *Archaeohippus* cf. *ultimus* (Cope). No. 3203, fragment of upper cheek tooth, occlusal view.
Figs. 6, 6*a*. *Merychippus isonesus* (Cope). No. 3096, Dp^4, occlusal and lateral views.
Figs. 7, 7*a*. *Merychippus isonesus* (Cope). No. 3047, P^4, occlusal and lateral views.
Figs. 8, 8*a*. *Merychippus isonesus* (Cope). No. 3049, M^1, occlusal and lateral views.

Calif. Inst. Tech. Vert. Pale. Coll. × 1
Beatty Buttes Miocene, Oregon

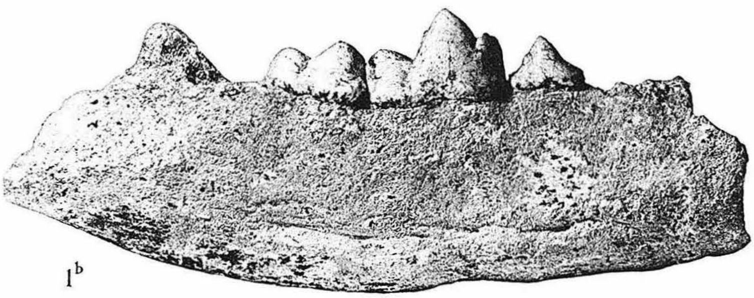


Figs. 1–1*d*. *Mylagaulus* cf. *laevis* Matthew. Nos. 3070A–E, 5 specimens of P_4, occlusal views.
Figs. 2–2*d*. *Mylagaulus* cf. *laevis* Matthew. Nos. 3069A–E, 5 specimens of P^4, occlusal views.
Fig. 3. *Oreolagus* (?), n. sp. No. 3074, P^3–M^2, occlusal view.
Fig. 4. *Oreolagus* (?), n. sp. No. 3088, M_1–M_2, occlusal view.
Fig. 5. *Sciurus* sp. No. 3078, P^4–M^1, occlusal view.
Fig. 6. *Sciurus* sp. No. 3077A, M^1, occlusal view.
Fig. 7. *Liodontia* cf. *alexandrae* (Furlong). No. 3082A, P_4, occlusal view.
Fig. 8. *Liodontia* cf. *alexandrae* (Furlong). No. 3083, P^3–M^1, occlusal view.
Fig. 9. Insectivore, possibly erinaceid. No. 3068, right ramus with M_1–M_3.

Calif. Inst. Tech. Vert. Pale. Coll. Figs. 1, 2 × 2; figs. 3–9 × 5
Beatty Buttes Miocene, Oregon



1a



1b

1

FIGS. 1, 1*a*, 1*b*. *Amphicyon frendens* Matthew. No. 3192, right ramus with P4–M2, occlusal, internal, and external views.

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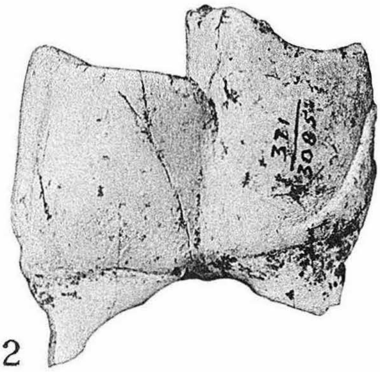
Beatty Buttes Miocene, Oregon

1



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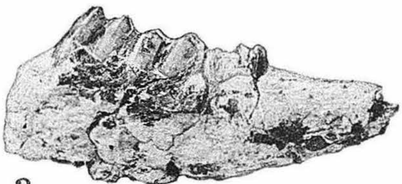

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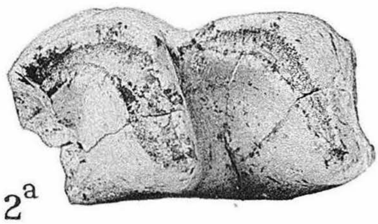
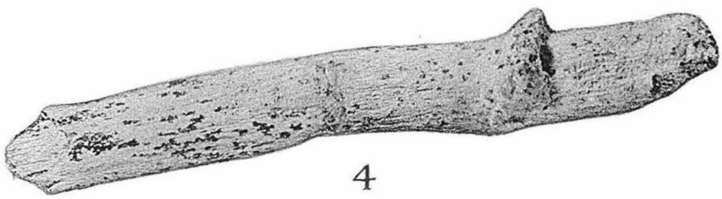


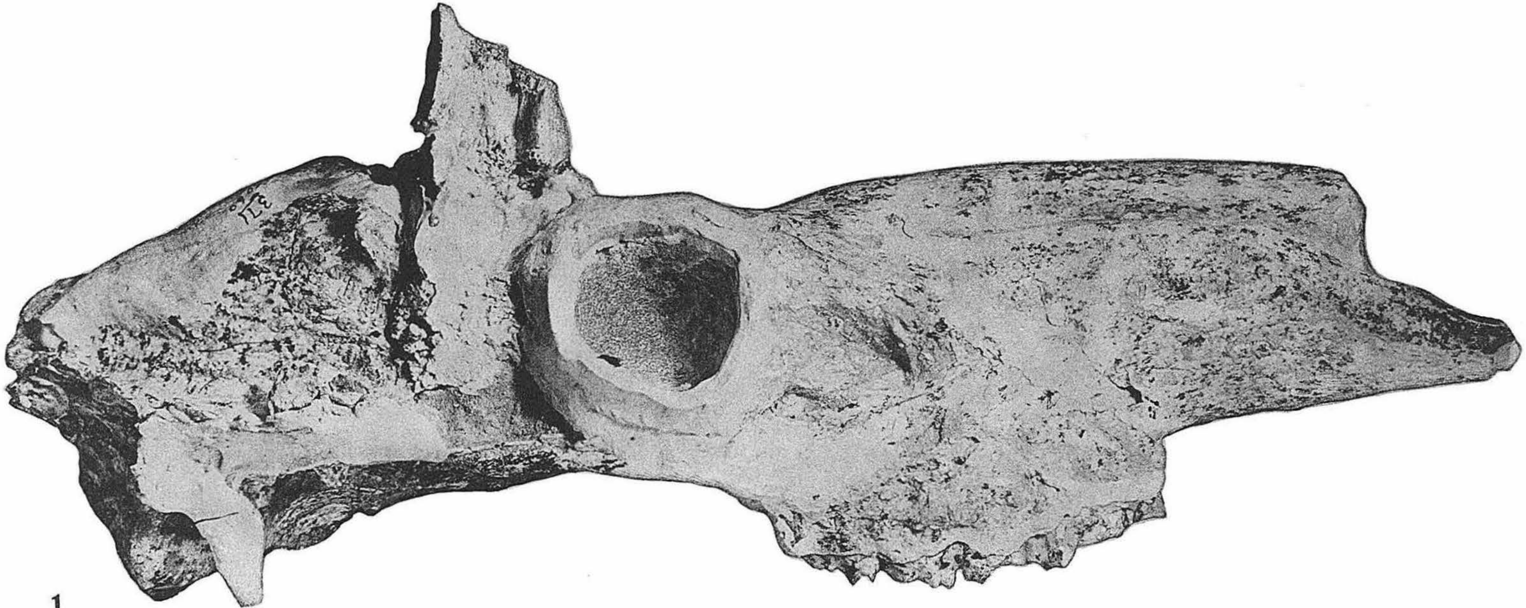
2a



4

FIG. 1. *Aphelops* sp. No. 3206, P^4?, occlusal view.
FIGS. 2, 2*a*. *Aphelops* sp. No. 3085, M_1?, occlusal and lateral views.
FIG. 3. *Merycodus,* possibly n. sp. No. 3066, right ramus with P_4–M_2, lateral view.
FIG. 4. *Merycodus,* possibly n. sp. No. 3194, horn core.

Calif. Inst. Tech. Vert. Pale. Coll. × 1
Beatty Buttes Miocene, Oregon



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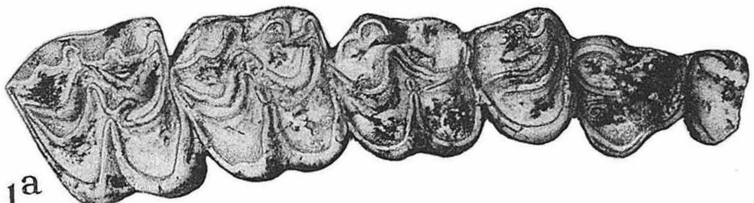

1a

2

Figs. 1, 1*a*. *Dromomeryx borealis* (Cope). No. 3060, skull and right cheek-tooth series. Fig. 1, lateral view; fig. 1*a*, occlusal view.

Fig. 2. *Dromomeryx borealis* (Cope). No. 3065, M3, occlusal view.

Calif. Inst. Tech. Vert. Pale. Coll. Fig. 1 × 0.5; figs. 1*a*, 2 × 1

Beatty Buttes Miocene, Oregon