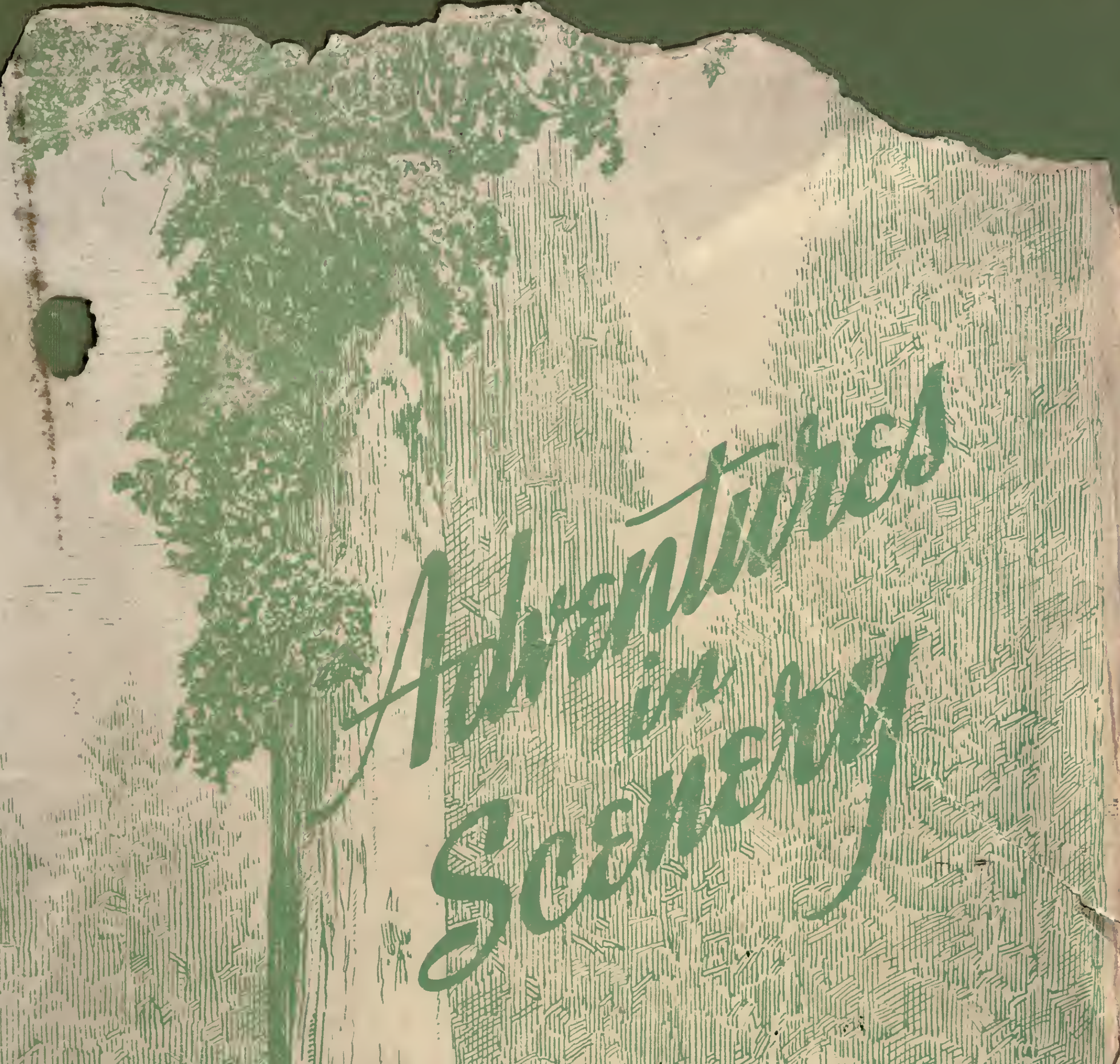


WILLARD

ABOUT OURSELVES

By

JAMES G. NEEDHAM
Emeritus Professor at Cornell University

Illustrated by
WILLIAM D. SARGENT

It is a sane, timely, original and entertaining account of the physical and social science of life written so that all may understand. The book is a study of human nature from the zoological viewpoint. Dr. Needham shows us the real meaning of our zoological heritage and offers a new and original classification of the components of social behavior and of the instincts that serve the needs of our mind. He gives us a clear understanding of the ultimate concern of biology—that part of human life wherein emotions mix with rationality, contributing when the mixture is good, to our welfare and happiness; when bad, to our confusion and disillusionment. The book presents in untechnical language important basic facts which must be taken into account to really understand ourselves individually and collectively.

44 ORIGINAL ILLUSTRATIONS

269 Pages

•

THE
JAQUES CATTELL
PRESS
LANCASTER, PA.

R. C. Terry

FIG. 1. Mission San Juan Capistrano. Corner arches of front garden. The early history of California is inseparably associated with the Missions founded by the Franciscan Fathers.

ADVENTURES IN SCENERY

A Popular Reader of California Geology

By

DANIEL E. WILLARD, A.M.

Fellow American Geographic Society, Fellow A.A.A.S.

Author of "The Story of the Prairies," "The Story of the North Star State," "Montana: The Geological Story"

THE JAQUES CATTELL PRESS

LANCASTER, PENNSYLVANIA

1942

PRINTED IN U.S.A.
THE SCIENCE PRESS PRINTING COMPANY
LANCASTER, PENNSYLVANIA

PREFACE

The aim of the author in the present volume has been to gather from a great field the results of studies by many men, specialists in various fields, and to present in simple form the facts that have been developed. The problems that confront geologists are many and varied. Many thousands of books and papers have been written about the western region of the continent. Not all of these are within the grasp of the general reader. An editor of national prominence, the late Glenn Frank, has said that there is need for interpreters who can gather the results of investigators and make this knowledge available to the general reader. Such an attempt is made in the present volume. The author's aim has been to gather the facts which have been presented by those who have made detailed and often technical studies of a wide range of geological problems, and present them in form so that any one who can intelligently read a newspaper or magazine may read and understand. The present volume is intended as an interpretation of facts gathered by investigators. Such originality as the volume possesses lies in the presentation of the facts.

Geology is sometimes thought of as something dry and hard. In fact, it is too often the method of treatment that is dry and hard, and not the subject itself. The science of the earth, its importance and bearing on the industrial activities of men, knowledge which vitally concerns the daily life and welfare of every citizen, is too often not fully appreciated. The people would appreciate, love, and enjoy their homes more if they knew more of the processes by which the land has been fashioned, and the history that is revealed in the rocks and soils. The author has been inspired with appreciation of the geologic history and the processes by which the land of our western coast has come to be the way it is—the most complex, the most varied, the most stupendously interesting, of all regions he has ever visited.

The author extends congratulations to the State of California and other western states for the splendid galaxy of scientific students and investigators who have studied the problems of geology in this western land, and who have so splendidly expressed in books and scientific journals the results of their studies. Books and papers that have been consulted are named in the bibliography at the end of this volume. Without these great sources of information it would have been impossible to complete the task that the volume undertakes. Students who may wish to verify statements made, or further pursue the subjects referred to may consult the bibliography, and in libraries pursue the subject further.

The author is personally indebted to representatives of Federal and State surveys, the University of California, Stanford University, to the geologists of California and of other States, whose works he has drawn upon. The kindly assistance and co-operation that have been extended by officials of scientific surveys, by authors, scientific journals and associations, and by individual geologists, is highly appreciated. Credit is extended in the bibliography, where these publications are listed. Illustrations which it is hoped will add clearness to the narrated facts have been drawn from a wide range.

To the James J. Hill Reference Library, of St. Paul, Minn., the author is under deep obligation for the splendid facilities offered by this institution. The vast assemblage of books, made available by a trained and efficient staff, and use of a private study room, have contributed immeasurably to the accomplishment of the author's task, and his sincere thanks for and appreciation of the courtesies extended are hereby expressed.

D. E. W.

San Clemente, California.

CONTENTS

LIST OF ILLUSTRATIONS

Chapter I

AN INTRODUCTORY PRE-VIEW

California is a land of scenery—none in the world more fascinating. Here are the highest and lowest points in the United States: Mount Whitney, rising to 14,501 feet, Death Valley, 280 feet below sea level, and Salton Sink, minus 296 feet. Rivers run down hill, as rivers should, and they have cut some of the most stupendous canyons in the world. Other rivers run upside down—the gravel and sand on top, the water down below. The hottest places known to civilized man, and regions of perpetual snow, beckon to each other through not very great distances. Off to the right are regions where rain is a curiosity, and away to the left a moisture-laden region, fog-bound, where thrive the Redwoods (*Sequoia sempervirens*), the grandest trees, the only groves of the kind in the world, a relic of the geologic past. Mountain scenery, through and over which railroads and paved highways have been constructed, where it was supposed to be impossible for travelers to pass, greet the visitor by whatever route he enters, and bring him to broad level expanses of prairie on which great farm machines drive long furrows. Athwart the State, cracks or vents in the crust of the earth have been rent through which mountains of molten rock have been poured (these are now cooled and quiet!). Veins formed by cracks in the crust of the earth into which gold from the deep recesses of the interior of the earth have been deposited thread through the rocks. Palms, dates, olives—tropical fruits galore—thrive down in deep valleys, and pines and cold-loving conifers thrive high on the mountains. Mountains have been upheaved and in the lapse of the ages have been worn down to plains; and the plains again have been covered

Courtesy Californians, Inc.

Fig. 2. Redwood forest. California State Park, Santa Cruz County.

by the waters of the seas. Then again, the sea bottom was raised and again upheaved into lofty mountain ranges. Archaean rocks—the oldest in the world—lie exposed to sun and rain alongside of formations deposited in the latest geologic period. The ocean laves beaches that are many hundreds of feet lower than beaches above them on which are remains of living things of past ages, along with wave-worn pebbles which were rolled and rounded by the same kind of waves that now beat upon the shores, but which gave up their grinding long ago when the land was uplifted to its present higher level.

Adventures in scenery? Yes, highways over which roll automobiles in high gear from palms to pines; from gardens which would compare favorably with Eden (would make what we know of the Garden of Eden look like a weed patch) to deserts of sage brush, cacti, and horned toads; from onion fields with rows a mile long to wheat ranches and cotton fields that extend beyond the range of vision; a turn of the road to ledges of granite in contact with limestone (often changed to crystalline marble), shale, and conglomerate rocks, to steep mountain climbs, across broad open plains, over rivers in which there is no water; to sand dunes that travel today in one direction and tomorrow return in the opposite direction; to oil wells and gold mines; across irrigation ditches in which water to the uninitiated observer seems to be running up hill; to vineyards in which wines are produced that cheer but do not inebriate; to orchards of apples, pears, peaches, and plums, oranges, lemons, apricots, and fruits the like of which are seen, by most, only in stores; mountain crags that seem to pierce the sky, and chasms with nearly vertical walls, their bottoms thousands of feet below the plain; level plains and broad acres of silty loam soils. Yes, this is California, land where the sun sets every day behind the Golden Gate, the geologists' paradise. Geology from a car window, geology on foot or on horseback, the lover of the outdoors may not be a geologist, but in California he will enjoy geology. He may not call it geology—the name does not count

—he will enjoy the panorama of mountains, rivers, and rocks; he will rejoice in the broad fields; he will smile as he views the orchards and vineyards; and he will laugh aloud as he revels in the great banquet of wild flowers. Few if any of the States of the Union have so complicated, and hence so interesting, a history geologically. The geologic "dates" run from the beginning of the continent through the ages to the present. The Beginning probably goes back to Archaean. Shore strands that have been recently elevated above sea mark dates in the uplifting of the land. Lands about islands off shore (as the Farallones) are not yet above sea, not yet born.

Geologic Processes Have Been Long at Work

Rent by mountain upheaval and volcanic outbursts, the crust of the earth has been shattered. Gold has exuded from earth's depths. Oil, segregated in pools, distilled from rocks in which organic matter once accumulated, by earth crumpling and faulting has been brought within reach of the skilled geologist. Upheaval and erosion have long been at work. Erosion following mountain uplift has caused great canyons (as the Yosemite) to be cut into hard rocks. The great Colorado Desert, a region once covered by an arm of the ocean, has been formed by the filling into the basin of detritus borne by the great Colorado River from the arid plain to the east. Lassen Peak, a volcanic cone, is surrounded by a vast field of lava outpoured from this and other vents. The Sacramento and Feather rivers run in deep gorges cut in the hard beds of lava and other rocks, fed by melting snows and rains from the high mountain range.

The "backbone" of the State is the Sierra Nevada Range, with the Coast Range forming an encircling elbow on the west. The Great Central Valley, surrounded by mountains, is so vast it is hardly to be called a valley. It is a great basin 9,000 square miles in area, into which has been borne the products of erosion from the surrounding mountains during the lapse of the ages. The Sacramento from the north and the San Joaquin from the south, and a battery of great streams from the east (Feather, Yuba, American, Mokelumne, Tuolumne, Merced, Kings) all pour into the great central basin, whose outlet is via the Golden Gate. But for the "structural valley," known as the Golden Gate, formed by a break or fault in the crust of the earth (a depressed block of the Coast Range) the Great Valley had been a vast lake, and the cities of Sacramento and Stockton, the broad fertile acres to the north and south, had been many feet beneath the water.

Time is Long in Geology

To attempt to express in years the time since the period known to geologists as the Jurassic, which marks an important milestone in the geologic history of California, would not mean much to the average mind. As far as it can be estimated it has been 174,000,000 years. This the mind can at best but imperfectly grasp. But something of what has happened can be seen. The work of erosion, which has been going on continuously, marks the great length of time. The tremendous gorges, the yosemites of the western Sierra slope, bear evidence that the time has been long. The formations that lie beneath the surface in the Great Central Valley are made up of rock particles that have been eroded from the high lands and washed by streams and spread out in the great body of water that once covered the area. The vast plain of desert sand that fills the basin that was once a bay or arm of the ocean, and now known as the Colorado Desert, represents the long-time work of a great river which in comparatively recent geologic time has gnawed into the rocks of the Great Plains of Arizona, Nevada, and Utah, and formed the Grand Canyon.

Geology Offers Key to Best Development of Natural Resources

These things are all geological in their nature. The study of California becomes the study of geology. Hardly a feature of the State, or any natural resource, but is related directly to geology and geologic processes. The geological story is long—time has been long—and the story is somewhat complicated. The story, however, is fascinating, for it contains the key to the utilization of all natural resources. There was probably land in what is now California in the very early stages of the continent, the Archaean. When the great Appalachian Upheaval occurred, by which the great mountain system of eastern North America was uplifted, bent and folded, California was probably largely covered by the sea, for rocks of Palaeozoic age (Cambrian, Devonian, Carboniferous) occur in California. The great Rocky Mountain system had not yet been "born." A vast sea extended over what is now the great central valley of the United States. Waters covered the Interior Basin, which embraces a vast area in Nevada, Arizona, New Mexico, Utah, and Colorado. It was not until Jurassic time that the beginning of the Sierra Nevada Range occurred. From and after Jurassic time the panorama of California's history has been enacted and the record has been marked in the rocks and land forms.

CHAPTER II

"CALIFORNIA, HERE WE COME!"

Surprise Awaits Arrival

The approach to California from the east is like entering another world, so great is the contrast. By whatever route one travels, and by whatever conveyance, the impression is that of marked contrast. It is a somewhat remarkable fact that California is separated from all its neighbors by desert. While California is herself in part desert, California's desert is California's own. It is unlike the desert farther east. It is abject desert. It is so desert that it is fascinating. The horned toad and the cactus are its natural habitues. But California is not all desert. The sea is near by. There are valleys that are veritable gardens. If approach to the State is by the northern route, cold snow-capped mountains greet the eye, and travel is through mountain passes and down rocky defiles cut out by torrential streams in hard lava or granite rocks. Entering the State from the north, Mount Shasta looms in view and dominates the horizon for many hours as the traveller rolls over the smooth highway or the steel rails. Entering the State by the Salt Lake route, a long ride through bleak and barren arid desert, one plunges abruptly into a mountain wall. By feat of engineering skill, roadways by auto or rail bring the traveller through high mountain passes, while snow-capped ranges stand far overhead. Now scenery, the grandest that the mind can conceive, invites on every hand. Here the gold diggers of a past generation have left their marks in the ragged and torn valleys and rough mountain sides. Turn aside and behold the Hetch Hetchy, Tuolumne, Yosemite, and King's River gorges. They overwhelm the traveller with their awe and grandeur.

On the Train, West Bound

On a transcontinental train a little girl awoke in the daylight of early morning and said to her mother: "We forgot to wake up when we crossed the line and say "California, Here We Come!" The little girl was filled with enthusiasm for the State to which she was going. California was far away from her home, and her imagination had been fired with anticipation of what was in the far-away land. The journey to California was long—there is no short route to California. The little girl had probably heard much about California, its climate, its flowers, its mountains. To her mind it was a fairyland. "California, here we come" was the greeting she had planned to utter as their train should cross the line from the desert waste through which they had passed. "California, here we come," expresses the eagerness of anticipation with which her mind had been fired; California, where there would be sunshine and sea breezes, flowers and strange vines and fruits, and a new landscape, a landscape different from any she had seen before.

Entering the State by a southern route, the Santa Fe or Southern Pacific, it is a change from desert to desert. The ride through Arizona and New Mexico, though long, is interesting to one who enjoys the wild and rugged arid plains. There is much climate; there is much scenery. Via the Santa Fe route, from the "dust bowl" of western Kansas to Albuquerque and Needles, there is constant charm in the varied parti-colored landscape. If time permits, stop off at Williams and visit the Grand Canyon, one of the marvels of Nature's handiwork. Here the Colorado River has cut deeply into the rock formations, and the eroded sediments will be seen later spread out in the great desert of southern California. From El Paso, via the Southern Pacific, there will be charm and fascination all the way, and at Yuma when the line is crossed into California you will probably feel like calling out as did the little girl: "California, here we come!"

FIG. 3. Pepper trees as they grow in Pepper Lane, Los Gatos.

Charm and Fascination Await

Now, by either route there will be desert—cacti, horned toads, dwarf trees, and soon irrigated valleys in which tropical fruits, figs, dates, olives and strange beautiful flowers luxuriate in the blazing sun. Then as the San Bernardino Mountains are approached and crossed, orchards of citrus fruits greet the eye, and the metropolitan city of Los Angeles soon lies ahead.

"California, here we come!" The journey has been long, but it has been interesting. The bleak and arid mountains and plains have held a charm all their own. Now we are at the end of the road. Ahead is the Pacific Ocean. All about us is spread the great landscape of the Golden State. It is an empire of vast reaches. We have passed near Mount Jacinto, whose top reaches far into the sky 10,805 feet, and near by lies the Salton Sea, 280 feet below the level of the sea. The ocean washes a shore that has but recently been lifted above the sea. Beach strands mark the shore from San Diego north past the Golden Gate to the rugged Humboldt coast to the north.

The Pacific Ocean Lies Beyond

And now we are in California, the State which has the distinction of the highest mountain peak in the United States and of land that is below the level of the sea. The rugged mountain range, the Sierra Nevada, a vast tilted block of the crust of the earth, lies on the eastern side, and the younger but complicated and much folded, crumpled and broken Coast Range is on the west. The Great Valley 200 by 400 miles in extent lies between. To the north is a vast lava-covered plain with Mount Shasta and Lassen Peak as great sentinels, and to the south spreads the vast desert domain of the Mojave and Colorado deserts.

Chapter III

CALIFORNIA, HERE WE ARE

The Golden West

California is a State of great size. It embraces 158,000 square miles of area, and is subdivided into 58 counties. In area it is more than three times that of the Empire State of New York. It has a population in excess of six million, two-thirds of which is concentrated in five metropolitan districts on or near the Pacific Coast. Two of the three great harbors on the western coast of the United States are within its borders, San Francisco and San Diego, the third being at Seattle. In point of climate California is unique among all the states. There is the greatest variety of climate, and yet not the extremes of temperature that make life trying in many localities. Rainfall also varies from the excessive downpour of 75 inches in a year to less than 3 inches. In soil there is arid and barren rock and about every intervening gradation to the most fertile and productive river alluvium. Agriculturally a greater range of varieties and kinds of food products are grown than in any state of the Union.

High mountain peaks pierce the very sky, and near by the surface is below the level of the sea. Plains that, in a state of nature, are almost destitute of vegetation when treated to waters from adjacent mountains become modern Gardens of Eden. Trees dwarfed to liliputian size by arctic cold reproduce their kind on snow-laden mountains, and the world's most famous Big Trees, centuries of years old and still thriving, inhabit slopes as nowhere else in the world. The State has long ranked first in the production of the precious metal, gold, forced from the depths of the earth during upheavals such as have not occurred probably elsewhere. In the production of

Courtesy Ed. D. Coates

Fig. 4. Date palms at Long Beach, among the most beautiful in the world.

petroleum or rock-oil the State ranks second among all the states. Fish and game, both from a commercial and the sportsman's standpoint, abound, both in the sea off her coasts and in streams of mountain torrents and rivers, and in the wild and untrammeled fastnesses of forest-clad slopes, in jungles of wild plants, and in impassable rocky gorges and mountain slopes.

Wild flowers of most fascinating beauty, desert palms, cacti, and foot-hills covered with chaparral, invite the nature lover.

The epicure can feast on dates, figs, and luscious fruits that are known to the inhabitants of the older east only in confectioners' stores. Citrus fruits that tempt the appetite, and the juice of the vine that pleases the palate, abound in the valleys where sunshine and clouds play hide and seek in climate the most salubrious of earth.

Sheep in great numbers graze on the hills, and wheat fields spread far in broad vistas. Cattle feed on alfalfa that abounds on thousands of acres of land on which mountain streams are diverted. Eggs from thriving poultry farms find quick markets in cities of the east. Waters of mountain streams, which gravity carries with mighty force from snow-capped highlands, furnish power for many industries, and light to illumine the world.

Great in Gold and Oil; Agriculture the Most Important Industry

While California leads all the states in the production of gold, and is second in the production of oil, agriculture is the State's greatest resource. The yearly value of the products of the soil runs into such staggering figures as to overwhelm the mind. What is produced directly from the soil in the form of crops reaches the astounding total of half a billion dollars. The annual production of livestock and livestock products adds 15 millions to the aggregate of agriculture's contribution to the world's food supply. While her mountains are among the grandest and her rivers among the most interesting from the standpoints of power, scenery, and sportsman's delight, it is after all in her soil that California's most lasting and inexhaustible resources lie.

Wheat, one of civilization's most important foods, is produced as a commercial farm crop in 50 of the State's 58 counties, on more than 6,000 farms. Barley, as a feed crop for livestock and for commercial uses, is a major crop in 47 counties, on more than 8,000 farms, with an annual production of more than 25 million bushels. Irish potatoes are grown on more than

6,000 farms, in 56 of the 58 counties, and as a major farm crop in 30 counties. Cotton, which can only be grown under certain climatic conditions, is a major farm crop in 9 counties, on nearly 4,000 farms. Rice, which can only be grown under special conditions of moisture and climate, is grown as a commercial crop in 11 counties, on more than 400 farms, with a total of nearly 100,000 acres. Beets, grown for the production of sugar, constitute a major crop on more than 1,300 farms in 10 counties.

With more than two million cattle on 65,000 farms, and nearly three million sheep on more than 8,000 farms; with garden vegetables produced on more than 30,000 farms, valued at upward of a million dollars; and with a longer list of fruits and nuts than produced by any other state, California may indeed be said to have a truly great heritage in the natural resource of her soil. In addition to the field crops already mentioned must be added beans (dry, not including green snap beans) grown on nearly 3,000 farms; corn grown on more than 4,000 farms; sweet potatoes grown on 1,600 farms; peas; cantaloupes; onions; asparagus; lettuce (who has not heard of Salinas-Watsonville lettuce?); watermelons grown on 1,400 farms; tomatoes grown on nearly 6,000 farms. Add the following fruits and nuts: almonds; apples grown on nearly 14,000 farms, the industry centering in Sonoma; apricots; avocados; figs; dates; lemons; olives; peaches grown on nearly 19,000 farms; pears grown on 13,000 farms and producing 70% of the national output; plums (including dried as prunes) grown on more than 20,000 farms; cherries grown on 8,000 farms; strawberries; walnuts, and peanuts.

Great Diversity in Topography, in Climate, in Rainfall

Truly there is great diversity in topography, in climate, in rainfall, and in the complex geological conditions that have resulted in the great variety of soils. California, here we are! The Golden Gate opens to the westward. We can go no farther unless we cross the great Pacific Ocean. The Golden Gate, a sunken trough through the Coast Range, offers a seaward outlet to the great empires. We may cross the Golden Gate and the harbor by two of the world's greatest bridges, then we may turn north or turn south. The setting sun points back over the broken and ragged crests of the Coast Range, across the great

Courtesy Redwood Empire Association

FIG. 5. Golden Gate Bridge across the Golden Gate at San Francisco. The world's tallest and longest single span suspension bridge.

Interior Valley, to the high Sierra Range. It is a far call from the Mojave and Colorado deserts far to the south to the gold fields of the central slopes and the barren plains of the rugged lava fields of the north. The great geologic panorama is opened before us. The story of California is complicated. The real history goes back through the geologic ages. All that is now before us is the product of what has gone before. The rugged mountains, the splendid canyon gorges, the gold washed from stream beds or dug from hard rock veins, the broad expanse of the great Interior Valley, the fields and fertile valleys in which are grown the marvellous variety of farm crops, fruits, vegetables and nuts, the pastures where graze herds and flocks of cattle and sheep, the arid plains where abound the horned toad and the cactus, the palms of the south and the pines of the north, the fertile soil and the barren, all are the product of the great geologic laboratory which is now called California. The geological story is long. Time has been long. California as we now see it is the product of a long past.

Chapter IV

EL CENTRO TO YREKA

A Bee-Line across the State

El Centro in the south, to Yreka on the north, represents a distance of nearly 900 miles. Probably no line of equal length in the United States (or any where else) crosses so great a diversity of soils and climate, or so varied geologic features. El Centro is on the great plain of the Colorado Desert near the extreme southern boundary of California and the United States. Yreka is on the high lava-plain which extends from the Sierra Nevada Range of California to the Cascades of Oregon. The line from El Centro to Yreka is purely an imaginary one. No highway traverses it. In imagination it may be traversed by air-plane. From this imaginary viewpoint a glimpse may be obtained of the geographic and geologic features of this remarkable State.

El Centro and the Salton Sea

El Centro is below the level of the sea. The great Imperial Valley, once a desert, has been reclaimed by harnessing the Colorado River. This great region was once an arm or bay of the ocean. The vast basin has been filled by detritus carried by the river from the great interior basin that lies east of the Sierra Range in Nevada, Arizona, Colorado and Utah. This vast southern desert region will be described elsewhere. Let us proceed northward on a Bee-line toward Yreka.

Centrally located in this great valley of southern California is El Centro. To the north is the Salton Sea, an enclosed basin of water having no outlet, and below the level of the sea. The Colorado River has carried and deposited sediments that form a

Courtesy U. S. Geol. Survey

FIG. 6. Relief map of California.

1. El Centro
2. Yreka
3. Colorado Desert
4. Salton Sea
5. Mojave Desert
6. Peninsular Range
7. San Jacinto Mts.
8. Santa Ana Mts.
9. Santa Monica Mts.
10. San Gabriel Mts.
11. San Bernardino Mts.
12. Santa Catalina Island
13. Santa Cruz Island
14. Great Central Valley
15. Sierra Nevada Range
16. Coast Ranges
17. Tehachapi Range
18. Golden Gate
19. Mt. Diablo
20. Mother Lode
21. Yosemite National Park
22. Sequoia National Park
23. Mt. Whitney
24. Owens Valley
25. Death Valley
26. Scotty's Castle
27. Lassen Volcanic Peak
28. Mt. Shasta
29. Cape Mendocino
30. Redwood Empire

barrier across what was once a great intermountain valley. The river, a few years ago, broke over the banks of its own delta deposit and filled the basin. Since the river has been made to deliver its waters again to the Gulf of California the Salton Sea has fallen so that it is much smaller in size. The water is a saturated brine. At the bottom is a bed of salt. Having no outlet the waters become more and more saline by concentra-

Photo by W. C. Mendenhall. Courtesy Journal of Geology

Fig. 7. Old water-line marking shore of Lake Cahuilla, west of Coachella.

tion of inflowing waters. An ancient beach or shore-line may be seen many feet above the present shore, marking the height at which the lake once stood. Streams enter the lake from the mountains from the east and west in flood times following heavy rains, but these streams are intermittent, and their courses become "dry washes" during much of the year.

The journey up either side of the Salton Sea is charming—early in the season. (It is *up* northward toward San Gorgonio Pass.) During the summer months it is desperately hot, 120 degrees being not uncommon. In the spring it is delightful. The desert wild flowers can never be forgotten once they are seen in their glory, and the fields of alfalfa and the luxuriant fields of vegetables and fruits, wherever there is water from the canals which lead from the Colorado River, are the grandest in the world. Mountains to the east, mountains to the west, with streams tearing down the steep slopes to be swallowed up in the parched soil of the arid desert basin, smile upon the plain. To the west Borregio Valley pushes between two projecting points of the impending mountain range, past Coyote Mountain into a troubled wilderness of bare slopes, treeless hogbacks, and dry canyons. Here is the desert's western wall. On the highway to the south the old Pony Express depot is passed. Off to the west again is the Painted Desert in the Bad Lands of the Borregio Valley, and the Petrified Forest. Travertine Rock, described in 1853 by W. P. Blake, marks the highwater mark of the larger Salton Sea, called by Blake Lake Coahuilla (pronounced Kow-wee-yah). Yonder in the northwest rises the bleak and barren peak of Mt. San Jacinto (Ha-cin-to), an abrupt rise of nearly 2 miles from the flat floor of the desert. In passing take a look at Toro Peak, about 25 miles in an airline from San Jacinto. This is probably as wild a region as exists in all this wonderland of southern California, scantily watered, uninhabited, unvisited except by a cowman in search of his cattle, or a nature-lover who has the temerity to seek out and the spirit to enjoy this wildest of the wild southern sierra. Toro rises to a height of one and a half miles, the highest of a cluster of mountains that noses out into the desert and is known as the Santa Rosas, a part of what was called by the early Spaniards the Sierra Madre de California.

The faces of the mountains are broken by deep precipitous canyons and arroyos, mostly dry in summer but carrying in the winter the run-off of the season's storms. Noteworthy among the "seasonal" streams by which these mountain slopes have been dissected is that of Palm Canyon, a gorge that extends from the foot of the San Jacinto range 40 miles southward into the Santa Rosa range. Occupying the bed of the canyon for several miles is a natural forest of California fan-palms which has been described as one of the most enchanting in the United States. The "creek" becomes a "dry wash" on the desert plain on which is Palm Springs, in the mountain valley of San Gorgonio Pass.

The Date Farms of Indio and Mecca

Before leaving the desert valley of the south (the Colorado) to cross the Little San Bernardino Mountains to the Mojave Desert a "call" should be made at the date farms at Indio. As has been before remarked, the desert is most abject. Yet the date palm requires a large amount of water. Streams which tear down the mountain slopes with great violence and large volume when storms break among the clouds of the sierra peaks cease to be streams soon after reaching the parched desert plain where the waters sink into the porous soil. What were floods in mountain canyons are now cool fresh waters deep beneath the surface, and wherever these break forth as springs or are tapped by wells there the palm tree finds a genial habitat. Water and bright sunshine are necessary to these tropical trees. The high temperature of the torrid summers, with underground mountain waters, with the ingenuity of man, have made possible the 119 varieties of dates which this modern Garden of Eden in the desert produces. Citrus fruits, olives, figs and nuts abound, and tropical dates, unexcelled in the world, give to this region a unique distinction.

Palm Springs and San Gorgonio Pass

Pause at Palm Springs—most famous desert resort in the world—for dinner at a palatial hotel and a bath in the naturally heated mountain underground water, and bid *adios* to the parched desert, the cacti, the horned toads, and the marvellous wild flowers that are sustained by waters that we cannot see, and hasten to cross the Little San Bernardino Mountains, noting the 17-foot bore and aqueduct by which water from the Colorado River is to be conveyed to Los Angeles and southern California.

To the west of Palm Springs is San Gorgonio Pass, discovered in 1853, and hailed as the long looked for pass through the mountains by which a railroad from the east might reach the Pacific Coast. To the north is San Gorgonio Peak, at the eastern end of the San Bernardino range, and to the south is the majestic Mount San Jacinto. The "pass" is a mountain valley formed by faulting of the rocks of the earth's crust. This break in the crust of the earth is the great San Andreas rift, which extends south and east of San Gorgonio Pass and north and west to and beyond San Francisco. Movement along this rift farther northwest, particularly near San Francisco, caused the earthquake of April 18, 1906. Many faults or breaks in the crust of the earth occur in this region. The Morongo Valley, which separates the San Bernardino mountain range from the Little San Bernardino range, is a "mountain valley" formed by faulting. The fault of this latter valley is crosswise of the original drainage of Little, Big, and Dry Morongo creeks, which enter the valley from the San Bernadino mountains from the northwest. The waters of these creeks sink into the alluvium of the valley and the streams disappear, re-appearing again at the lower side of the valley and then flow over the rock-bottomed gorges to the Colorado Desert. The walls of Morongo Canyon are about 300 feet high and are nearly vertical. The rock walls are composed of granitic gneiss beautifully laminated and very much distorted, twisted, and folded. The broad plain between Whitewater River and Morongo Canyon is known as Conchilla Desert. It is thickly covered with many varieties of cactus, especially the large picturesque barrel cactus, and for this reason it has been labeled the Devil's Garden! Probably more cactuses, or more species of cactus, are observable here than anywhere else on the Colorado Desert. A Joshua Tree National Monument has been established in the Morongo Valley. It is worthy of note that a movement is on foot to establish a Joshua Tree park

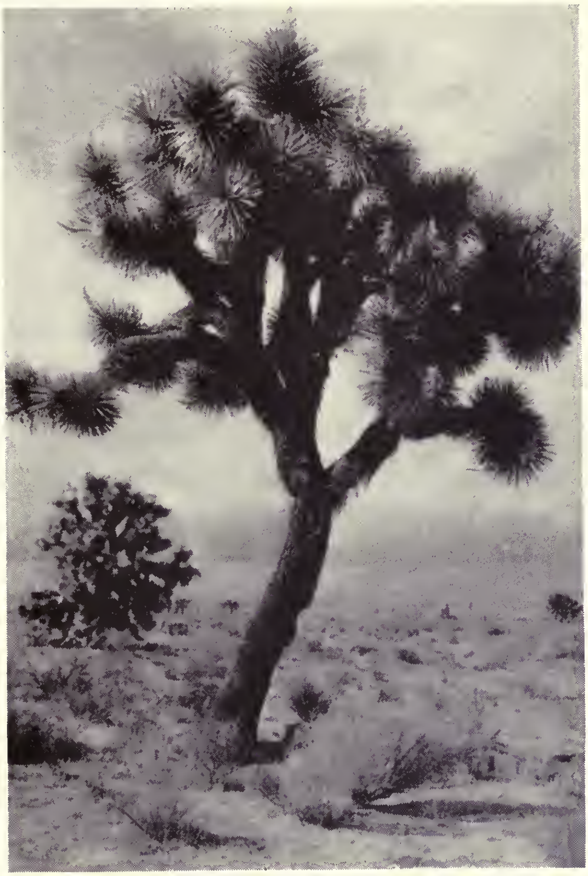


Photo by Frasher's, Inc., Ramona, Calif.

FIG. 8. Joshua tree in Devil's Garden, San Bernardino County. A characteristic giant cactus of the desert.

of 2,000 acres farther west in Antelope Valley east of Lancaster. The Joshua tree is a cactus of immense size, and characteristic of this desert country. It attains a height of nearly 100 feet, and specimens are thought to be more than 1,000 years old.

San Bernardino Mountains and Mojave Desert

The Bee-line has now crossed the Little San Bernardino

Range and now enters the Mojave Desert. These mountains are composed of pink granite or granitic gneiss, like that about the Morongo Valley and the San Bernardino mountains. East of Morongo Valley is Warren's Valley. Yucca trees are very prominent in this valley, and for this reason it has been designated on the maps as Yucca Valley. Steep alluvial slopes rise along the south side of Warren's or Yucca Valley to the base of the Little San Bernardino range. The north wall of the mountains, which extend away to the east, is broken by deep rugged canyons. On the north side of the valley east of Warren's Well is a ridge of pink granite composed largely of massive blocks of granite rounded to smooth outlines and projecting 100 to 200 feet above the residuum in which they are buried.

Water is an all-important consideration in this desert land. The desert plain is made up of detritus from the adjacent mountains and hills, and these being largely of granite the soil is an arkose sand (broken granite), though limestones and slates contribute clay to the soil. Playa basins—flat undrained areas—are common. The soil is by nature rich if there were only water. Wherever springs or wells supply water there alfalfa and livestock are likely to be found. The principal locations on the map are therefore springs or wells. Off to the east is Twentynine Palms, an oasis in the desert. Here is a group of palm trees, some older trees 70 to 80 feet in height. There is also a grove of Cottonwood trees, also willows and other vegetation. Springs issue along the line of a fault, which crosses an alluvial slope coming from the mountains to the south.

Northward for 15 miles extends the vast desert, interrupted by mountains and anon spreading out into broad valleys with playas or dry lakes. Springs and wells are designated on the maps instead of towns. Streams rush down rocky canyons for a little while, the waters to be lost to sight presently in the sandy soil. Government markers point the direction of springs or wells. Twenty miles east of Warren's Well is Twentynine Palms, and north of this 6 miles is Mesquite Springs, and near by a playa where water is near enough to the surface to enable mequite brush to grow. Northeast of Warren's Well 25 miles is Surprise Spring, so named because of its occurrence on a flat plain where water would not be expected to break out. North 20 miles is Means Well, and 10 miles west of this is Old Woman's Spring, the water perhaps coming through the alluvial soil from Rattlesnake Canyon a few miles south in the slope of San Bernardino mountains. Twenty miles north of Old Woman's Spring is Sweetwater Spring, in the Ord Mountains, then for 15 miles to Barstow the traveler will need to carry his canteen of water. And hardtack or some non-perishable food had better be carried, for the desert is little frequented by white men (or Indians either for that matter) and the scant vegetation and the rare animal denizens of the desert will furnish little to the hunter.

Mojave River starts boldly from the northern slope of the San Bernardino Mountains, but it is a losing game against the odds of little rainfall and high temperature. At flood seasons the channel, a few hundred yards wide, carries enough water to entitle it to be called a river. Most of the year it is a river in name only, with water at intermittent points along the channel. It starts courageously toward the Colorado River, but at Soda Lake it gives up the ghost and ends in the playa or dry lake basin of the so-called Silver and Soda Lakes 100 miles from the Colorado.

North and east of Barstow, where the Mojave River is crossed, lies the Calico Mountains, so called because of the different colors of yellow, red, green, and brown in the rocks. The rocks are of Tertiary age and consist of lava, sandstone, and clay. Silver has been extensively mined, and most of the borax produced in the State was at one time mined at Borate, on the east side of the mountains. The mountains rise to a height of 5,000 feet. Harper's Lake is a playa several square miles in area. Many wells furnish water, mostly at depths of less than 100 feet. Some fields of alfalfa show the effect of water, but no extensive irrigation is apparent. In Fremont Valley water is obtained from wells, and fruit trees have been planted in efforts to reclaim the desert. Alfalfa and melons are the most profitable crops grown. It is however a problematical country from an agricultural view point.

In the Rand Mountains mining of gold, silver, and tungsten have been important. A large part of the world's supply of tungsten came from this district at one time. El Paso Mountains lie to the north and west. A marked fault extends along the southeast front of these mountains. To the northeast is Searles Lake, a playa from which borax and potash in commercial quantities have been taken. Indian Wells Valley is enclosed by mountain ranges, beyond the El Paso range, and is without drainage. The Sierra Nevada Range rises on the west from the valley floor at about 3,000 feet to 6,000 feet. Streams pour down from all the mountain ranges surrounding the valley, but more largely from the Sierras. The aalluvial wash from the mountains forms the plain of the valley. Playas occur, as there is no drainage outside the valley. Water is pumped from wells for irrigation, and considerable development of agriculture has been made.

Steep Eastern Slope of Sierra Nevada Range

Our Bee-line is now along the steep eastern face of the Sierra Nevada Range, and the Mojave Desert is left behind. The eastern face of the great Sierra uplift is very abrupt, and serrated by deep canyons. The streams of the canyons cease as they approach the desert plain and the waters disappear in the alluvial soil at the foot of the high range. Owens River flows for 50 miles near the foot and along the front of the great Sierra Range. From this river water is conveyed by aqueduct to Los Angeles, more than 100 miles. Owens River nominally drains into Owens Lake, now dry. The elevation of the lake bed is 3,550 feet. We are now climbing rapidly toward the crest of the great Sierra Range. Kern Mountain, a few miles west of Owens Lake is 11,493 feet above sea. Kern River has its sources in the snow-laden high mountains and its waters move down the western slope towards the Pacific Ocean. This region is aptly called the Alps of America. The most southerly moving glacier in the United States gathers its snows on these high peaks. Mt. Langley, elevation 14,042 feet, and Mt. Whitney, 14,496 feet, stand as guardians at the eastern edge of Sequoia National Park. Mt. Whitney represents the highest elevation above sea-level in the United States, while 70 miles away to the east is Death Valley which is nearly 300 feet below sea level. Sequoia trees, the most magnificent and the most ancient specimens of growing plants in the world have their home on the high cool slopes to the west. To the east, at the foot of the steep slope of the Sierra Range, is Owens Valley. In a reservoir south of Big Pine waters which pour down the steep eastern wall from the snow-covered crest of the Sierras are impounded and conveyed by aqueduct to Los Angeles. Owens River, the railroad, the highway, and a power transmission line, occupy the valley. To the east is the desert. Owens River disappears in Owens Lake. To the north from Mt. Whitney, along the crest of the Sierra Range, all having elevations of more than 13,000 feet, are Mt. Bernard, Junction Peak, University Peak, Mt. Baxter, Split Mountain, Mt. Sill and Palisade Glacier, Mt. Goddard, Mt. Darwin, Mt. Humphrey, Mt. Hilgard, Mt. Abbott, Mt. Morgan. From the snow-clad crest come the headwaters of Kern, Kaweah, King and San Joaquin rivers. Glacial lakes of alpine beauty nestle in pockets. The great canyons of King and Kaweah rivers are below on the western slope. The Devil's Post Pile (National Monument) is a vast pile of basaltic columns (ancient lava) which rivals in grandeur and character the Giant's Causeway in Scotland. Near by is Casa Diablo hot springs and geysers. Alpine lakes, relics of past glaciation, abound in fish. This is the high sierra. Tioga Pass, elevation 9,941 feet, affords a highway across the great range. The Mari-

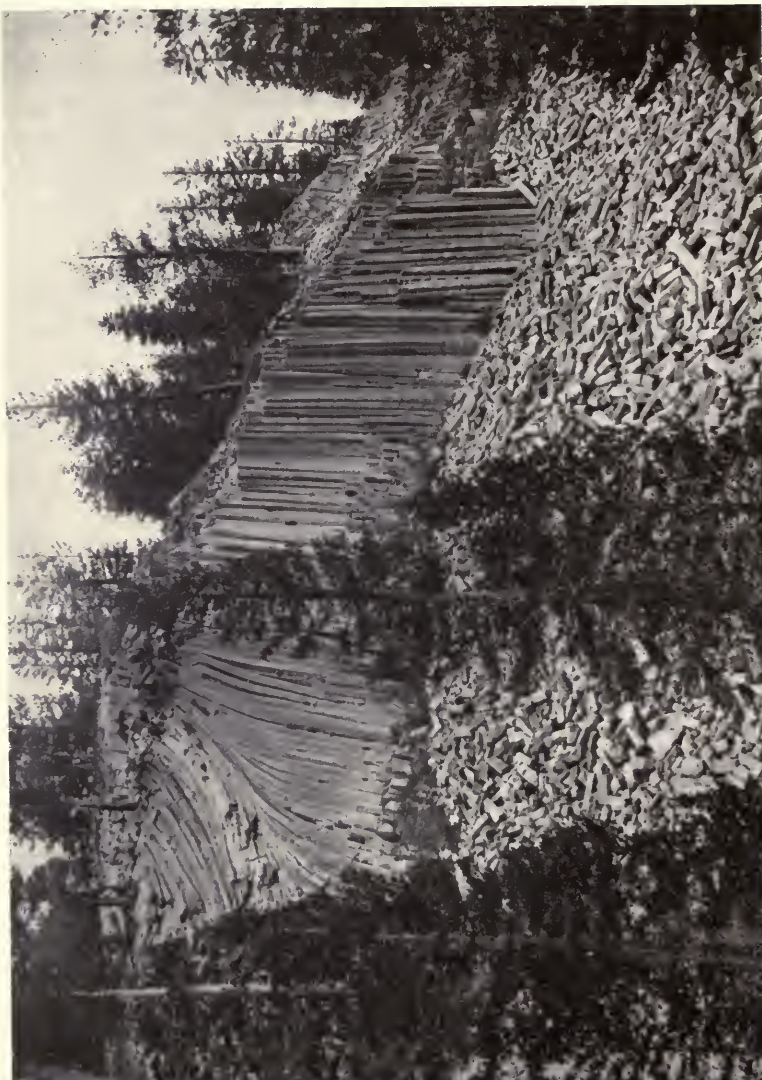


Photo by Erwin E. Richter. Courtesy the Sierra Club

Fig. 9. Devil's Post Pile. Columnar basalt. Structure resulting from cooling of out-poured mass of molten lava.

posa Grove of Big Trees is on the western slope, as Yosemite National Park is approached. Mt. Lyell, 13,090 feet, stands at the boundary of Yosemite Park. Glaciers cling to the high peaks of Mokelumne Basin. These lie in amphitheaters on the north slopes. Dana Glacier lies nestled on the north side of Mt. Dana in a deep amphitheater. Largest and most prominent on the landscape are the glaciers of Mt. Lyell and Mt. MacClure. These dazzling ice bodies give the group of peaks a truly alpine aspect. Down the valley of the Merced is Yosemite Valley, Yosemite Camp, Bridal Veil Falls, and Yosemite Falls. To the

Photo by Adolph Knopf, U. S. Geol. Survey

FIG. 10. Cirques on crest of Sierra Nevada. The gathering grounds of glaciers. At head of South Fork of Bishop Creek.

north is the Cathedral Range and Cathedral Peak. Tuolumne River is fed by streams from canyons that flank the crest of the great Sierra Range. Tuolumne Meadows and Hetch Hetchy Valley are below. The Tioga Road leads via Tioga Pass across the high range to Mono Lake. North of this is Sonora Pass, via the Devil's Gate. Mono Lake is a desert lake in the Great Basin east of the Sierras. On the (western) slopes of the Stanislaus is the Calaveras Grove of Big Trees. Alpine County is on the crest of the Sierra Range. Mountain torrents rush down to feed the Stanislaus, the Mokelumne, and the American rivers. The steep eastern slope of the range is drained to Carson River, which carries the mountain waters out upon the arid plain of the Great Basin where they are lost. Lake Tahoe is fed by streams from the mountains, but its waters evaporate and it has no stream outlet to any ocean. It is at an elevation of 6,225 feet. A beautiful mountain drive leads around the lake.

Ice of the Glacial Period Left Its Mark

During the Glacial Period the high region of the Sierra was extensively covered by ice, snow, and névé. There are few more imposing sights than the ice-swept rock-deserts of the upper Rubicon and Devil's Basin, west of Lake Tahoe. The region of Pyramid Peak and the Tellac range is characterized by frequent glacial rock basins (cirques) separated by sharp ridges. Lakes of glacial origin, in basins scooped out of the rocks, or formed by morainal dams, are common in this once ice-bound region. Moraines hundreds of feet in height represent the deposits made by ice at the extremities of glaciers. From high up on Ralston Peak a magnificent view may be had of the moraines of Devil's Basin and the rock-strewn basin of the glacier that filled the upper Rubicon Valley. Above rises a vast expanse of polished white granitic rock (granodiorite) swept clean of any vestige of soil by the great glacier. A short distance from Echo there is a knob of this hard granitic rock 700 feet high rounded by the moving ice, and south of this is Lover's Leap, a nearly perpendicular cliff of this granitic rock 1,000 feet high. The cliff is due to the action of ice and the vertical jointing of the rock.

Glaciers moved from the crest of the Sierra Range eastward toward Lake Tahoe. The valleys in which are Fallen Leaf, Cascade, and Emerald lakes were ice filled, and magnificent moraines now lie alongside and at the lower ends of these valleys. On both sides of Fallen Leaf Lake the lateral moraines are very large and typical. That on the eastern side is from a half mile to a mile in width and is 3 miles in length and 900 feet high. The terminal moraines form a dam that causes the waters of Fallen Leaf Lake to stand 100 feet above the level of Lake Tahoe.

Cascade and Emerald lakes are beautiful glacial relics similar to Fallen Leaf Lake. Less majestic than the crest region of the Sierra Range farther south this region is still of surpassing interest. The divide between the Pacific Ocean and the Great Basin is the crest of the main Sierra Range, on the right of our Beeline. To the west the waters flow into the Sacramento. To the east the waters find their way to the saline sinks of the Great Basin, a part first emptying into the great natural storage basin of Lake Tahoe, called one of the most beautiful mountain lakes in the world. The grades of the westerly flowing streams are very steep, a fall of 100 to 200 feet per mile being common. The north fork of American River has eroded a canyon which attains a depth of 4,000 feet, and is known as the American Royal Gorge.

Hunters' and Fishermen's Paradise

This is a somewhat wild and tempestous country. It is not the garden spot of California as such. Valleys have been scoured by glacial ice, and lakes occupy picturesque pockets. To the west on the Sierra slope are the great California gold fields. Waters that come from the high mountains in torrential streams, or impounded in lakes, have been harnessed for hydraulic mining. Old washings and once productive mines, deserted towns where once life was stirring, tell of the past. Fishing is fine in the lakes and streams. This is the hunter's paradise. Magnificent views of volcanic peaks, hard granitic rocks polished by glacial ice, deep-walled canyons cut by streams forced by the ice of the Glacial Period to find new channels, huge moraines deposited by the melting glaciers, lakes of clear cold water abounding with fish, and the homes of geese and ducks, forests in which roam deer, bear, and cougar, it is indeed a wild country. The forests furnish lumber, and grassy slopes and meadows furnish grazing for great numbers of sheep. Geologically the country is charming. The air is fresh and invigorating. The camper, the recreationist, the lover of the wild in nature, find in these less frequented Sierra slopes a genial habitat. It is high, but not the highest. It is rough, but not the roughest. It is a rocky mountain desert, but there are no horned toads or cacti. It is a grand mountain panorama that greets the eye. Whether it is the grandest or not depends upon the observer. It is alpine mountain scenery of a noble type.

Lassen Peak Lava Field

Lassen Peak lava field lies ahead. This great peak and lava field are in northern California between the Sacramento Valley on the west and the Great Basin on the east. The Peak marks the southern terminus of the Cascade Range. It is a great volcanic cone surrounded by a lava field which lies in a depression between the Klamath Mountains and the northern end of the Sierra Nevada Range. The peak is of volcanic origin, like Mounts Shasta, Hood, and Rainier. Running northwest through this great lava field is Lassen Peak Volcanic Ridge, formed by a belt of volcanoes 25 miles in width and 50 miles in length. Its great peaks, such as Butt Mountain, Lassen Peak, Crater Peak, Burney Butte, and a host of other smaller conical hills, are all ancient volcanoes. The lava which issued from earth's interior through many volcanic chimneys has formed conical hills or mountains about each vent. This great volcanic ridge was built up by the eruption from over 120 vents. Some of the craters are more than a mile in diameter. Lassen Peak is connected by lava with Mt. Shasta 70 miles to the north and west. It is regarded as the southern end of the Cascade Range. From the volcanic vents of this (Cascade) range were emitted the lavas which make up what is perhaps the largest lava field in the world, extending eastward covering a large part of northern California, Oregon, Washington, Idaho, and Montana, estimated to be 200,000 square miles in extent.

The latest eruption in the Lassen Peak district occurred at Cinder Cone 10 miles northeast of Lassen Peak about 200 years ago. Some of the trees killed at the time are still standing.

That volcanic activity is not yet extinct in the Lassen Peak district is shown by the presence of numerous solfateras and hot springs. At Bumpass's Hell, near the southern base of Lassen Peak, there are boiling mud pools and vigorous solfataric action. Considerable deposits of sulphur occur at the head of Mill Creek, in Hot Springs Valley, at Lake Tartarus, and the Geyser near Willow Lake. Pitt River, principal headstream of the Sacramento, crosses the lava plain from the plain of the Great Basin in northeastern California. As has been stated before, Mt. Shasta is a vast volcanic cone, built up by successive deposits of lava poured from its great throat. Its top now stands 14,161 feet above sea. Its snow capped head stands high against the sky, visible for many miles. Lavas from its crater flowed far down the valley of the Sacramento. The river has eroded a gorge in the hard lava rock, and thus nature has opened a way for the railroad and the highway between San Francisco on the south and Portland and Seattle on the north.

Here Is Yreka

This is a wild and romantic country, and here is Yreka, 850 miles from El Centro by a line such as a bee might follow, but along which there is no highway! The vast rough lava plain broken by many volcanic peaks, and dissected by streams, offers a striking contrast to the low-lying desert plain of the far south. This is a desert of broken lava rock, high, exceedingly rough, home of wild game, fish, and fowl, scene of terrific Indian warfare, favorite haunt of the hunter, land of logs and sawmills, an empire in the rough, wildly fascinating. Yreka, here we come. The journey has been long but it has been delightful. We are prepared now to study the marvelous story of California's geology.

Chapter V

THE BEHAVIOR OF RIVERS

Two Opposing Forces Always at Work

Throughout the earth two great geologic forces are constantly at work, tearing down and building up. Wherever there is land the forces of destruction or tearing down are at work. Correspondingly somewhere building-up processes are going on. Frost and heat, wind, and chemical agencies are all the time at work breaking down the rocks, and the broken particles tend to be carried away by running water. No rocks are so hard that they are not affected by chemical agencies. No rocks are so resistant to the action of wind and the impact of running water that they are not worn and broken and reduced to particles. Then running water tends to carry the broken fragments down-hill in response to gravity. Thus the continents are being all the time worn down and the rock particles transported to the sea. On the sea bottom ultimately all come to rest. Here the tiny sand grains and muds settle and new sedimentary formations are built up. These tend to become solidified, and new geologic formations are the result.

Continents and seas are all the time changing. Land areas are depressed and sea bottoms are uplifted. Sediments deposited in the seas have become dry land; the muds have become solid rock. Wind, frost and water all set to work again to destroy the rocks, and again carry the particles to the sea. This has been going on throughout all geologic time—ever since the land of the primitive continents first appeared above the surface of the primeval ocean. Rivers have been the great agency of transportation. They not only carry away the bits of broken rock, but running water is a powerful agent of destruction, acting as a hammer in striking and breaking and grinding the hardest rocks.

The California that we know is above the sea. Some parts of the State have been above sea level and subject to the processes of erosion just mentioned for long periods. Portions of the State have been very recently lifted above the level of the waves. Part of what we call California is below sea level, as witness the islands off the coast which are mountain tops that project above the surface of the sea from a continental shelf. Rivers, some of them mighty rolling hammers, traverse the land surface. Large or small, they are all working at destruction of the land, and carrying broken rock toward the sea. Some are mighty rolling reservoirs whose currents are sluggish so that they deposit their burden of sand and mud and build up plains which may in time of flood be again torn up and carried farther on toward the sea. Some "rivers" are rivers in name only except in time of deluge from rain or melting snows. "Dry creeks" become raging torrents that move with terrific power and great destructiveness. The streams are all agents of destruction. Large or small, crossing broad plateaus with constant flow or sinking into the parched soil of the arid desert, or hammering down mountain slopes through deeply eroded canyons, all are working at the great task of wearing down the land, tending to reduce mountain, plateau and hill to a plain, and ultimately transferring the rocks of the land to the sea bottom, there to again become rock formations.

How Rivers Work

It is well to inquire how rivers behave. The methods by which running water does its work may serve to explain much of the geology of this great and vastly varied State. The geology of California is very complicated. There have been many upheavals; there have been many down-throws or depressions (subsidences). But during all the long geologic ages running water has been continually and persistently at work. Every uplift has meant increased velocity in the streams and therefore greater eroding power. Every subsidence or depression has meant stagnation of erosion and a tendency to deposition of the materials eroded on higher lands. Thus vast mountain ranges have been worn down and carried away, and deposits of rock waste to almost unbelievable thicknesses laid down in basins or depressions which may or may not have been filled with water, may or may not have been bays or arms of the sea.

Courtesy Los Angeles Flood Control Commission

FIG. 11. Mouth of Lytle Canyon, about six miles north of Fontana.

That a basin such as the Los Angeles basin shall have received deposits of broken rock thousands of feet in depth is not more difficult for the mind to grasp than that rock formations thousands of feet in thickness, whole mountain ranges, have been worn down and carried away. Through such changes has California passed. Running water has been acting all the time. Rivers have been "behaving" as rivers do during all the ages from Jurassic time to the present.

How does a river begin? What is a river any way? Is there any difference between a river and a creek except in the matter of size? May a creek grow to be a river? If rivers begin and grow do they also grow old? It is said any fool can ask questions but only the wise can answer. Geologically all these questions may be answered, and no more "wisdom" is required than that of common sense and a study of what is going on all about us, almost within our own back yard.

How Does a River Begin?

Imagine a land surface having a uniform slope to be lifted above the sea. It has been stated that all lands that are above sea level are being worn and eroded, and that the particles of rock tend to be carried to the sea. (All earth materials in a general sense are rock.) If rains fall and winds blow and heat follows cold then the land will be eroded and streams will tend to be developed. For simplicity let the new land area be thought of as a continent. Where will a river begin? Let the rains descend and the winds blow. The first water to reach the sea from the land will be that which fell nearest the edge of the land. Then the *next* water to reach the sea will be that which fell next beyond inland. This will be granted without much "wisdom." Then it must follow that the *next* water to reach the sea will be that which fell a little farther inland. Then the water that fell at the center of the new continent will be the last to reach the sea. Running water erodes the land, hence some particles of rock will be carried to the sea by the waters that first reached the sea, and so the waters that fell next inland will have the benefit of the eroded channel made by the waters that have already gone. So, farther and farther inland, the waters will take advantage of the channel eroded by the waters that have gone before. The waters from each successive area will erode as they go, and so there will be more and more erosion nearer the shore or edge of the land surface, and less and less farther from the shore, and the new valley will have less and less width and depth toward the center of the land. If we imagine the soil (or rock) of the new continent to be somewhat heterogeneous in composition (and most soils are) then the water will erode most where the soil is more soft, and so the newly formed channel will tend to become crooked. A bend in a stream means that the current will be more swift on the outside of the curve, and so the bank in the bend of the channel will be cut harder and the bend therefore be made greater. The current striking the bend or curved side will be deflected over to the opposite bank, and this bank further down-stream will in turn be cut into, and so the crookedness of the stream will be increased. Hence the winding courses of streams.

If water fell uniformly over the new continent what becomes of the water that fell as rain farther from shore? All it can do, and this is what does happen on flat lands, will be to stand in sheets and shallow ponds if there are irregularities in the surface until it is evaporated into the air or soaks into the soil.

How then does a river begin, and where does it begin? Evidently it begins at its own mouth. How does it grow longer? By pushing its head back landward. Does a river grow old? Yes. It was young when it started. The first channel was a V-shaped gully. The V-shaped valley grows longer by pushing back its head. It becomes crooked because of inequalities in the soil. The stream valley is older down stream and younger upstream. Every bend tends to widen the valley by reason of cutting the bank and building up a bar on the inside of the curve. Farther down the valley is more broad. Side cutting of the banks tends to the development of a wider and wider floodplain. A wide floodplain means that more sediment is carried down from above than can be delivered at the mouth. The river in its lower course has ceased to be down-cutting and has become a building-up stream. It is building up its bottom instead of digging it deeper. This is called aggrading. Up stream it is degrading. Down stream it is older; up stream it is younger. A river has grown old when its floodplain has broadened till only low hills or ridges separate it from other rivers on either side and the whole landscape has been reduced to low hills. When the hills are practically all gone the stream has reached its ultimate limit and is essentially "dead," and the landscape is mature or "old." It has reached base-level, the ultimate of all lands that are above the sea.

Photo by G. W. Stose, U. S. Geol. Survey

FIG. 12. Tidal lagoon at mouth of San Luis Obispo Creek, showing how streams behave when they cannot get into the ocean.

California Rivers Not So Simple

Some of California's rivers are old, but the principal rivers that flow in well defined valleys have not come into existence in the manner that has been described. Rivers such as have been described are spoken of as *consequent* rivers, because they follow as a consequence the topography of the land. Water runs down hill and erodes as it runs. If not disturbed this would be the natural method of development of drainage streams. Along the coast where the land has but recently been uplifted above the sea streams that follow the simple pattern that has been described occur. They are mostly short. The two great rivers of the State, the Sacramento and the San Joaquin, are not "consequent" rivers. The Feather, the Mokelumne, the Tuolumne, the Merced, Kings, and Kern, are not consequent streams. Some tributaries of these rivers are consequent; have developed from their own mouths where they join the parent stream. That is the way streams develop where rains fall on the land and drainage develops without interference of some geologic catastrophe. But great catastrophies have occurred in California. Great upheavels, great ruptures of the earth's crust, have occurred. Rivers that had been established as a consequence of the natural slope of the land have been interrupted by the upheaval of mountain ranges, and by the outpouring of vast masses of molten rock from the interior of the earth, by the outflow of lava from volcanoes. Ice of great glaciers flowed over large areas and filled river valleys, and on melting left deposits of gravel, sand and clay. Sometimes these deposits filled and obliterated valleys. Valleys were sometimes dammed and lakes formed in basins, and new outlets had sometimes to be formed.

Stream Courses Determined by Rock Structure

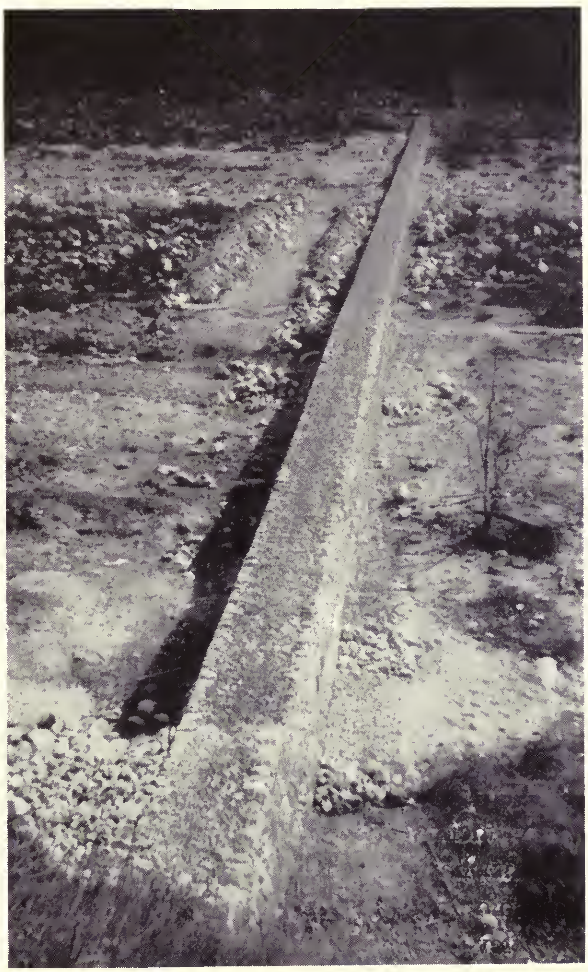
Thus "subsequent" streams came, following or subsequent to the changed conditions of the land surface. The changed conditions of the land surface were not in any way caused by the streams that already existed. The new streams developed to fit the new conditions. Since the streams followed the changes in the surface of the land and adapted themselves to the new conditions they are spoken of as *subsequent* streams, and the drainage is subsequent drainage. The upper Sacramento, Feather, San Joaquin, and many rivers of the western slope of the Sierra Nevada Range would not have been where they are had it not been for the great uplift by which the range was formed, and had not the great slope from the crest of the range toward the west been established. The Truckee River would not be carrying waters from the crest of the Sierra Range eastward and leaving it to evaporate in Pyramid Lake if it had not been for the great uplifted mountain range on which snows gather and melt, and the waters seek the easiest way to escape to the lower lands of the Great Plains. The river is subsequent to the uplifting of the mountains.

The rivers of California offer a fascinating study. A glance at a map of the State showing the rivers suggests at once that the rivers have not developed in the simple manner described above. The rock structure of California is very complex, resulting from the geologic changes that have occurred. The development of drainage systems on a new continent recently lifted above the sea has been outlined. The principles of stream action remain valid even though interruptions by geologic forces modify and change the normal development of streams. The streams of California are no exception to the streams of the world. Water runs down hill in California, and running water carries earth materials and erodes the land. Streams in California grow longer by pushing their heads back landward. Young valleys are V-shaped. Far up-stream of the great rivers that serrate the wide western slope of the Sierra Range many examples may be seen of head gullies cutting back into the higher land beyond. Branches or tributaries are developing today just as they may be imagined to develop on an ideal continent newly elevated above sea level. It is apparent, however, that the rivers of California are not generally *consequent* streams. They do not flow from higher land down uniform slopes to the sea. Upheaval of mountains and other movements of the crust of the earth have obstructed streams that had already been established and changed their courses. Thus consequent streams have become *subsequent* streams, i.e., they have been forced to adopt new courses because of obstructions, such as the upheaval of mountain ranges, the pouring out of lava from volcanoes, and filling of valleys by glacial deposits.

San Joaquin and Sacramento Rivers Flow Where Opportunity Offers

The two principal rivers of California, the Sacramento and the San Joaquin, conform only in their upper courses to the principles indicated for the development of rivers on an ideal continent. The San Joaquin and its tributaries flow down the western slope of the Sierra Range. These streams, or those that preceded them, probably once discharged their waters into a body of water that occupied the great basin now known as the Great Valley of California. These streams and their ancestors have been carrying sediments into the Great Valley for long ages. The great mountain uplift which preceded the present Sierra Range was eroded by streams, and was worn down to a plain, and the rock materials carried by the streams now form strata of sedimentary formations that form the floor of the Great Valley. The streams that now flow down the Sierra slope may have had their courses determined by drainage systems that had been developed before the latest upheaval of the Sierra Range. However, in their upper courses they are now active streams. Tributaries of the main streams are pushing their heads back into the land. But the main streams have been developed not by pushing back from the sea landward but from greater rainfall and from melting glaciers high on the mountains. They thus have come to flow where opportunity best offered. They are *subsequent* streams, streams that have developed subsequently to the uplifting of the land. They have cut deep canyons because they flowed across hard rocks, and carried much sand and gravel which have acted as chisels cutting the rocks over which they were driven by rapid streams. Breaks in the crust of the earth, faults, have in some cases furnished channels ready made, and streams have followed along their courses. Streams whose courses have been determined by rock formations, that is, streams that follow the contour of the land, are called subsequent streams because they follow the contour of the land.

The coast of California has but recently been lifted by earth crustal movement above sea level. Along a narrow belt bordering the sea there is land that is akin to the ideal continent that has been described. North and south of San Francisco Bay raised beaches, in many places marked by wave-cut terraces, show that the land has but recently been raised above sea level. Short streams have developed, pushing their heads landward in



Courtesy Los Angeles Flood Control Commission

FIG. 13. Cucamonga Creek, Los Angeles County. Dam designed to spread the water in time of flood.

V-shaped valleys. These are consequent streams. Where the mountains are close to the shore-line short channels with steep gradients extend landward only short distances. Others enter the ocean by comparatively broad mouths, their lower courses having broad floodplains. Farther upstream the valleys become V-shaped. Many such streams flow in torrents down mountain sides eroding deep canyons, but slackening in speed over terrace plains toward the sea, and so depositing sediments borne from the high lands, and building up floodplains.

Rivers Superimposed Upon the Landscape

In striking contrast are such streams as Salinas and Coyote rivers south of San Francisco Bay, and Russian, Eel, and Klamath rivers north of the Bay. These latter enter the ocean over broad floodplains, often meandering widely through large mountain valleys. Their courses are determined by mountain ranges, or by softer and more easily eroded rocks. They are mostly subsequent streams.

The Salinas River occupies one of the important valleys of southwestern California. The valley of this name, or more properly the Salinas Basin, is 150 miles in length and its greatest width is 45 miles. It is a long narrow valley walled in by steep mountain slopes. It is flanked by parallel ridges on the west and by a broad mesa or elevated plain on the east back of which are the crests of the Santa Lucia and Diablo ranges.

There are some striking features of this river and valley. What is commonly spoken of as the Salinas Valley is not really the valley of the Salinas River at all. The present drainage of the basin is an inheritance from past geologic ages, and not a normal development such as has been described for a newly raised continent, howbeit this part of California has only recently, in a geologic sense, been elevated above the ocean, as is shown by the elevated beach marks and wave-cut terraces along the coast. The Salinas River has its source on the eastern slope of the San Lucia Range, 150 miles south of its mouth near

Castroville. The streams which enter the basin from the adjacent mountains are torrential, as is the Salinas during the season of heavy rainfall. The annual precipitation is light, probably not more than 10 inches. The river is a raging torrent during the flood season, but its bed is dry so far as any active stream is concerned during much of the year. Gullies are cut into the mountain sides at the headwaters of the tributary streams. At these headwater sources the principles of stream development for consequent streams apply. The Salinas itself, however, does not conform to the simple law of drainage development. In fact the Salinas is not a drainage stream but is what is known as a *superimposed* stream. In other words, it has inherited its present course from a series of geologic events that go back through a long series of changes.

The river does not follow the valley to which it would seem to belong. North and east of San Luis Obispo the stream leaves the flat open valley bottom and flows through a canyon eroded into the hard granite rocks of the mountains that border the valley on the northeast. This canyon has been cut by the river to a depth of 500 to 700 feet. The river continues in this canyon for three miles when it approaches the flat bottom of the valley, only to again turn back into the hard granite, and emerges again upon the broad valley bottom northeast of Margarita. Three principal tributaries enter from the west across the broad valley bottom. These are the Rinconnaida, the Trout, and the Santa Margarita. These streams cross the broad valley in a generally northerly direction. The Rinconnaida joins the Salinas at a point where the latter emerges from the granite and touches the edge of the valley. From this point the Salinas again turns away from the valley and pursues its course through the granite. The Trout and the Santa Margarita flow across the flat valley bottom, being separated only by a low divide. These enter the Salinas about three miles apart, about three miles northeast of Santa Margarita, where the main river again emerges from the granite canyon. The

Salinas thence proceeds northward on the floor of the great valley.

Such behavior of a river can hardly be explained on the basis of differences in hardness or texture of the rocks encountered by the streams. It has been stated that the history of drainage in this region goes far back through periods of great change in the development of the landscape. During preceding geologic periods, the full story of which need not be entered into here, this region was depressed, or subsided, below sea level, and sediments were deposited of widespread geologic formations. Subsequently upheaval occurred and erosion of streams ensued. During long ages (as time is measured in years) erosion continued and the rock formations that had been laid down in what was probably a bay or arm of the ocean were carried away. Drainage systems adapted to the conditions that then prevailed were developed. The rocks that formed the surface of the land then are thought to have been soft and easily eroded. The ancestor of the Salinas River was developed upon the landscape. It cut down its channel into the soft rocks which overlay the granite of the present mountain ranges. As the channel of the Salinas River was deepened it came upon the hard granite rocks below. A river cannot change its course simply because it cuts down and encounters hard rocks. What it does is to proceed to cut for itself a channel into the hard rocks. That is what the Salinas River did, and the river now flows through canyons cut in hard granite rocks, because it could not get out of its established channel. Because the land stood at a higher altitude than now the current was more swift, and as sand and gravel were carried from higher lands these in the accelerated stream chiseled the hard granite rocks and cut the canyon. The broad flat plain of Salinas Valley is part of what is called a peneplain. This was formed by the erosion of streams that reduced the region to a stage of old age, leaving only the hard ridges of granite or uplifted mountain masses standing above the general level. The drainage that had been established on the earlier landscape was let down, as it were, upon the older rocks below. Thus the Salinas River was *superimposed* from above upon the harder rocks below. The channel once established, the river could not get away. And so it remains to this day.

Unique Behavior of Santa Ana River

Santa Ana River is interesting not only for its own behavior but for the behavior of men toward it. The total length of the river is about 100 miles. It rises in the San Bernardino Mountains, its highest head channels cut in the hard granitic

Photo by H. C. Troxell, U. S. Geol. Survey

FIG. 14. Sawpit Canyon, near Monrovia, Los Angeles County. Boulder transported onto bridge by flood water.

rocks, 11,000 feet above sea. The fall toward the sea is terrific, and the main upper stream and tributaries are deeply incised into the hard rocks. The waters tear through a rugged canyon westward a matter of 25 miles when the stream turns southwestward across the San Bernardino Valley. The Santa Ana Mountain range lies across its course. The river crosses the mountain range through a deep and rugged canyon, and then crosses the flat coastal plain to the ocean at Newport Beach. In the upper canyon the water is used in a hydroelectric plant to generate power, then passes through two more hydroelectric plants farther downstream before it reaches the great San Bernardino Valley. Here it is diverted into high-level canals and is used for irrigation and municipal purposes about Redlands and Highland. Water which seeps through the porous soil of the plain is recovered by pumping, by flowing wells, and from springs, and is used for irrigation about San Bernardino and Riverside. The river itself furnishes the power from farther upstream for pumping purposes. The hard bedrock beneath the porous soil forces some of the water which has soaked into the gravel of the river bed above Riverside Narrows to come to the surface and form a stream again. This is again diverted for irrigation through canals about Santa Ana and Anaheim. The seepage water from irrigation is once more recovered by pumping and from flowing wells on the lower coastal plain west of Santa Ana. Thus it is seen that water may be used seven times in its journey to the ocean from the mountain heights from which it comes.

The river has its own "behavior" in respect of the rocks and the character of the land over which it flows. Man's behavior toward it makes it serve a manifold useful purpose. The source of the river is high in the San Bernardino Mountains. There snows gather, and on the mountain slopes torrential rains pour. Some water is stored in reservoirs high in the mountains to be released as needed. The annual precipitation on the higher tributaries may be as much as 50 inches. Since most of the precipitation is during the rainy season of winter, and often in violent storms, the upper main stream and tributaries become raging torrents. Such streams scour their bottoms (corrade) because of the rapid current caused by the steep grade and the vast amount of sand and gravel carried. Thus canyons having steep side walls are developed. The young tributary valleys would tend to be V-shaped if it were not for the hard rocks into which the streams cut. The hard rock walls of the canyons resist weathering so that the bottoms of the channels are cut down faster than the side walls weather. Young tributary streams, gullies, push their heads back after the fashion of consequent streams, that have been described. The river as a whole, however, can hardly be regarded as a consequent stream. It is rather a subsequent stream, that is, it tears along where it can find the path of least resistance between obstructing masses of hard rocks. The principal source of water supply is high in

Courtesy Los Angeles Flood Control Commission

FIG. 15. Rubble wall, in Sierra Madre conduit, Los Angeles County, showing effects of flood.

the mountains and the water simply has to go somewhere. It therefore goes down hill by the easiest course it can find. The course of the river from the high mountains across a broad plain and then across a mountain range and finally meandering across the flat coastal plain to the sea suggests that the course of the river was determined during an earlier geologic period, and that the stream has been let down, as it were, from an earlier landscape which has been eroded away. Thus the stream is called a *superimposed* stream.

The Santa Ana is an interesting stream. Its "behavior" is determined by natural conditions. It conforms to the laws that govern all streams. It is crooked for the same reasons that control in all streams. It corrades or cuts down its channel where its gradient is steep and the current swift enough to carry away all the sand and gravel and debris. It aggrades, or builds up, a floodplain when its current is slackened, and it meanders over a plain with lesser fall. Thus it is a meandering and comparatively sluggish stream over the plain of the San Bernardino Valley and the coastal plain, but hurries with rapid current down the slopes of the San Bernardino Mountains, and across the axis of the Santa Ana Range. Man's behavior combined with the river's behavior under the conditions that prevail gives the river an unique record. A tremendous stream in its upper reaches, it delivers but little water to the sea. As has been indicated, water from the river is used repeatedly in its downward course. Its own current is used higher up to generate power to recall the water which has already furnished power, into irrigation canals for the use of crops. Due to the "lay of the land" and the porous character of the soil it is possible for man to make repeated use of the water. However, by the river's own behavior most of the water is disposed of before it reaches the sea. But little reaches the sea. The granitic rocks of the mountains break up into a porous gravelly soil, and the water, descending from the highlands, is taken up and becomes ground water of the slopes and plain. The river, a raging torrent in its upper courses during the winter or rainy season, becomes a dry gravelly pavement in its lower courses during the dry summer season, and tributary valleys in which torrents rage in winter become dry "arroyos" in summer.

Remarkable Group of Rivers Descend Western Sierra Slope

Probably nowhere in the world is there a more remarkable group of rivers than those which flow down the western slope of the Sierra Nevada Range in California. Their general direction toward the west down the broad slope of the mountain range suggests that they are subsequent streams, following the broad topography of the land. They flow from the crest of the highest mountain range in the United States, where snows accumulate and precipitation is heavy. The streams are thus fed at their sources. They tear down the steep mountain slopes with torrential force in their upper courses. Starting from snow-covered crests 11,000 to 13,000 feet above the sea they descend with terrific force till their velocities are checked in the axis of the Great Valley of California, only a little above sea level. In their mad careers down the mountain slope they have eroded great trenches in the hard rocks, the gorges of Kern, King, Merced, Mokelumne, American, and Feather being among the grandest and most impressive of any rivers on the North American continent.

In the Great Valley of California are embraced two great river systems, the Sacramento in the north and the San Joaquin in the south. These can hardly be called drainage systems. They are escape systems for waters that fall as rains and snows in the high mountain regions that constitute the eastern rim of the great basin of the interior of California. In their lower courses they are sluggish subsequent streams. The tributaries of these two great rivers deliver the waters from the western slope of the Sierras to the axis of the Great Valley where they pool their way to the Golden Gate, or are lost in the accumulated sands and debris which have been borne from the Sierra slopes and deposited on the floor of the Great Valley.

Far to the north is the Sacramento, coming south from Mt. Shasta. The Sacramento is joined far north by the Pit, which should be regarded as the upper Sacramento. The Pit comes from the extreme northeast corner of the State, bringing water from Goose Lake, which is on the arid plain of the Great Basin east of the Sierra Range. It crosses the vast lava plain which connects the Sierra Range with the Cascade Range of northern

California and Oregon. It is not strictly speaking a drainage stream, but a channel of escape for the waters from melting snows and rains of a high, rocky and exceedingly rough lava plain. It is thus a subsequent stream. To the south is the Feather, the Yuba, and the American, all tributary to the Sacramento. These come from the northern Sierras, and traverse deep precipitous canyons. This is a vast, rough, rocky and desolate land. Plumas, Sierra, Nevada, and Placer counties, traversed by the headwaters of these streams, were the scenes of the gold diggers of '49. All this region of north-central California contributes water to the Sacramento.

The southern and major portion of the Great Valley of California is occupied by the San Joaquin River and its tribu-

Photo by R. W. Pack, U. S. Geol. Survey

Fig. 16. Boulder of granitic rock in San Joaquin Valley, two miles from mouth of Tacuya Canyon, and moved that distance by running water.

taries. The San Joaquin rises in the high Sierra southeast of Yosemite National Park. It flows southwestward to the trough of the Great Valley, and thence pools its way northwestward but little above sea level to Suisun Bay, meeting tidal waters from the ocean. The principal tributaries of the San Joaquin north of the main stream descend the Sierra slope in a southwesterly direction parallel to the upper main stream, and join the lower main stream from the east. These are, from north to south, the Mokelumne, Calaveras, Stanislaus, Tuolumne, Merced, Chowchilla, and Fresno. The principal streams from the Sierra south of the San Joaquin are, in order from north to south, the Kings, Kaweah, Tule, and Kern rivers. The Kaweah, Tule, and Kern rivers are lost in the Tulare Lake depression, and under normal conditions send no water to the San Joaquin River. Kings River at times discharges directly into the San Joaquin. No water from Kern River has reached the San Joaquin in recent years. Kern River may sometimes send waters to Tulare Lake but mostly to Buena Vista Lake. Buena Vista Lake is in the Kern Basin, which is in the extreme southern end of the San Joaquin Valley. The lake has no outlet to the ocean, its waters disappearing by evaporation and soaking into the porous soil.

The streams from the west side of the Sierra Range are notable for the great gorges they have cut. The gradient of the stream beds is high, being as much as 250 feet in a mile. Such fall gives tremendous eroding power. Rains occur in violent downpours. These, with the melting snows, which gather to great depths in the high altitudes of the Sierra, give high velocity to the streams. Much sand and gravel, supplied to the headwaters streams by erosion of the mountain slopes, give rapid cutting power to the swift flowing currents. Under these conditions bottom cutting is rapid, and gorges with steep walls result. The Yosemite Valley is regarded as one of the most marvelous in the world. It is, however, rivalled in stupendous grandeur by the canyons of Kings, Kern, Tuolumne, and Stanislaus, and by the Royal Gorge of the American and that of the Feather farther north.

At the mouths of the streams that enter the San Joaquin Valley vast deltas or alluvial fans have been deposited as the currents of the streams are slackened. Across these alluvial plains channels have been cut and the waters finally merge into the San Joaquin, which moves slowly northward through the great trough of the Central Valley. The great streams of the

Kern, Kings, and Tule, descending with high velocity from the mountain slopes, become lost in the porous soils of their own deposits. The vast amount of debris which has been borne down the courses of the streams of the Sierra slope forms a floor of porous soil in the lower San Joaquin Valley. Into this great plain of alluvium much of the waters that pour down the mountain slopes soak and are lost. The deltas that have been built by the rivers from the east merge with those built by streams flowing east from the Coast Range. Thus a vast alluvial plain has been built up across the southern part of the Great Valley. The delta of Kings River has been built out till it meets that of Los Gatos Creek from the Coast Range, and a ridge thus crosses the Great Valley.

Several Types of Rivers

Several types of rivers have been considered, consequent, subsequent, and superimposed. Another type of river remains, to which, since they have ceased to be active and have gone out of business as rivers, the name "Retired" river may be given. Such are the Mojave and the Amargosa. These rivers rise in the mountains, the former in the San Bernardino Mountains, the latter far north in the Pahute Mesa, in Nevada. Both rivers start off with alacrity. But the odds are against them. They start with the torrential vigor of mountain streams, consequent at their sources. Heavy rainfall in sudden storms give vigorous currents in the upper stream courses.

In the San Bernardino Mountains the precipitation, as great as 50 inches annually, makes the headwaters vigorous. Small streams tear down the mountains. The great plain to the east and north is mantled with a porous soil which has been formed from wash from the mountains. Soon the head streams have gathered and attempted to form a real river. Out on the plain the precipitation is 2 inches, or in some years none at all, up to 3 or 4 inches. The porous soil takes up the water. Flat saucer-like basins, playas, serve as catch basins for what water does fall. Evaporation is very rapid. The river loses more and more of its water. Presently there is no river save occasional pools separated by beds of sand, silt, and gravel. For a short time in the winter and spring the river operates. Then it dwindles. At length about 125 miles from its "source" in the San Bernardino Mountains it gives up altogether and spreads out what water it still has on the flat saucers of Soda and Silver lakes (playas). So it ceases to be a river. It has "retired" from active service. It is a relic of what was under a more humid climate a real river. (That was during the Ice Age, when waters from melting glaciers kept it at flood stage.)

Retired Rivers of the Desert

With all its eccentricities the Mojave River tells of a past that is far gone. Once the land was higher. Much rock and soil have been carried away by erosion. Once the proud river ran over a landscape that was many feet above the present landscape. The granitic rocks of the mountains that now stand above the plain were buried underneath softer overlying formations. The river then went about its business. It cut down into the soft rocks. Presently it encountered the granite rocks below. It had established a channel. It could not get away from the channel. It carried sand and gravel, and these served as chisels to cut the hard granite. So as the landscape was reduced by erosion and lowered the river kept cutting down its channel. And thus there is now the granite canyon through which the river moves (when there is any water) instead of going around the mountains over soft easily eroded rocks. This is to say, the river has been "superimposed" upon the present landscape—let down from above. Thus it started out as a consequent stream. It got itself superimposed upon a hard rugged landscape, and finally, its work being done it has "retired." It is dead. Its place is marked by its channel and by the work it has done.

The Amargosa River has a hard time trying ever to become a river. It starts away north in Nevada, in the Pahute Mesa. Drainage from a large area of mountainous country is collected into larger stream lines, and what is known as the Amargosa River begins a few miles north of Rhyolite, Nevada. To the south it emerges from the dissected hilly and mountainous region into a broad valley known as the Amargosa Desert, and continues thence south for 50 miles. It gathers some water, and flows south, actually flows, across into California. Swinging around a mountain range it turns to the northwest and discharges what little water it has left into the bottom of Death Valley, the lowest point in the United States, and 296 feet below sea level, 80 miles east of Mount Whitney, the highest point in the United States.

The Amargosa tries as best it can to be a river. It emerges from the arid region of Nevada with what water it can get, loses more and more as it moves into the Mojave Desert region, then seems to get discouraged and turns north between mountain ranges, and gives up the ghost in Death Valley. Let us call it a subsequent stream. Such stream as it is, it follows the lines of least resistance between mountain ranges. It finally gives up because here in the hottest place in the United States (highest known temperature 134°) it cannot get enough water to save its face. It therefore "retires" under the brow of Mount Whitney.

Chapter VI

THE GEOLOGICAL STORY BRIEFLY TOLD*

"In order to gain the truths of rock history it is necessary to know the processes which cause the results, and the conditions under which those processes operate." (Herbert Gregory.)

The Beginnings of California Very Remote

The beginnings of California date far back into the dim ages of the past. The geological story of the State extends over the lapse of time since the beginning of the North American continent. When "The Beginning" was is enveloped in uncertainty.

"It appears probable that the beginning of Caenozoic was about 60,000,000 years ago; of the Mesozoic about 200,000,000 years; and of the Palaeozoic about 540,000,000 years. The oldest rock thus far determined is in Carelia, Russia, and its age is computed to be 1,850,000,000 years. Rock from the Black Hills, at Keystone, South Dakota, records an age of 1,460,000,000 years. Since the oldest dated rocks are intrusive into still older formations it is probable that the earth is at least 2,000,000,000 years old. Thus nearly three-quarters of geologic time transpired before the Cambrian, which preserves the first adequate record of life.

"Jeans has expressed the immensity of geologic time effectively in the following simile: 'Let the height of the Woolworth building represent geologic time. We may then lay a nickel on the tower to represent the time of human existence. A thin sheet of paper on this will represent all historic time.'" (Schuchert and Dunbar, Textbook of Geology.)

* This chapter is somewhat technical, and may be omitted by the general reader without losing the thread of the narrative.

The primitive continent, the ancient Archaean land, was represented in California by small areas that stood above the level of the sea. The backbone of the continent was a ridge which is now the axis of the Rocky Mountains. A large land area, spoken of as the original V-shaped continent, extended from Labrador southwest into what is now the northern United States, and northwestward far toward the Arctic regions. Probably parts of what is now California have been above sea level during all the ages since Archaean time. All lands that are above sea level are subject to the weathering action of the elements and the erosion of streams that flow off the land. The sediments carried from the primitive land areas became the stratified rocks of later formations.

Cambrian, Silurian, Devonian, Carboniferous rocks now occur in the geologic formations of the State. These rocks are recognized by the fossils that they contain. So also about all the geological formations represented in the great eras of the Mesozoic and Caenozoic down to the Quaternary and Recent occur in the rock formations of the State. The Geological Record, shown in the table of geologic formations, will give some idea of the great length of geologic time. All geologic formations that are shown in the table do not occur in any single geologic section or locality. The formations are not continuous over the State. The Geological Map of California is a rather complicated checkerboard of colors, each color representing a formation. The "formations" were made by the accumulation of mud, sands, and gravels on the bottoms of bays or arms of the sea. It has been stated that there has been land in what is now California since the "beginning." In places the land has been upheaved and in other places the surface has been depressed and covered again by the sea.

Much granite rock which now forms the surface of the land was forced up from the depths of the earth in a molten condition. The axis of the great Sierra Nevada Range, rock known as granodiorite, was once a molten mass forced up from below, Table of Major Divisions of Geologic Time, with estimated duration of each in Millions of years:

Eras	*Periods*	*Millions*	*Years*
Caenozoic	Quaternary	1	
	Tertiary	59	
Mesozoic	Cretaceous	80	
	Jurassic	35	
	Triassic	25	
Palaeozoic	Carboniferous	70	
	Devonian	40	
	Silurian	30	
	Ordovician	70	
	Cambrian	90	540,000,000
Pre-Cambrian Time	Algonkian	446	
	Archaean	926	1,912,000,000

Three great erosion intervals, or "lost intervals," occurred in Pre-Cambrian time, viz., between Laurentian and Huronian; between Huronian and Algonkian; and between Algonkian and Cambrian. Other erosion intervals, or "lost intervals," separate the systems of rocks representing the geologic periods.

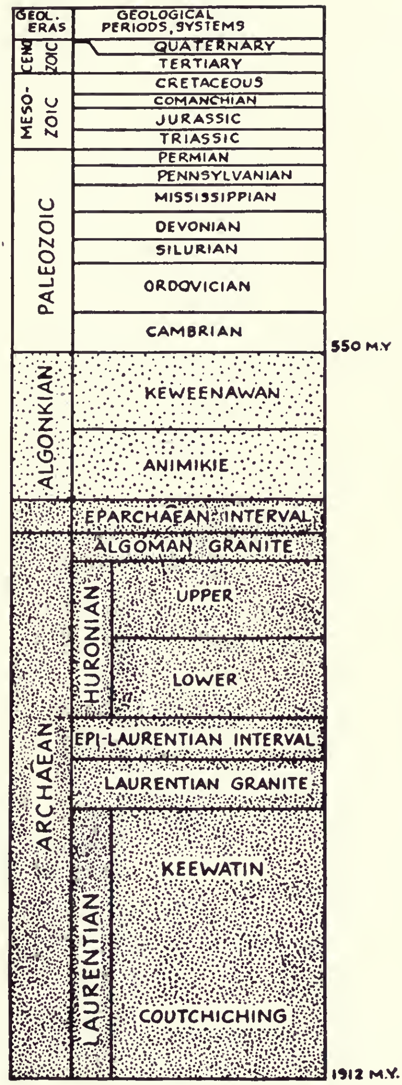


FIG. 17. The major divisions of geologic time, with thicknesses proportionate to length. (From C. A. Reeds, modified by the substitution of Prof. A. C. Lawson's classification of Pre-Cambrian.) Figures on right indicate millions of years back from present time. (After W. B. Scott.)

but was not spread out upon the surface. It was upheaved by great forces deep in the earth. The surface formations were not broken through, but were uplifted by the great mass intruded from below. (This upheaved mass is known to geologists as a batholith, from two Greek words meaning a deep lake of rock.) The surface formations which were uplifted have been removed over wide areas by erosion, so that the cooled molten rock now appears at the surface as granite rock. Much of the rugged Sierra Nevada Range is this granodiorite rock. The upheaved granitic rock, with the metamorphosed ancient sedimentary rocks into which the granite was intruded, make up the bed-rock or "basement complex" which underlies most of the formations of California.

The Geologic Record

Turning to the record of geological formations: the great geologic era following the primitive Archaean or Archaeozoic was the Palaeozoic. The earliest period of the Palaeozoic era was the Cambrian. The oldest of the sedimentary formations in which definite remains of organic life, plants and animals, have been found is the Cambrian. Cambrian rocks occur in several areas of the State. So also rocks of Devonian and Carboniferous age are found. The definite geological history of the State, however, begins mainly, or dates from, Triassic and Jurassic, or Jura-Trias, time, which time marks the early stages or beginning of the great Mesozoic era.

At this time (beginning of the Mesozoic era) a profound change in the conditions of the continent occurred. The Palaeozoic era was very long. It was essentially a time of erosion and sedimentation. The widespread formations of the Cambrian, Silurian, Devonian, and Carboniferous periods are but slightly represented in California, which means that what is now California was during this long time mostly above sea level, and hence was being weathered and eroded. At the close of the great Palaeozoic era a revolution which affected the conti-

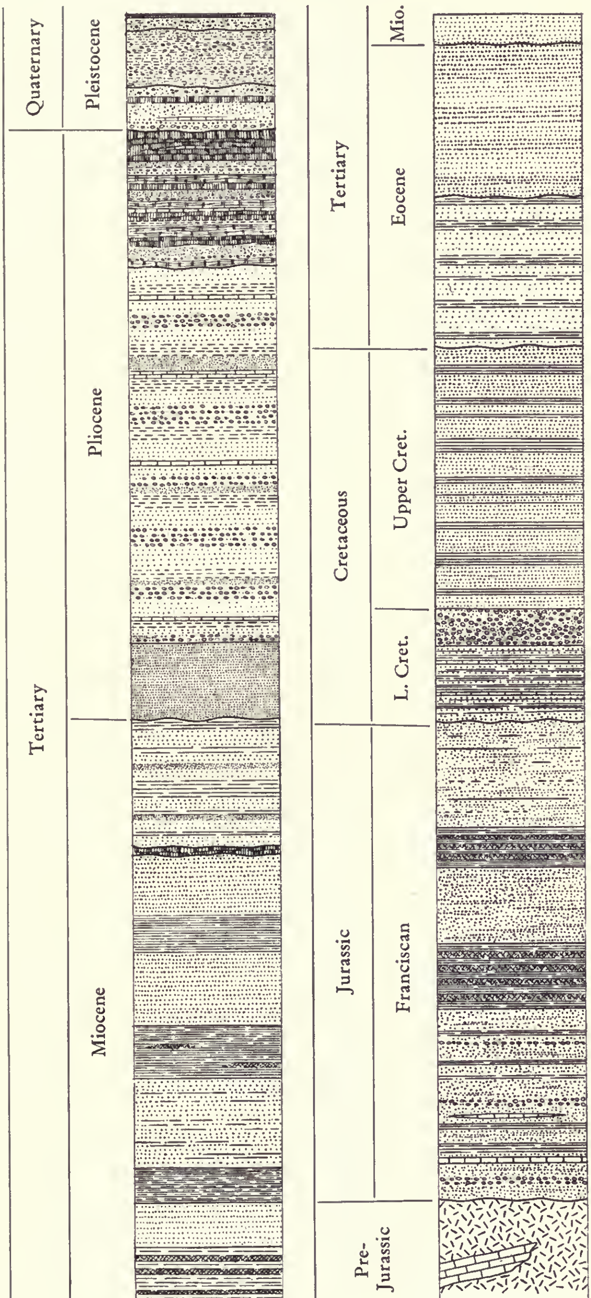


Fig. 18. Generalized section of the sedimentary rocks of the San Francisco district. The wavy lines between the formations represent unconformities or "lost intervals." (After A. C. Lawson, U. S. G. S.)

The bottom of the column at the left joins with the top of the column at the right.

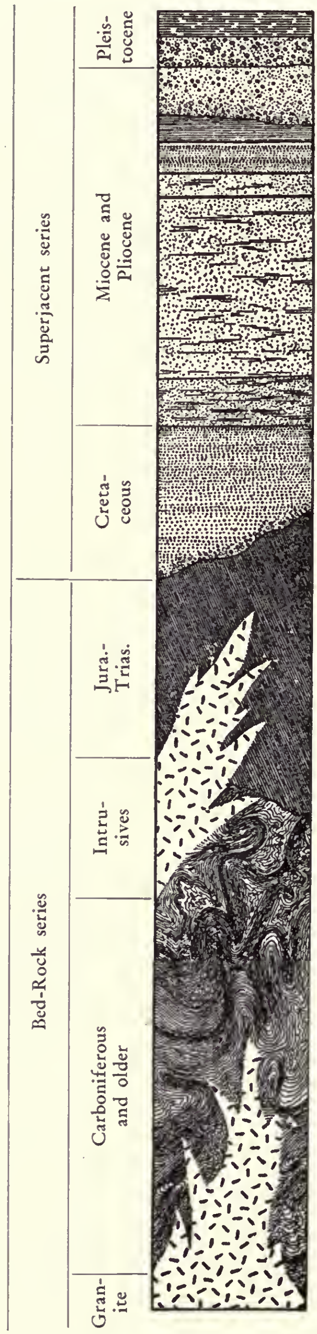


Fig. 19. Generalized section of the formations of the gold belt. (After H. W. Turner and F. W. Ransome, U. S. G. S.)

nent very widely occurred. This was a time of mountain-making on a grand scale. It affected the eastern half of the continent, however, more than the western. The Rocky Mountains had not yet been born, so to speak. The general outline of the continent was much as it is now. Much of the western half of the continent was covered by the sea and was receiving sediments from the land areas. There were lands above sea level where the Rockies now are, but this great system of mountains had not yet been uplifted. The first ancestral mountains where is now the great Sierra Nevada Range date from the Permian period, some 200 million years ago. The Permian was the transition period between the Palaeozoic and Mesozoic eras, or between the Carboniferous and the Triassic periods. It was during Permian time that the first definitely known upheaval occurred of what is now the Sierra Nevada Range.

The Basement Complex

How far back in geologic history the landscape of California reaches we do not know definitely. The most ancient sedimentary formation, that which rests upon the upheaved, contorted, crushed and broken "basement complex," as the underlying granitic bed-rock is called, is the Franciscan (Jurassic). These rocks occur over a wide area, extending both north and south of San Francico Bay, and hence the name. Rocks of the Franciscan formation, or perhaps it would be more correct to say of the group of Franciscan formations, rest unconformably upon the older rocks below. "Unconformably" is a big word, but it has a definite meaning in geological literature, and because there is no better or simpler word we are compelled to use it. It means that there is a break in the record of the rocks, a lost interval, a hiatus or gap in the succession of formations. When we say that the Franciscan rocks rest unconformably upon the older rocks below this means that there was a land surface long exposed to erosion and the weathering of the elements, and that later this old land surface was depressed so that it was covered by the sea, and sediments from other lands were carried in and deposited, so that a new formation was laid down on the rough and worn surfaces of the old landscape.

The Franciscan group of formations rests unconformably upon the very ancient rocks of the so-called "basement complex" or "plutonic basement." How old the plutonic basement is we do not know. Just when in the geologic past the vast granitic batholith which underlies the great mountain ranges of the State was welled up from the depths of the earth we do not know. It is generally thought, from such evidence as has been found in the study of the rocks, that the time was probably Jurassic, that is, that it occurred after the close of the Palaeozoic era.

The age of the ancient sedimentary formations into which the molten rock of the upheaved batholith was forced is not known. If fossil remains of plants or animals were once entombed in them—and they probably were if there were any plants or animals existing on the earth when these sediments were deposited—they were so far destroyed by the metamorphism of the rocks that thus far no evidence has been dug from the earth that tells the story. The opinion of geologists generally is that they are very old. That they were once sediments deposited on sea bottoms, and came from the weathering and erosion of rocks that formed a landscape somewhere there is not serious question. That these rocks are older than the granitic rocks that were forced in molten form under and into them there is not a question, for the ancient sedimentary rocks were intruded by the granitic rocks, and this could not have occurred unless the sedimentary rocks had been first formed. These ancient sedimentary rocks, uplifted, bent, folded, and broken, had existed as a land mass, subject to weathering and erosion, for a long time. This is evident from the rough and irregular character of the land surfaces which were buried beneath the sediments of the seas in which the Franciscan formations were laid down.

Many Unconformities

Unconformities, representing lost intervals, are common. Within the San Luis quadrangle, in San Luis Obispo County, there are sedimentary formations separated by five unconformities marking periods of elevation and erosion. The periods of elevation were often so long that sediments thousands of feet in thickness were removed by erosion. In the vicinity of Santa Cruz, south of San Francisco Bay, there are 14 recognizable formations. Nine distinct and far-reaching disturbances, recorded in profound unconformities, took place during the deposition of these 14 formations.

The Sequence of Events a Profound Problem

This is a tremendous problem for the mind to grasp. That whole regions sink till they are below sea level and then later rise and again become dry land requires some exercise of the imagination to understand. The length of time is almost inconceivable. The land does sink, and it does rise. Movement is slow, but it is none the less real. The coast of California shows by terraces that it has but recently been lifted above the sea. The movement of elevation or subsidence is so slow as not to be perceptible to the eye, and indeed cannot be detected by any measuring instruments. Thus it is seen that time is long in geology. Geological periods and epochs are marked often by unconformities which represent slow earth changes. There is a good deal of geology compressed in the above sentences. Seven sedimentary formations separated by five distinct unconformities reads very simply, but it represents a tremendous lapse of time. As we measure time in years it runs so far into the millions that the figures become almost beyond the comprehension of the mind. The time from the close of the Jurassic period to the present is estimated to be more than 130 millions of years. This the mind can hardly grasp except by comparison. Seven periods of deposition when the land was below sea level and sediments from land somewhere were being carried in by streams and deposited, followed by periods of elevation when these sediments became dry land and were in turn subject to erosion, represent a long series of chapters of geologic history. "Unconformity" means that what had been land was again below sea level, and sediments were again deposited on the eroded surface. How long the period of erosion it may be impossible to tell, but the sediments deposited on the uneven surface do not "conform" to the eroded rocks. Thus there is an "unconformity" in the series of rocks as they are observed in after ages. The unconformity represents a lost interval, as no record was preserved in the rocks of what happened on the submerged land surface while it was being eroded. Periods of elevation were so long that thousands of feet of sediments were removed by erosion, and beds thousands of feet in thickness were laid down. Can the mind conceive of such periods of time? Only by comparison. Seven sedimentary formations, and five unconformities, and in the Santa Cruz region 14 formations and nine disturbances, have been recognized where changes of land and sea were so great that unconformities or breaks in the sedimentary record occurred.

Early History of the Coast Ranges

These great and profound events in the region of the Coast Ranges occurred after middle geologic time, that is, they are post-Jurassic events. (See Geological Table, Fig. 17.) The long periods of the Palaeozoic era preceded. Before Palaeozoic was the immensely long primeval era, the Archaean. It has been estimated by competent geologists that the time preceding Cambrian (the earliest period of the Palaeozoic, and the oldest in which a definite fossil fauna has been found) was longer than all geologic time since. We may therefore accept with some assurance the conclusion that time in geology is long!

The earliest geologic event of which there is any clear record in the region of the Coast Ranges of California is the invasion of the crust of the earth by great masses of molten granite. The exact time in geological history when this great disturbance occurred cannot with certainty be stated, but it is thought to have been in early Jurassic time. It is of great importance to observe that this great upheaval of molten rock was injected into rocks which had been previously deposited as sediments on sea bottoms. The age of these earlier sediments is not known. They are, however, known to be very old. For anything we know to the contrary they may date back to the ancient Algonkian (latest period of the Archaean or Archaeozoic). All this goes to show the great age of the land of California.

Very long ago this tremendous upheaval occurred. A vast mass of molten rock was forced up from the depths of the earth. This molten rock was not poured out upon the surface, but welled up under and into the rock formations that had been laid down in ancient seas, lifting them as a great roof to the height of high mountain ranges. The culminating event of this series of great earth disturbances was the upheaval of a high mountain chain in the region of the Coast Range, and of a great mountain range or chain of ranges in the region where the great Sierra Nevada was later uplifted.

Rocks Changed by Heat and Pressure

The heat of the molten rocks changed the character of the sedimentary rocks which were intruded and upheaved. The heat of the molten granite was very great, and this combined with the great pressure involved, resulted in the metamorphism of the rocks. Thus sandstones were changed to quartzites; clay rocks, such as shale, were transformed into slate and schists; limestones were changed to crystalline marble. So great pressure resulted in folding, bending, crumpling, and crushing of the intruded rocks.

It is difficult to conceive of so great disturbance. What we now see is the crumpled, folded, crushed rocks, now eroded and broken during the long lapse of time. These are the broken and shattered schists, crystalline limestones (marble), quartzites, and other metamorphic rocks that today occur over wide areas in the mountain districts. These metamorphosed ancient sedimentary rocks, together with the granite which was forced upward in molten condition and intruded into them, now form what is called the "basement complex" or bed-rock of the Coast Ranges and of the Sierra Nevada. This bed-rock, or basement complex, forms the core or axis of the great mountain ranges of the State. It extends continuously from the southern Sierra Nevada, in the region of Mount Whitney, around the southern end of the Great Central Valley into the Coast Ranges where it becomes the bed-rock or basement upon which the Franciscan rocks rest unconformably.

After a long time of cooling of the intruded molten mass, and during long ages, the overlying sedimentary rocks that were intruded by the molten granite were worn by weathering and erosion, and in time were entirely removed over wide areas, so that the once molten rock, now cooled and forming the crystalline granitic rocks of the basement complex, has been exposed over wide areas, and now forms the rugged granitic rocks that characterize the mountain ranges.

Franciscan Rocks Rest upon Basement Complex

Upon the eroded surface of the basement complex of plutonic and metamorphic rocks rests the Franciscan. In the central Coast Ranges, over wide areas, erosion has completely removed the sedimentary rocks, uplifted, folded, crumpled, and broken, which were intruded by the molten granite. The time required for the complete removal of these early sedimentary beds must have been very great. A fact of great interest is that in very early geologic time, that is during the Archaean or Archaeozoic era, land existed in the Pacific border region. The boundary of the continent was much as now. The absence of all sedimentary formations in the central Coast Ranges between the basement complex of granites, schists, and marbles and the formations of the Franciscan group is evidence that a land area existed in the region during the long Palaeozoic era, till the ushering in of the Jurassic seas, when the sediments of the Franciscan period were deposited.

The high mountain chain which had been formed in the region of the Coast Ranges by the earth disturbances that culminated in the intrusion of granitic rocks in early Jurassic time was subjected to long-continued erosion and was greatly degraded before the subsidence which brought in a great arm of the ocean and the deposition of the Franciscan sediments. Toward the close of Jurassic time the sea encroached upon the land, and the Franciscan sediments began to be deposited over the deeply eroded surface of the crystalline complex. Wherever the base of the Franciscan sediments is exposed by erosion it is seen resting upon these granitic rocks in the form of a thick basal conglomerate or of sandstone.

The Franciscan group occurs extensively in the Coast Ranges. This encroachment of the sea upon the land extended northward as far as the region of the Klamath Mountains and southward as far as eastern Monterey County. Farther south the sediments of this period pass under the Cretaceous and other younger formations. No formation is known between the Franciscan and the crystalline basement complex. The latter then must represent the ancient land over which the sea gradually crept as the Franciscan sediments were deposited. The absence of all sedimentary formations in the central Coast Ranges between the basement complex of granites, schists, and marbles and the various members of the Franciscan group is convincing evidence that an extensive land area existed in the region during a long time, an interval sufficiently long for the removal through the whole of the Coast Ranges of the ancient sediments into which the granite magma forced its way, and for the exposure over large areas of nearly uniform granite rocks.

The character of the formations of the Franciscan group indicates a migration to and fro of the shore-line of the Franciscan sea. Limestones and cherts were deposited on sea floors far from shore, whereas sandstones are clearly littoral or beach deposits. The migration of the shore-line indicated by the alternation of sandstone with either limestone or chert means a vertical movement of the land in respect to sea level. In the Franciscan group of formations there are three deep sea deposits that are separated by rocks formed of coarser material, and sand, which indicates three notable depressions of the region in Franciscan time, and three movements of uplift. Thick deposits of sandstone means sinking sea bottom, the floor of the ocean slowly subsiding and the sands continuing to be deposited as the bottom sank. Conglomerates indicate shore deposits, as the pebbles sink before being carried far out from shore. The coarse pebbles of a conglomerate formation generally mean erosion by streams having rapid currents coming from higher lands near by. At Slate Springs, on the coast of Monterey County, the basal conglomerates and sandstones are fully 1,000 feet thick. The sandstones of the Franciscan formation are usually thick-bedded. The outcrop of sandstones, together with thin beds of shale and lenses of jasper, on the coast of San Luis Obispo Bay, near Port Hanford, show a vertical section of approximately 10,000 feet, or nearly two miles. Such a vast thickness of sandstones means that the sea bottom progressively sank as the sands accumulated. Coarse sandstones and conglomerates are usually spread over a sinking continental slope by a transgressing sea. The jasper beds, like shale, represent deep-sea conditions. The rock is made up of minute skeletons of microscopically small animals such as inhabit only deep water. The occurrence of beds of jasper rock in the widespread sandstone formation indicates abrupt change in the conditions of the ocean bottom as to depth and distance from shore.

Franciscan Rocks Much Folded and Faulted

The rocks of the Franciscan group of formation have been folded and faulted in a most complex manner, and have been penetrated at various times by dikes of igneuos rocks, in great abundance and variety. In contrast with the younger rocks of later formations the strata have been sharply folded, shattered, and crushed together through mountain-making movements as well as igneous intrusions. Volcanic lavas are inter-stratified with the sedimentary deposits. These volcanic rocks occur in sheets of moderate thickness that conform to the planes of stratification.

The Franciscan epoch of sedimentation was brought to a close by the uplift and deformation of the region. A feature of the disturbance was the intrusion into the Franciscan strata at many places of basalt and diabase, followed by the intrusion of other igneous masses. The masses of intrusive rock cut boldly and irregularly across the strata of the sedimentary beds, whereas the volcanic lavas occur in sheets that conform to the sedimentary strata. The greater part of the igneous rocks associated with the Franciscan sediments are not of contemporaneous origin but were intruded after the formation of the sediments. One of the results of the intrusion of the igneous rocks was the metamorphism of rocks with which they came in contact.

The exact age of the Franciscan formations is in doubt. The great disturbance of the strata due to upheaval, crushing, crumpling and shattering of the rocks has largely destroyed any fossil remains of plants or animals that may have been once deposited in the sediments. Such evidence as there is makes it possible to place the time of the invasion of the Franciscan sea tentatively in the Jurassic period. The Franciscan rocks rest unconformably upon the greatly eroded surface of the crystalline basement complex of granites, schists, and marbles, and over the Franciscan lies the younger Cretaceous. The earliest and oldest Cretaceous (the Knoxville) rests unconformably upon the Franciscan. Thus a "lost interval" occurs both before and after the deposition of the Franciscan.

The story is somewhat long and somewhat complicated. The age of the Franciscan is not definitely known, but is provisionally placed in Jurassic time. This, it will be seen from the geologic table, is in the Mesozoic era, and after the long Palaeozoic era. The unconformity or "lost interval" that preceded the Franciscan marks a long period of erosion of an old land surface. This part of the earth's crust sank and was covered by the sea. An uplift of the sea bottom again brought the region above sea so that it was again dry land, and was again for a long time subject to weathering of the elements and the erosion of streams. How long these "lost intervals" were we do not know. During both of these intervals this part of California was land and became dissected by streams.

The next great geologic period following the Jurassic is the Cretaceous. In the region of the Coast Ranges the "lost interval" represents a long time of degradation of the land before the subsidence which ushered in the Cretaceous.

An Arm of the Ocean Covered Central California

Far back in ancient geologic time, during the Palaeozoic era, an arm of the ocean covered much of central and southern California. In the far northern Sierra region Silurian rocks occur, and extending southward are rocks of Devonian and Carboniferous age. Sediments, outwash from continental lands somewhere, accumulated to thousands of feet in thickness. Many of these deposits were buried later beneath sediments of succeeding periods. In places these ancient sediments have been uncovered by erosion after uplift of the ancient sea bottom and now form the surface rocks. Fossil remains buried long ago in the muds, silts and sands reveal the age of the rocks. On the western slope of the great Sierra range rocks of Carboniferous (Palaeozoic) age occur, bent, folded, and wrinkled by mountain upheaval, and farther west on the lower slope are rocks of Jurassic (Mesozoic) age, also contorted by mountain upheaval and compression of the rock strata. Both these groups of sedimentary rocks have been metamorphosed by the great heat and pressure of mountain building from the original muds, sand and lime into slate, quartzite, and marble. Extending through the belt of metamorphic rocks is a group of gold-bearing quartz veins, the Mother Lode, made famous in the days of '49. These upturned beds are the remnants of the worn and eroded folds and wrinkles of sedimentary formations that were upheaved and metamorphosed in the upheavals of mountain building that preceded the great final upthrust of the Sierra Range.

Earliest Upheaval of Sierra Nevada Near Close of Palaeozoic Era

The earliest mountain upheaval of which we have definite knowledge in the region of the present Sierra Nevada Range occurred near the close of the Palaeozoic era, in the Permian period. This is estimated to have been more than 200 million years ago. This ancient mountain system was formed by the uplifting and folding of a great series of layers of slate, shale, and sandstone, rocks that were originally mud, silt, and sand derived from a land mass lying mostly to the west of the present border of the continent and laid down in an arm of the ocean. After the uplifting of this ancestral mountain system there ensued a long period of erosion. The mountains were gradually worn down. During millions of years the persistent weathering of the rocks and the erosion of streams reduced the mountains to ridges and hills. What had been a great mountain system became reduced to a rolling plain with moderate hills. Then after the lapse of perhaps 40 to 50 million years the land again sank and was covered again by the sea and became a place of deposition. For millions of years new layers of mud, silt, and sand, together with beds of volcanic material, accumulated upon the submerged remnants of the ancient mountain system.

At the end of the Jurassic period, about 130 million years ago, there came another upheaval and the new sediments which had been deposited on the sea bottom were upheaved and became dry land. These rocks were folded and crumpled, and invaded by molten granite from below. Thus there arose a second system of mountain ranges that occupied most of eastern California and the site of the present Sierra Nevada Range. Throughout the Cretaceous period, which followed the Jurassic, this second mountain system was gradually worn down, until by the beginning of Tertiary time only ridges of moderate height were left.

The degradation and removal of the Franciscan formations was interrupted by the depression or subsidence over a wide area that ushered in the Cretaceous period. With the beginning of Cretaceous much of the Coast Range region again became submerged. The Cretaceous formations were once co-extensive with the territory now occupied by the Coast Ranges. Although removed by erosion over wide areas, where Franciscan and other rocks now appear at the surface, they still constitute one of the largest elements in the stratigraphy of the region. They are composed chiefly of shales and sandstones.

The Franciscan rocks have been much broken, folded, and crumpled by earth eruptions. Dikes of molten rock were forced up from below. Lavas also were poured out upon the surface. During the long interval while the Franciscan rocks remained above sea level they were worn and eroded and the surface was reduced to a peneplain. This means that the mountains that had been upheaved were worn down by the long-continued weathering of the elements and the erosion of streams till they became low hills and ridges. The subsidence of a great area transformed this landscape from an undulating and deeply eroded plain to a vast flat sea bottom on which sediments from the adjoining land areas were deposited. This time of erosion, which must have been very long, is a "lost interval" so far as any record is preserved in the rocks. The Cretaceous, which overlies, rests "unconformably" upon the old eroded landscape. The fact that deposits of Knoxville time are largely shales, with very little sandstone or conglomerate, indicates a shallow sea into which sediments were borne from lands of low relief. The region extending from the Sierras to the Coast Ranges is thought to have been a sound, or series of sounds, with islands, similar to the coast of Alaska and British America. The Cretaceous rocks form one of the most important and widespread systems of the Pacific Coast. The Lower Cretaceous deposits (Knoxville) occur from central Oregon to southern California, while the Upper Cretaceous (Chico), which is still more widespread, extends from Vancouvers Island to the Peninsula of Lower California. Thus a vast area of the present State of California, including the region of the Coast Ranges, was under water.

Photo by W. C. Mendenhall, U. S. Geol. Survey

FIG. 20. Devil's Kitchen. San Emigdio Canyon, looking east across the canyon. Oligocene formation. The sharp peak at the right is Eagle Rest.

Long Subsidence and Sedimentation in Coast Range Region

Subsidence continued through Lower Cretaceous (Knoxville) time, the bottom of the shallow sea slowly subsiding as sediments continued to be spread upon its bottom till shale and sandstone had accumulated to depths of 3,000 to 4,000 feet in the San Luis region, and in the Coast Ranges north of San Francisco Bay the deposits have a measured thickness of between

5 and 6 miles. That the Knoxville beds attain so considerable a thickness in the region of the Coast Ranges indicates that the sea floor continued to subside steadily during Knoxville time. The Knoxville subsidence was widespread, and is spoken of as an epeirogenic movement, that is, a movement of the earth's crust that embraces a wide region.

The long-continued deposition of muds (forming shale) in the lagoons and marshes of the shallow Knoxville sea was interrupted by an orogenic movement (mountain building) which lifted the coasts of the Cretaceous sea but did not greatly affect the broad sea bottom. The result was the quickening of the streams that flowed into the sea, and coarse sediments were deposited in deltas on the shores, and sands carried out to sea. Thus a changed condition was brought about and a new series of sediments deposited. This change marks the end of the Lower Cretaceous, and the beginning of the Upper Cretaceous (Chico) series of formations, and thus marks the break in the geologic record between the Lower and Upper Cretaceous periods. With this disturbance the present region of the Coast Ranges became dry land.

Great Changes Mark Close of Mesozoic Era

The close of the Cretaceous period marks the end of the great Mesozoic era and the beginning of Tertiary. Great changes in sea and land throughout the continent occurred at this time. It was at this time that the great ranges of the Rocky Mountain system came into being. The ushering in of the Tertiary era was marked by no violent mountain-building movements in the Pacific Coast region, but there was marked uplift which brought the floor of the sea to dry land. The sea was shut off from much of California by the uprising of the Coast Ranges. There remained a great sound or arm of the ocean where is now the Great Valley of California. A long interval of erosion ensued. The region of the Sierra Nevada was uplifted into a low mountain range, and during Eocene time (early Tertiary) remained a low mountain range undergoing erosion.

After a prolonged interval of elevation and erosion the Coast Ranges began to sink, and continued to sink till nearly or quite all of the central and southern portions were beneath the Pacific Ocean. During the Martinez epoch (of the Eocene period) more than 2,000 feet of sandstone and shale were accumulated. The Martinez epoch was interrupted and deposition terminated by earth disturbance and uplift. During the succeeding epoch,

Photo by Ralph Arnold, U. S. Geol. Survey

FIG. 21. Natural Bridge, in Monterey shale, three miles east of Santa Cruz. Tidal waves cut a channel along a joint-plane in the shale.

the Tejon, the land again subsided and was covered by a shallow sea, and essentially the conditions that had prevailed in Martinez time were re-established, but over a somewhat more widespread area. Sediments to a thickness of 2,000 feet of sandstones and shale were deposited in the shallow Tejon sea. The Tejon subsidence and sedimentation was brought to a close by earth movement and uplift. A considerable interval of erosion followed.

The next great geologic period is the Miocene, and the rocks are known as the Monterey group. A widespread subsidence ushered in the period of deposition of the Monterey group of formations. The formations of the group have a wider distribution south of San Francisco Bay than those of Eocene age, and in some places they rest upon Cretaceous or older rocks, showing a widespread extent of the sea during Monterey time.

The interval between the Tejon (Eocene) and Monterey (Miocene) epochs was a notable one in the geologic history of the region. Large areas were raised above the sea and the forma-

Photo by G. W. Stose, U. S. Geol. Survey

FIG. 22. Terrace deposits (Quaternary) resting unconformably upon eroded edges of Monterey shale (Miocene), on coast of San Luis Obispo Bay. The contact is a wave-cut plain. Rain sculpture is shown in the soft terrace gravels.

tions that had been deposited were bent, folded, and faulted by earth disturbance and uplift. The new land surface was extensively eroded before the subsidence which brought in the Monterey, so that Monterey rocks lie unconformably upon the Tejon and older formations.

A fact of much interest is the record of crustal oscillation shown in the rocks. Four movements of depression and four of uplift occur during Monterey time. The net result was deposition of sediments to a total thickness of more than 6,000 feet. The most characteristic feature of the Monterey group of rocks is its content of bituminous shale. Nearly all the oil in California is directly or indirectly associated with this shale rock. Monterey time was brought to a close by uplift and disturbance of the Coast Range region. The deposits of the San Pablo epoch (the next following the Monterey) rest upon the worn and eroded edges of the upturned Monterey rocks, showing that an interval of erosion followed the uplift and contortion which closed the Monterey epoch.

During Miocene and Pliocene time a large part of the Great Valley of California was under water, a great gulf connected by sounds with the ocean. Along the eastern shore of the gulf the Sierra Nevada formed a low range along the western side of which was deposited a series of clays and sands, the Ione formation. These sediments came from streams which flowed down the western slope of the Sierra. In these streams beds of auriferous (gold-bearing) gravels accumulated.

Tertiary Time Marked by Earth Disturbances

During the Tertiary period events of great importance occurred in California. In Cretaceous time the Sierra region had been uplifted, warped and wrinkled, and during Tertiary time was repeatedly disturbed by uplift and mountain-building. Volcanic activity and faulting of the crust of the earth added to the changes that occurred. Throughout the first half of Tertiary time the Sierra region remained a land traversed by mountain ridges of low altitude. Gravel, sand, and clay were brought down by rivers of the western Sierra slope and deposited in the shallow sea which during most of Tertiary time occupied the basin of the Great Valley of California. Toward the end of the Eocene epoch (estimated to have been about 40,000,000 years ago) occurred a series of volcanic outbursts along the eastern side of the Sierra region. From these volcanoes lavas poured down the valleys. A long interval of erosion ensued during which lavas which had been poured out, and much rock waste, were carried away by streams. During late Miocene time volcanic activity and earth movements were renewed on a vast scale both in the region of the Coast Ranges and the Sierras. The earth movement at this time increased the altitude of the Sierra region by several thousand feet. Lavas were poured forth filling valleys and covering all but the highest mountain peaks. Rivers were choked and forced to seek new courses. Faulting or breaking of the earth's crust occurred on a large scale along the eastern border of the Sierra region. The great depression in which Lake Tahoe is situated was formed at this time by a sinking of a block of the earth's crust. A long time of comparative quiet from volcanic or earthquake activity followed, which lasted mainly throughout the Pliocene epoch. In the northern Sierras where the valleys had been filled by lavas rivers sought new courses. The grade of the western slope had been increased by uplift, and most of the deep canyons of the Range—the Yosemite, the Tuolumne, and the Mokelumne—were established at this time. Sequoias, ancestors of the big trees of the present time, flourished in Pliocene time.

Final Uplift of Sierra Nevada in Quaternary Time

The end of Tertiary time was marked by events of stupendous importance. The Quaternary period was ushered in with a grand climax of mountain building. It was at this time that the Sierra Nevada acquired its present great altitude. Uplifting and tilting of a great block of the earth's crust brought the summit peaks to almost double their former height. Mt. Lyell, which in Eocene time probably had an altitude of 7,000 feet, now was elevated to 13,000 feet. At the same time fracturing and faulting of the rocks took place on an enormous scale. Thus the Sierra Nevada came to stand out in its present imposing form, one of the most stupendous and imposing mountain ranges of the continent, and indeed of the world. The great mountain mass stands as a huge block of the crust of the earth, uplifted more at its eastern side and tilted toward the west, having a gentle westward slope, sharply defined crest, and abrupt eastward-facing escarpment.

Widespread uplifting of the land in Quaternary time brought about important climatic changes, due to change of wind currents. The Pleistocene epoch of the Quaternary period was the Ice Age, the period in which widespread glaciation occurred over northern North America. During the Ice Age the crest of the Sierra Nevada above 5,000 feet altitude was covered with a mantle of ice. Ice, despite its hard and brittle character as we commonly know it, when in great masses possesses something of the character of a plastic substance. Under the pressure due to its own weight the ice of glaciers flows in the manner that may be likened to cold stiff pitch or tar. The accumulation of ice upon the crest of the high Sierra was so great that vast tongues of ice ploughed down the valleys of the Sierra slope both west and east, excavating and widening them, and carrying vast quantities of earth materials which were deposited on the lower slopes as the ice finally melted. Loose soil and broken rock were swept from the higher reaches of the range, and the surface left often naked and bare. Marks of ancient glaciers, naked, scoured, and polished rock surfaces on the slopes below the crest of the range, cirques or rock basins in which glaciers originated high on the crests of peaks and ridges, bear testimony to the work of ice. Deep V-shaped canyons which had been cut in the hard rocks by swiftly flowing streams that descended the western slope of the great tilted Sierra block were widened and made U-shaped by the power of the great ice streams that coursed through them.

While these great activities were in progress in the Sierra region tremendous changes were occurring in the region of the

Coast Ranges and in the Great Valley of California which lies between.

Region of Coast Ranges Sinks and Rises

In a basin on the Peninsula on which the city of San Francisco is built sediments had accumulated during Pliocene time to a thickness of more than a mile. The valley bottom sank as sediments accumulated till this (Merced) formation reached this astounding thickness. At the close of Tertiary time this area was upheaved so that the basement on which these sediments were deposited stood far above sea level. The extent of this upheaval shows the magnitude of the mountain-building (orogenic) earth movements that closed the Tertiary period.

At the end of the period of uplift, which extended well into the Quaternary period, a general subsidence took place. At the end of this subsidence a great uplift again occurred, the land being raised probably higher than at present. The uplift took places by stages, as is attested by terraces that mark the Pacific Coast. A wave-cut terrace is the mark made by the waters where land and sea meet. Submerged cliffs or banks off-shore show that what had been shore has subsided now below sea level.

North of the Golden Gate a striking wave-cut terrace at Bolinas is 250 feet above the cliff that is now being cut by the waves. South of this the Marin Peninsula between Bolinas and San Francisco Bay has undergone depression. This depression or sinking is associated with the complex crustal movements which enabled the sea to enter San Francisco Bay by way of the Golden Gate. The recent subsidence of San Francisco Bay has been estimated at 300 to 400 feet. The earth movements about San Francisco Bay are complex and will be considered in another chapter.

Terraces showing uplift of the land are conspicuous at many points along the coast. Near Santa Cruz terraces occur at 100, 250, 500, and 800 feet above the present waves, showing successive uplifts of the shore. At Half Moon Bay a terrace that is 100 feet above sea level rises progressively to over 400 feet at Tunitas Creek 10 miles south. This shows that uplift progressed differentially southward, and not at the same rate at all points. At Fort Ross, 60 miles north of San Francisco Bay, a series of wave-cut terraces occurs marking successive uplifts of the short at 280, 350, 440, 760, 1,180, 1,400 and 1,520 feet above the present waves. Near Kenney, in northwestern Men-

Photo by G. W. Stose, U. S. Geol. Survey

FIG. 23. Wave-cut terraces, San Luis Obispo Bay. The upper beach is 100 feet above sea-level; the middle one is sixty feet; and the lowest one is ten feet.

docino County, wave-worn pebbles lie on a wave-cut beach 1,200 feet above sea. Farther north in Humboldt County the uplift as shown by the elevated terraces is 1,600 to 1,700 feet.

A Lake or Inland Sea Covers Central Great Valley

Where is now the Great Valley of California was a vast lake or inland body of water, into which poured the waters of the rivers from the western slope of the great Sierra uplifted block, and with them were borne clay, sands and gravels from the higher lands. The waters of this lake were cut off from the ocean by the earlier uplift of the Coast Ranges. A channel or strait where now is the Bay of San Francisco allowed the waters to escape to the ocean. Uplift of the floor of the Great Valley in Quaternary time caused the waters to drain away. The Quaternary deposits of clay, sand, and gravel have been buried in the lower valley by recent river alluvium. The lowest part of the Great Valley is now hardly above sea level. Boats pass from the harbor of San Francisco Bay to Sacramento and Stockton. This low part of the valley is filled with silt that has been carried down the Sacramento and San Joaquin rivers and deposited, building up the deltas of these rivers. Below the river alluvium is clay, sand, and gravel carried into the valley during Quaternary time.

Southern California Covered by the Sea

An arm of the ocean extended over southern California in late Tertiary and Quaternary time. Where Los Angeles and San Diego now stand rolled the great sea during later Tertiary, becoming dry land at the time of the uplift in early Quaternary. During late Tertiary the great Colorado Desert region was a huge oyster bed. This arid land would be the last place one would look for oysters, yet in the rocks at Coyote Wells, along Carrizo Creek, and in the sides of the San Jacinto mountains 1,000 feet above sea level, oyster shells and those of other marine mollusks occur in great numbers. The gulf or arm of the ocean, after the early Quaternary uplift, extended over the region of the Colorado Desert and the Salton Sea to the San Bernardino and San Gabriel mountains on the north. The peaks of the San Jacinto and Peninsular ranges were islands on the western side of the gulf. After the great uplift which raised the Sierra Nevada Range Mt. Whitney, monarch of the Sierras, looked out over the shallow sea which covered the region of the Mojave Desert.

A Summary of Geologic History

In this chapter an attempt has been made to pass over in panoramic review the history of California from its beginning to the present. In years the lapse of time passes beyond the grasp of the human mind. In number of years the time cannot probably be expressed in less than 10 figures. A decade, a generation, even a century, we can comprehend. But a thousand years, a million years, which takes us back only to a geologic yesterday, leaves the mind agasp as in imagination the great panorama of the past rolls backward toward the Beginning, to the third "day" when "the waters were gathered together into one place, and the dry land appeared." To attempt to grasp geologic time in terms of billions of years, goes beyond finite understanding except in a relative or comparative way.

If land in California stood above the level of the sea in Archaean time—which it probably did—then California's history can be truthfully said to go back to the very ancient, to the geologic Beginning. Professor Barrell has deduced by studies of the atomic behavior of lead—studies that are beyond the understanding of most of us—that geologic time is vastly longer than has been commonly supposed. The writer, as a student, tried to reach some conclusions as to the age of the earth based on astronomical and physical data. Lord Kelvin, an eminent English astro-physicist, reached an estimate of something like 100 million years that the sun had been shining upon the earth. Under the latest studies of the problem of geologic time 100 million years carries us back to a geologic yesterday! The Archaean lands that stood above the world-wide ocean, islands which are thought to have existed in California, date back beyond what can be expressed in millions, and 10 figures are required. The geological story has not yet been fully written. Upheavals by which lands have been elevated above the sea are shown in the record of the rocks. Great mountain ranges have been born and worn down by erosion and the unceasing action of the elements. Lands that have been land during long periods and on which organized systems of living things had been developed have subsided and been covered by the waters of the sea. Just when living things first appeared we do not know. We know that life appeared very long ago. Fragments of the history of plants and animals have been gathered from the rocks. Successive events of upheaval and subsidence of the land occurred, geographic changes that have marked important chapters in the long history that we undertake to read in the rocks. If the narrative seems to lack completeness it may be stated that our knowledge of the record is not complete. If the narrative does not possess interest, if the story has not been told so as to lead the reader to see in California more than scenery, more than climate, more than rocks, mountains, great rivers and deep gorges, wealth of mines and minerals, beautiful shores and fine harbors, charm of desert and broad fertile fields, if he does not see beyond these to the great geologic causes which produced them, then the story has not been adequately told. "He who does not see beyond the rocks does not see the rocks."

If the history of California is long so also the record is complex. Probably no region embraced within the boundary lines of any single State has as complicated a history as has California. The reader maybe has become wearied of names and geologic facts. Yet these facts are history. Names are but the handles for convenience. The facts are of fundamental importance. On these rest the natural resources of the State. On the knowledge and understanding of these facts rests the development of industries. If the reader has been wearied in the attempt to follow the narrative of the historic panorama the fault is that of the writer. The story is interesting because it is what Nature has unfolded. If the story has not been interestingly told it is not the fault of the facts.

Chapter VII

THE GEOLOGIC MAP*

The Geologic Map

The State Geologic Map of California shows the areal geology, that is, the character of the land, the rock formations, as these occur at the surface. It really goes much below the surface. It shows what particular formation occurs at the surface at any given place, but to be understood the map should be studied in connection with a geologic cross section. A cross section shows the formations in the order of their occurrence, the younger above the older. The geologic map may be more clearly understood by reference to columnar sections of the formations (Figs. 18 and 19), and cross sections (Figs. 25 and 26). The geologic section shows the order of succession of rock formations, the oldest known rocks being shown at the bottom and later formations represented in the order of their age. On the geologic map the formations are represented as they occur *today* at the surface. A geologic section at any locality shows at the top the formation that occurs at the surface in that locality. From the top down whatever formations are known to occur beneath the surface are shown.

Geologic sections in different localities of California differ. The succession of "ages" is the same, but formations that appear in one may not appear in another. The ideal section shows the geologic time scale, the historical succession of geologic formations throughout the world. In the actual section gaps or "unconformities" may occur, and formations that appear in one section may be absent in another. (Compare the San Francisco and Gold Belt sections. Figs. 18 and 19.) The absence of a formation in the geologic column or section, or

* Geologic Map of California, by Olaf P. Jenkins.

an unconformity, means that there is a "lost interval" here in the succession of formations. It may mean that this place was not sea bottom but was a land surface at this period of the earth's history, and that no sediments were deposited. Or it may mean that this region was elevated above sea level after deposition of sediments and that these were removed by erosion, and that later the land sank and was covered by the sea and another formation deposited. In either case there is a break in the geologic record. It means a "lost interval" for this locality.

Region East of Berkeley

In figure 24 the areal geology of a portion of the Conrad quadrangle lying east of San Francisco Bay, immediately east of Berkeley, is shown. Cross sections of the formations along the lines A—B, and C—D are shown in figures 25 and 26. The surface of the land is that of a rolling hilly plain. The formations at the surface are shown on the map and designated by numbers. The cross sections show that the rocks have been much folded, bent and faulted by upheavals. At the surface are the worn and eroded outcropping edges of the disturbed formations.

Rock formations in California have been upheaved, bent, and folded since they were deposited, and irregularities appear in cross sections. Where an uplifting of the rocks has occurred and the crown or top of a fold or arch has been eroded, the ends of the bent strata will be exposed at the sides and the older formation will appear in the center.

In the cross section, figure 25, four geologic formations occur at the surface in a distance of about 3 miles. The Briones sandstone (12) has been uplifted and the top of the arch or fold has been removed by erosion. The younger rocks of the San Pablo formation (14) dip away from the uplifted Briones, and the two formations are separated by an unconformity, showing that an interval elapsed after the Briones

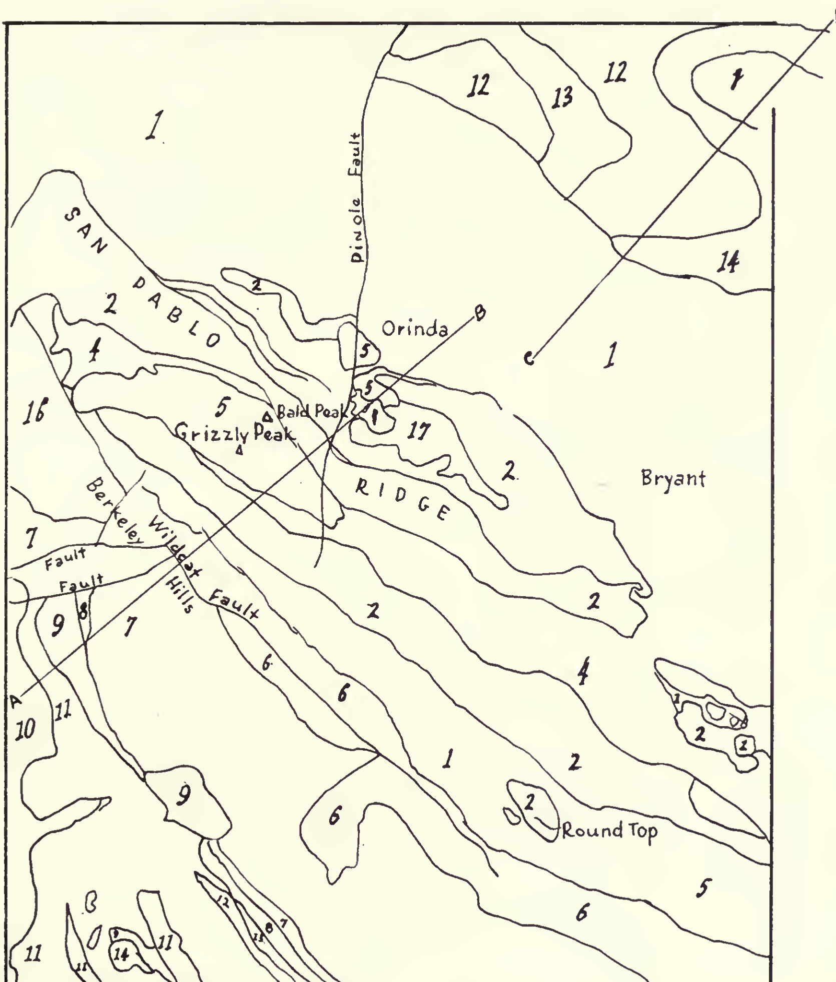


FIG. 24. Areal geology of a portion of the Conrad Quadrangle, east of Berkeley. The formations, designated by numbers are: 1. Orinda (Pliocene), fresh-water conglomerate, sandstone, shale, clay, and limestone; 2. Moraga (Pliocene), lava flows, with gravel, clay, and limestone; 4. Siesta (Pliocene), fresh-water conglomerate, clay, sandstone, chert, limestone, and lignite; 5. Bald Peak Basalt (Pliocene), lava flows with included fresh-water limestone; 6. Claremont (Miocene), shale, chert, sandstone, and limestone; 7. Chico (Upper Cretaceous), sandstone and shale, with conglomerate; 8. Knoxville (Lower Cretaceous), shale; 9. Ryolite (Pliocene), lava; 10. Temescal (Quaternary), alluvium; 11. Franciscan (Jurassic), metamorphic schists, with radiolarian chert; 12. Briones (Miocene), sandstone, with shale; 13. Rodeo (Miocene), shale; 14. San Pablo (Miocene), sandstone, with volcanic tuff; 15. Hambre (Miocene), sandstone.

sandstone was deposited and before the San Pablo was laid down. Below, and older than the Briones, is the Rodeo shale (13), which appears at the surface farther east.

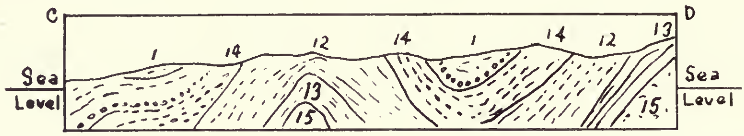


Fig. 25. Cross section along the line C—D in figure 24. Formations numbered as in figure 24.

The formations have been uplifted, squeezed or compressed together into folds or arches (synclines and anticlines), as have the rocks in many places in California. Many faults or breaks in the crust of the earth occur, the rocks on one side of a fault or break being uplifted relatively to those on the other side. Rocks of different ages may lie opposite each other on either side of a fault. In figure 26 no less than 10 geologic formations are crossed in a distance of 3¾ miles along the line A—B. The formations are cut by the Wild Cat and Pinole faults (F and F′) and by other faults of lesser extent. San Pablo Ridge is capped by lava flows, the rocks of which, being hard, resist erosion. Grizzly Peak and Bald Peak rise to altitudes of 1,759 and 1,930 feet respectively. It will be seen from the figure that the lava rock forms the cap of the broad San Pablo Ridge, and that this broad ridge is the top of a syncline. The eroded edges of the formations outcrop on the slopes of the ridge.

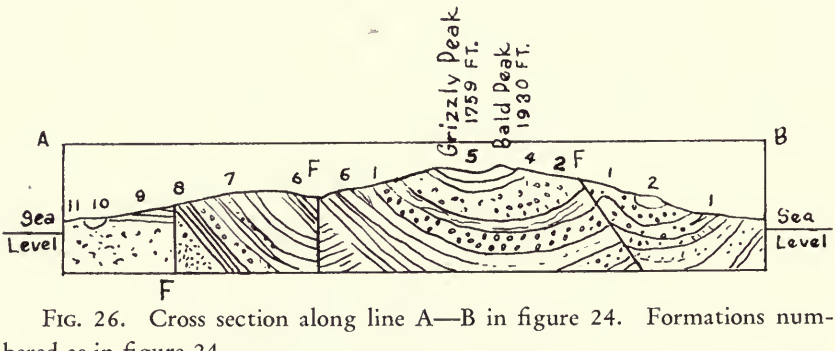


Fig. 26. Cross section along line A—B in figure 24. Formations numbered as in figure 24.

Thus it is seen that much disturbance has occurred by which the distorted, folded, and broken conditions shown in the cross sections came to be. The areal geology map shows the rocks that now occur at the surface. All are more or less obscured by the mantle of soil which has resulted from the weathering of the exposed rocks.

A Segment of the State Geologic Map

In figure 27 a part of Inyo County is represented, from the State Geologic Map. This segment of the large State map will give some idea of the long history of California. Very old rocks, and very recent formations are shown. The different formations are indicated by numbers.

On the State geologic map of California about all the geologic formations of the earth are represented, though the "beginnings" of California are involved in much uncertainty. Whether rocks of the primitive Archaean—the oldest known rocks in the world—occur amongst the ancient granitic formations is not with certainty known. That later Archaean (Algonkian) rocks occur in the granitic basement complex of the Coast Ranges seems reasonably certain. The very ancient sedimentary formations of the Cambrian, and about all succeeding sedimentary formations, occur in California. Extensive deposits of older formations it is thought are buried beneath later deposits. Some of these have been uncovered by erosion and so appear on the geologic map as surface formations. Very old Cambrian, or pre-Cambrian, rocks, much crumpled, folded, and metamorphosed, occur in southern California. On the western slope of the high Sierra Range, and farther north in the vicinity of Mount Shasta and the Klamath Mountains, ancient sediments of the Palaeozoic era occur. The Cambrian seas may once have covered large areas in central California. Much rock then formed has been buried under younger formations, or has been eroded and carried away.

Batholith Up-Welled in Region of Coast Ranges

In late Jurassic time an upheaval of tremendous proportions brought a vast batholith or underground lake of molten granitic rock from the depths of the earth in the Sierra Nevada region and in the region where the Coast Ranges are now. It is thought that this molten rock did not reach the surface, but

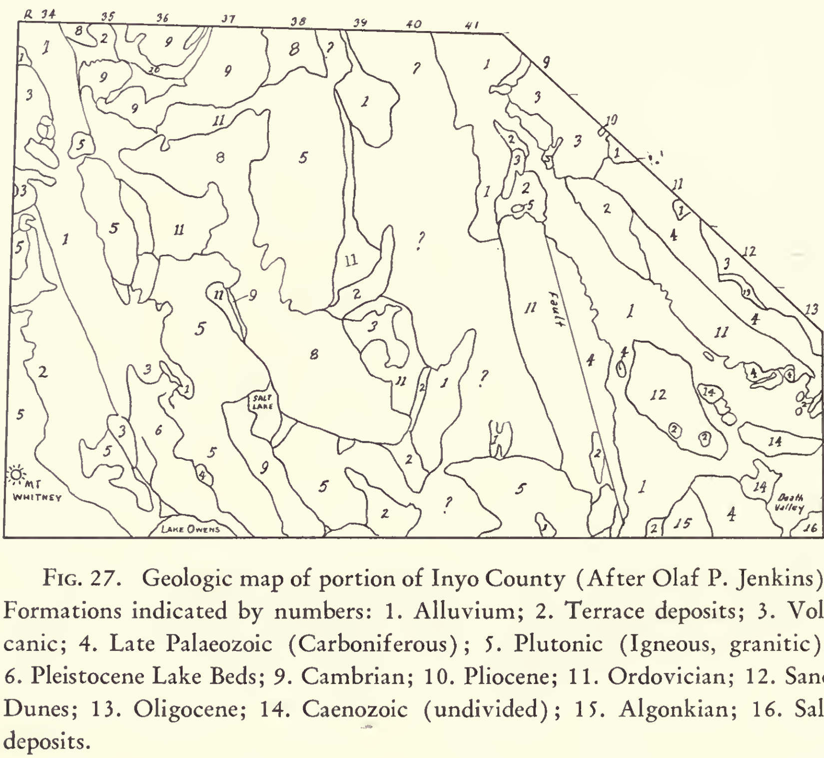


FIG. 27. Geologic map of portion of Inyo County (After Olaf P. Jenkins). Formations indicated by numbers: 1. Alluvium; 2. Terrace deposits; 3. Volcanic; 4. Late Palaeozoic (Carboniferous); 5. Plutonic (Igneous, granitic); 6. Pleistocene Lake Beds; 9. Cambrian; 10. Pliocene; 11. Ordovician; 12. Sand Dunes; 13. Oligocene; 14. Caenozoic (undivided); 15. Algonkian; 16. Salt deposits.

was forced up into and under existing sedimentary rocks, where it slowly cooled. The age of the sedimentary rocks that were intruded by the molten mass in the Coast Range region is not known with certainty, as no fossils have been discovered which make it possible to determine the time of their deposition. They are thought to be very old, possibly dating back as far as the Algonkian. These sedimentary rocks were metamorphosed (i.e., changed by heat and pressure), sandstones becoming quartzites; muds, silt and clay transformed to slates; limestones to marbles. The rock strata were crumpled, bent, folded, and contorted, and intermixed with the intruded molten lava. All slowly cooled and form what is now spoken of as the basement complex on which later formations have been laid down as the region sank beneath the sea. These rocks are represented on the State areal geology map as Plutonic rocks. (Geologic Map of California, by Olaf P. Jenkins.)

State Geologic Map Shows Plutonic and Volcanic Rocks

Plutonic rocks are shown widely distributed over the State. The basement complex of granitic rocks, together with quartzites, schists, slates, and marbles, extends far south forming the foundation of the Coast Ranges. The rocks of the basement complex meet and join with a similar batholith or underground lake of molten granitic rocks in the San Emigdio Mountains and form the basement complex of the Sierra Nevada. Much of the basement complex of granitic rocks, quartzites, slates, schists, and marbles has been covered by the sea and buried beneath later sedimentary formations, only to be again uplifted and the formations removed by erosion. Thus on the State geologic map plutonic rocks are shown over vast areas of the State.

Another widely distributed surface rock is shown on the geologic map under the designation V, meaning volcanic. Volcanic as distinguished from plutonic means that the rocks were poured out from volcanic vents upon the surface, or thrown out in violent explosions as volcanic ash. Northern California is a vast lava field. Mount Shasta and Lassen Peak are outstanding volcanoes. Many other volcanoes, not only in the north but along the Sierra Range far into southern California, have emitted vast millions of tons of lava which now covers wide areas. The geologic age, or time of outpouring, of many lava beds is known, but they are shown on the geologic map as V, that is, volcanic.

Quaternary deposits of clay, silt, sand, and gravel have been spread by streams from higher lands upon earlier formations. Detritus borne by streams covers an extensive plain in the Great Central Valley of California, forming the Sacramento-San Joaquin basin floor. Much of the vast desert region of southern California is valley fill from streams from higher lands, of Quaternary age. Marine Quaternary deposits occur along the southern coast.

Columnar Sections Show Succession of Events

In a columnar section for the San Francisco district (Fig. 18) the formations from the Jurassic to the present are shown. The older formations of Palaeozoic time are not represented. At the bottom of the column granitic rocks are shown, the age of which is somewhat uncertain. It is thought that land areas extended farther west than the present coast, but our knowledge of these ancient lands is largely lacking. It is thought that sediments eroded from lands farther west than the present coast were deposited in an arm or bay of the Pacific Ocean that extended over what is now the western slope of the Sierra Nevada in pre-Jurassic time.

In the Gold Belt section (Fig. 19) very old sedimentary formations, probably Carboniferous or older, are represented as intruded by molten granite in late Jurassic time. The section shows a great unconformity between the Jurassic and the Cretaceous, indicating a long "lost interval." Most of the gold-quartz veins for which California is famous date from time after the Jurassic upheaval, or early Cretaceous time.

The ancient roof rocks that were uplifted by the batholith in the Coast Range region have been practically all removed by erosion. The ancient roof of the Sierra region has been largely removed. As has been stated, the Calaveras and Mariposa formations on the slope of the Sierra Range are remnants of the ancient roof. Where the roof rocks have been removed the granitic bed-rock of the batholith is now exposed at the surface, and these rocks are shown on the geologic map as plutonic rocks.

A geologic map is thus seen to be a somewhat complicated affair, but it shows the formations that lie at the surface in any locality. The geologic section at any given place shows what formations extend from the surface downward, and may, but does not always, extend to the ultimate basement or foundation rocks. A generalized or ideal geologic section would show all the formations of the earth from the soils and alluvium of the present down to the ultimate basement, the Archaean granite rocks of the foundation of the earth. As has been stated, these formations are not all known in any one place, but by generalizing from a great number of observations in widely distributed areas the perfect or ideal geologic section of the crust of the earth may be made.

Chapter VIII

THE LAVA PLAIN OF THE NORTH

An Immense Lava Plain

A part of what is probably the largest lava field in the world is in northern California. This vast outpouring of molten rock covers an area of approximately 200,000 square miles in northern California, Oregon, Washington, Idaho, and Montana. It was during Tertiary time that this great outpouring of lava was emitted from the depths of the earth. It spread far, covering plains and low hills and filling valleys. Mounts Shasta, Hood and Rainier are three outstanding volcanic peaks which contributed to the molten mass. A great number of volcanoes of lesser size, now extinct craters, occur in the great lava field and contributed to the flow.

A broad high plateau of lava in northeastern California extends to the east, including Modoc County, and beyond into Nevada. What is known as Lassen Peak Ridge extends across Shasta, Lassen, Plumas, and Tehama counties, from the north fork of American River to Klamath River. Lassen Peak Ridge is a vast hill of lava 50 miles long and 25 miles wide, built up in a valley which lies between the north end of the Sierra Nevada Range and the southern end of the Cascade Range. The ridge has been built up by outpourings of lava. The original valley was an ancient depression in which a sound or arm of the ocean once lay, now filled with lava. It was a valley in very ancient (Palaeozoic) time. The ancient valley is a continuation of the Great Central Valley of California.

The Northern End of the Sierra Range

The Sierra Nevada Range may be said to end and the Cascade Range to begin in northern California. Lassen Peak, in

Shasta County, is regarded as the southern terminus of the Cascade Range. Mount Shasta and Lassen Peak are immense lava cones. Mount Shasta rises 14,401 feet above sea level. The summit of Lassen Peak is 10,437 feet above sea. Their bases, on the bottom of the ancient valley, are probably not much above sea level. Mount Shasta, Lassen Peak, Butt Mountain, Crater Peak, Burney Butte, and those at the head of Burney Creek, as well as a host of smaller conical hills, are all ancient volcanoes which contributed to the outflow of lava.

The Klamath Mountains include the complex group of mountain ranges which interrupts the Great Valley of central California in the north. The rocks of this group of ranges are much bent, folded, and crumpled. This group of mountains forms a sort of connecting link between the Sierra Nevada, the Cascade, and the Coast ranges. The Klamath Mountains are located in part in Oregon, but mostly in California. The Klamath Mountains are similar to the Sierra Nevada Range in structure and character of rocks. They overlap the northern end of the Coast Ranges in California, and so may be regarded as belonging to the Coast Range system.

Many Formations in Northern California

Twenty-two geologic formations occur in this district of California. Of these 13 are sedimentary rocks, that is, formations deposited as sediments in bodies of water. The remaining nine are igneous; emitted as molten lava or ejected as volcanic ash. This region of northern California and western Oregon was covered by the sea in the Silurian, Devonian, and Carboniferous periods of the Palaeozoic era, and till the close of the Jurassic period of the Mesozoic era. Marine sedimentary rocks having a total thickness of more than four and a half miles accumulated during this long time. These rocks, although laid down in horizontal position, have since been folded, crumpled and metamorphosed. Fissures in the rocks have been filled with gold-bearing quartz veins. In the upheaval which marked the close of the Palaeozoic era and ushered in the Mesozoic era the rocks were tilted and eroded. Then later formations were deposited upon their up-turned edges. The rocks were again upheaved and folded in Triassic time. The great upheaval which occurred about the close of the Jurassic period raised all of northern California above the sea. It is thought that islands had existed in this region since very early Archaean time, but the great uplift which marked the close of the Jurassic period extended the land area far to the northwest into the Pacific Ocean west of Cape Blanco. Just how far the land extended beyond the present coast line is not known.

During the Cretaceous period the land sank again so that the sea covered the land where are now the Klamath Mountains and much of the coast ranges. The Sierra Nevada Range remained above the sea. The Chico formation, the earliest Cretaceous deposit, was deposited along the western base of the Sierra Nevada Range and around its northern end. The Pacific Ocean covered most of the region about Lassen Peak and Mount Shasta, and extended far into Oregon. The Chico is the oldest of the sedimentary rocks that overlie the bent, folded, and crumpled Palaeozoic rocks, the auriferous (gold-bearing) slates. There is marked "unconformity" between the old Palaeozoic rocks and the overlying horizontal rocks. The older (Palaeozoic) rocks, which are bent, folded and much metamorphosed by the heat and pressure of the mountain-building processes, contain the gold-bearing rocks from which the "auriferous gravels" have come.

At the close of the Cretaceous period the Klamath Mountains were again raised above sea level, and the Cretaceous (Chico) strata which had been laid down as horizontal sediments were much folded and broken. A large part of the Chico beds thus exposed to erosion were washed off the land. The land of what is now northern California was long subjected to weathering and erosion, and was finally worn down nearly to a plain (peneplain). Streams had nearly reached base-level, i.e., the land had been worn down so that the stream currents were sluggish and unable to carry away any but the lighter sediments. There was left spread over the land surface the hard heavy rock materials which the sluggish streams were not able to carry away, such as quartz gravels and gold.

In early Tertiary (Eocene) time, about 60,000,000 years ago, an upwarping of the land occurred so that the grades of the streams were greatly increased. Most of the fine and light material was carried down and deposited in a body of water that covered the Sacramento Valley, but the coarse and heavy material, such as quartz gravel and gold, accumulated in the old channels. These ancient river gravels furnish the principal placer mines of today. The ancient auriferous gravels of the northern end of the Sierra Nevada were deposited by streams that flowed into the body of water referred to which surrounded the northern end of the Sierra Nevada. Some of these gravels, which were once but little above sea level, are now on the summits of the Sierra Nevada at altitudes ranging from 5,000 to 7,000 feet above sea level. This indicates that the northern end of the Sierra Nevada range has been uplifted several thousand feet since these early gravels were deposited. This uplift of the range increased the eroding power of the streams, and as a consequence all the streams flowing down the western slope of the northern portion of the range have cut deep canyons. The canyon of the North Fork of Feather River is nearly 4,000 feet deep.

A Variety of Lavas Emitted

Volcanoes of the great lava field have furnished a great variety of igneous rocks. Igneous rocks are distinguished by their structure, the proportions of the mineral silica which they contain, and the minerals of which they are composed. Lavas of different character have been emitted from the same crater at different times. Lavas of the same character have been emitted from different craters. Lava, as it is poured out of volcanic vents or emitted from fissures in the rocks, is molten rock. Each mineral has its own melting-point. In cooling each mineral in theory should solidify as the temperature of the mass lowers. This does not strictly follow in the case of molten rocks, owing to the fact that the melting-point of a mineral may be lower when mixed with some other mineral. For example, quartz or silica alone is infusible, but when mixed with

Photo by R. H. Finch. Courtesy Univ. of Calif.

FIG. 28. Brokeoff Mountain, showing fault scarp. The hummocky foreground is lava, part of the down-faulted crater of Brokeoff Volcano.

soda or potash it is fusible. Glass is made from quartz sand which is mixed with soda. The mixture of minerals in the molten mass is called the magma. In a cooling magma a great variety of combinations of chemical substances occurs, resulting in many different kinds of igneous rocks. Thus many varieties of lava occur among the volcanic or igneous rocks due to the varying conditions in the cooling mass and the different minerals involved.

All, or nearly all, the chemical elements known on the earth are found in igneous rocks. Of the 70-odd chemical elements known only eight are of such importance that they need to be considered in a general study of the igneous rocks. From these elements various chemical combinations arise resulting in the formation of the various minerals, and out of the mixtures of minerals come the various rocks. In importance oxygen is at the head of the list of elements. Next to oxygen, silica, SiO_2, is the most important of the rock-forming agencies. Silica is the oxide of silicon. (Silicon is very rare in nature.) The union of oxygen with the six more common elements forms oxides, and the oxides are fundamental in the rock-forming processes. Of these oxides silica acts as an acid while practically all the rest act as bases. An acid and a base combine chemically to form a salt. The acid silica combines with the basic oxides to form salts, which are called silicates. Thus in general igneous rocks are silicates of the six leading basic oxides, viz., alumina, potash, soda, lime, magnesia and iron. This is the general fact, but in nature there are many complications in the combinations of minerals, and the total number of silicate minerals is very large. These become the problem of the mineralogist. The student need not feel embarrassment or discouragement if he is unable to recognize the constituent minerals of the crystalline rocks. Their classification is technical and somewhat difficult, and is the task of the professional mineralogist.

It is not known that any volcanoes existed on the continent of North America before the Cretaceous period of geologic time. Molten rocks that have been forced out of fissures in the crust of the earth are the same in kinds as those of volcanic origin, and are classed as igneous. Rocks that have emanated from the depths of earth's interior are often spoken of as plutonic. Those that have been poured out on the surface are lavas. Volcanoes reached their maximum at the close of Cretaceous and during Tertiary time. There were tremendous outpourings of molten rock during Archaean and throughout Palaeozoic time, but these should be regarded probably as poured out of fissures rather than ejected from true volcanic vents (cones).

Recent Volcanic Activity

The volcanic activity which has built up Lassen Peak, Mt. Shasta, and many cones or peaks of this great lava field is com-

Photo by J. S. Diller. Courtesy Univ. of Calif.
FIG. 29. Chaos Crags, viewed from north slope of Lassen Peak.

paratively recent. Probably the greatest outpouring of lava was at the time when the great Sierra Nevada range was finally uplifted to essentially its present height, which was in early Quaternary time. Volcanic activity in this region of California has continued till the present time and is today marked by the presence of numerous solfataras, hot springs, and geysers. At Bumpass Hell near the southern base of Lassen Peak are boiling mud pools and fumaroles with escaping sulphurous gases. Nearby sulphur deposits have been sufficient so that attempts at commercial mining have been made. Most of the major volcanoes are of such recent origin that their forms have scarcely been modified by erosion.

The latest volcanic eruption in the Lassen Peak region, and possibly the latest in the United States south of Alaska, occurred at the Cinder Cone, 10 miles northeast of Lassen Peak,

Photo by R. H. Finch. Courtesy Univ. of Calif.
Fig. 30. Bumpass Hell, looking west.

about 200 years ago. Some of the trees killed at that time are still standing. The lava, though very viscous, spread more than a mile from the vent. The lava formed a dam across a small stream in southwestern Lassen County and thus Snag Lake came to be. This lake contains stumps of trees drowned at the time the lake was formed.

One hundred twenty volcanic vents in the Lassen Peak region have contributed the great mass of lava of which the Lassen Peak Ridge and plateau have been built up, chimneys through which issued from earth's interior countless tons of molten rock. A conical hill or mountain has been built up around each vent or chimney. Some of the eruptions were on a grand scale. A few of the craters are more than a mile in diameter. In the Lassen Peak region, and farther north in the Cascade Range, the lava was generally of a viscous nature. Being too stiff to flow far the lava accumulated about the craters and formed large cones. One of the lava flows that continued farthest from its source in the Cascade Range came from the southern slope of Mount Shasta, and descended the canyon of Sacramento River for 50 miles. The lavas in the eastern part of this great field, extending through the Columbia, Deschutes, and Snake valleys, were less viscous (more liquid) and flowed more freely. They spread in thin sheets following the winding valleys and surrounding isolated hills as islands in a lake. The average thickness of the lava in this vast field has been estimated to be thousands of feet.

The California lava field extends from Susan River to Pit River and the Oregon line, and eastward to the Modoc lava beds, and beyond. It is densely wooded with conifers, and mantled in places by a thick growth of Manzanita, while over most of the region the volcanic rocks are obscured by a bouldery cover of glacial debris. Small but well defined morainic ridges occur, and where the bed-rock protrudes it is generally striated and finely polished by glacial scour. Three well preserved cones, Hat Mountain, Fairfield Peak, and Crater Butte, rise conspicuously above the general level, each about 500 feet high and half a mile in diameter. Four outstanding volcanoes in the plateau region east of Lassen Peak are Prospect, Raker and Harkness peaks, and Red Mountain. Of these three the largest, Prospect peak, has a diameter of four miles and rises 2,000 feet above the surrounding country. Its slopes are almost perfectly symmetrical. The other three are so slightly affected by erosion that a cinder cone is still preserved on the summit of each. The lavas to the east are among the oldest in the Lassen Peak district and were deeply eroded by streams before glaciers covered the region with ice.

Lava Beds Polished by Glaciers

Glaciers have done much to shape the features of this district. Rock tarns, U-shaped valleys, perched blocks, roches moutonnées, abound. Steep-sided, dome-shaped or truncated pyramidal peaks rise in profusion in the northeast corner of Lassen Peak Park, chief among them Lassen Peak itself, Eagle Peak, Bumpass and White mountains, and the Chaos Crags. In general these domes represent the products of the latest volcanic activity in the Lassen Peak region.

Lava Rocks Become Soils

By and large the great lava plain of Northern California is a vast desert of rock. Rugged, broken, angular fragments of

Photo by Univ. of Calif. Courtesy U. S. Bureau of Soils

Fig. 31. Rough surface of basaltic lava flow two miles north of Lookout, Modoc County.

rock, originally poured from earth's interior in a molten condition, and flowing as a thick viscous liquid over great areas, or thrown from craters in terrific explosions as so-called volcanic ash or cinders, slowly cooled into crystalline hard rocks, or deposited in wide areas of scoriaceous tufa and pumice, such a land surface does not offer the most inviting field for the growth of vegetation. Yet nature never sleeps. The hardest rocks yield to the constant attack of the weathering agencies, frost and heat, wind and rain. Many productive acres of meadows and pastures furnish forage for the flocks and herds of the husbandman. The latest flow of lava, known as basalt, flooded valleys, and cooling formed dams in valleys which caused the streams to pond forming lakes. These slowly but surely filled with accumulated sediments carried in by streams or blown by winds from meadows. Minerals in the basalt by decomposition and disintegration furnish an excellent soil. Trees find a roothold in the volcanic sands and in cracks and crevices of naked lava rocks. Two hundred years ago a forest was growing about the base of Lassen Peak when renewed volcanic activity caused hot lava and cinders to cover the land and the trees were killed. Today dead standing tree trunks remain to tell of the forest that once was. In sight of these dead trunks are living trees in green forests. These show by the number of annual growth rings approximately the length of time since the former forest was killed.

Chapter IX

THE COLORADO DESERT

The southeast corner of the southwest corner of the United States is one of the most unique regions of the North American continent. California has the distinction of the most extreme variations in physical features of any State, province or country. In no State or region are there acres that produce more in value of products annually than do acres of California's fer-

Photo by David G. Thompson, U. S. Geol. Survey

Fig. 32. Creosote bush, in Mojave Desert.

tile fields in this unique region. Hard by are acres that produce nothing, and by no stretch of the imagination can be conceived to have any value whatever for any agricultural use. Here, in a State famed for its productive soils, is also the abject desert.

Nature has her moods and man has inventive genius. A peasant laborer from far-off India (more a philosopher than he knew) looked out upon the broad land, then looked far away to the river, then said: "Much land; much water. Sometime man get water on land;—much crop!" Behold! In the midst of an arid and parched land is a veritable garden. Fruits, vegetables, and forage crops, in advance of most other districts, go to the markets of the world.

With annual rainfall of less than 3 inches, with some seasons a trace only of moisture from the sky, an unmeasurable fraction of an inch, with summer temperatures of 120 degrees

Courtesy U. S. Bureau of Soils

FIG. 33. Stone date garden, near Indio, in Coachella Valley, showing clusters of fruit on trees.

and even as great as 140 degrees, normal vegetation, as vegetation is known generally, is unknown. Not a blade of grass, but horned toads, cacti, and such life as is adapted by nature to high temperatures and almost no moisture, the expanse of arid plain is weird and fascinating. But man has overcome the obstacles of nature. By feat of engineering skill the river has been harnessed and water brought to the arid plain. "Much land; much water—much crop!"

Where water can be brought to the land here as by magic the desert literally blossoms as the rose. No longer is it necessary to go to India for dates, or to the equatorial regions for olives. Men do not gather figs from thistles, but here they gather them and other sub-tropical fruits from the desert where nature planted the spiny cactus and the hardiest sage brush. The absence of rainfall negatively fertilizes the soil. The soluble plant foods that are leached from the soil in humid regions, in this desert land remain where the rocks give up their mineral salts. Water from the harnessed river and from wells which reach waters entombed in porous sand strata, locked by beds of clay above and below, supplies the magic that transforms the arid plain into a modern Garden of Eden.

This is indeed an unique region. In part below sea level, surrounded by rugged mountains, the Pacific Ocean hard by on the west, the great Basin Plateau of the American Desert on the east and north, here is the mouth of a great river which has long been delivering its silt-laden waters to the Gulf of California and the Pacific Ocean from the mountainous plateau region of Arizona, New Mexico, Utah, Wyoming, and Colorado, cutting the Grand Canyon to a depth of more than a mile. Whether or not the ocean was willing to receive the contribution of water and earth, these were delivered long and incessantly, sometimes in a moderate stream and sometimes in floods of tremendous proportions. Here was the river's end. At its mouth all that had been carried had to be thrown down with the slackening of the current. Nature has her own ways of handling her problems. One of nature's relentless tools is a river. It must go on forever. Here is an arid plain built by the river, but a river cannot of itself water a plain which it has itself built up. High mountains cut off the moisture-bearing winds from the ocean. So here in this mountain-hemmed basin is an arid desert plain built by a great river.

A Delta in the Gulf of California

This is the delta of the Colorado. It was first explored in

1853 by Professor William P. Blake, and was by him named the Colorado Desert. There was then no State of Colorado, and since this great geologic feature was built by a river bearing the name of Colorado it was fittingly so named. This great river deposit of sand and silt occupies the basin from the head of the Gulf of California north to San Gorgonio Pass, a distance of 200 miles. It is a vast wedge-shaped or triangular area having its base south of the International Boundary in Mexico and its apex in San Gorgonio Pass between the San Jacinto and San Bernardino ranges. On the northeast side are the Chocolate, Chuckawalla, and San Bernardino ranges, and on the northwest side the San Jacinto, Santa Rosa, and Superstition Mountains, and in Mexico Signal Mountain and the Cocopah Range. Its width at the International Boundary is about 80 miles. The distance from the real mouth of the Colorado River, where it debouches from the high plateau at Yuma, to the head of the Gulf of California is about 60 miles in an air-line. This great arid plain, built up of silt and sand carried by the Colorado River to the Gulf of California embraces an area of more than 2,000 square miles. It is in large part below sea level.

The Gulf of California once extended north to San Gorgonio Pass. The mouth of the Colorado River was near Yuma. Here the river discharged its silt-laden waters into the gulf. The Colorado now deviously meanders by ever-changing channels over the delta plain of its own building. Earth that has been eroded from the mile-deep Grand Canyon of the Colorado now rests in this plain in the basin of the Gulf of California. It is estimated that the silt borne by the Colorado to its mouth at the beginning of the delta plain is sufficient to cover one square mile to a depth of 53 feet annually.

The Building of the Delta

When the river first discharged into the gulf at Yuma a delta bar was built out into the water of the gulf, and continued to be built higher and longer till a ridge extended toward the

Cocopah Mountains, and was in time built entirely across the gulf. This ridge was built up till its crest was 40 feet above the water level of the gulf. Then the waters as they continued to be discharged into the filling gulf spread each way from the backbone of the delta, alternately southward to the Gulf of California and northward into the basin which had been cut off by the delta ridge. Thus the trough of the original Gulf of California was separated into two parts. The basin to the north, which represents the extreme north end of the trough, was filled with water, probably originally salt or brackish. This body of water has been called Lake Cahuilla, or Blake Sea, the former name being given by its early discoverer, Prof. W. P. Blake, and the latter assigned in honor of the man who first discovered this remarkable region and explained its true character in 1853.

It is thought that the waters alternately discharged into the gulf below and to Lake Cahuilla above as floods carried debris and repeatedly blocked the channels of discharge. If Lake Cahuilla was at first salt it must soon have become brackish or fresh with the influx of waters from the river. Tides which drive in from the ocean with great force disrupted the channels by which the waters of the inpouring river sought to reach the ocean. Due to the intense heat, evaporation carried away the water from Lake Cahuilla, and its surface was gradually lowered. It ultimately became a dry basin with layers of salt on its bottom. This is called the Salton Sink.

The long depression in which the waters of the Gulf of California had ebbed and flowed was a trough or sunken portion of the earth's crust formed by faulting of the rocks. The basin is walled in by mountains on either side. With the building of the delta ridge from Yuma to the Cocopah Mountains, and the further filling of the trough with sediments, the sea was effectually shut out, and Lake Cahuilla came to occupy the north end of the trough. The Chocolate, Chuckawalla, Cottonwood, and San Bernardino ranges on the northeast, and the San

Jacinto, Santa Rosa and other mountains of the Peninsular Range, including the Cocopah (which is in Mexico) on the west side of the desert, are ancient mountains. They consist of granite, gneiss, and schists, igneous and metamorphic. They are probably pre-Cambrian in age. They have been weathered and eroded during the ages. Alluvial debris has been washed down their slopes and forms deposits around the edges of the desert basin.

The Geologic Formations

Formations of Tertiary age flank the mountain ranges, known as the Mud Hills formation. Extensive beds of oyster shells and other marine fossils occur on the west side of the desert, notably along Carrizo Creek and at Coyote Wells west of El Centro. Near Mecca, on the east side of the Salton Sea, the basal deposit of the Mud Hills formation is a conglomerate. This is a continental or land deposit as distinguished from a marine or sea deposit. It is thought that this deposit was made as the sea retired from the trough. The deposit of alluvial strata of the Mud Hills formation was interrupted by violent upheaval in late Tertiary or early Pleistocene time. The Mud Hills formation is much bent, broken and contorted. Bordering the ranges of mountains that form the enclosing walls of the basin are foothills of much disturbed Tertiary strata, remnants of former alluvial aprons. Below these foothills are deposits of recent and modern alluvial fill. The great structural trough itself is deeply filled with erosional debris from the granitic, gneissic, and schistose rocks of the surrounding mountains.

Mountains of the Colorado and Mojave deserts are thought to belong to one great mountain system. The mountains were long eroded, and finally the whole region subsided. The present mountain peaks and ranges stand out in a sea of erosional debris washed from the slopes of these mountains and deposited in the intervening valleys. These valleys are now broad flat desert areas. The subsidence was so great that many old valley bottoms are now hundreds of feet below sea level.

Tertiary Time Was Long

The Tertiary period lasted about 58 million years. During Tertiary time the Colorado River discharged into the Gulf of California upon its own delta. It has been stated that the backbone or axis of the delta was built as a ridge across the gulf from Yuma to the Cocopah Mountains, and that then for a long time the river discharged its waters both ways from the axis of the delta. That much filling of the basin to the north occurred is shown by the deposits that are revealed in borings for wells. Alluvial deposits in Lake Cahuilla, washed in from the shores, and silt carried into the lake by the river, make possible the flowing and other artesian wells which today mark oases in the great desert.

Wells, some of them 1,000 feet deep, penetrate alluvial clays, sands, and gravels. None has reached the valley bottom however. No bed-rock was encountered at depths of 600 to 700 feet below sea level near Imperial. Wells in the Coachella Valley, in the vicinity of Indio, in the narrow part of the trough between the San Jacinto and San Bernardino ranges, and at Salton station, indicate that bed-rock is at least 1,000 feet below sea level. Thus is seen how great was the downsinking or subsidence of the bottom of the basin, and what a tremendous amount of earth has been borne into the basin by the Colorado River and by in-wash from the surrounding mountain slopes.

The problem of watering the desert was one to be solved. Irrigation is almost as old as civilization itself. The use of water from wells for irrigation dates back far into antiquity. In the Colorado Desert it has caused oases to appear where thrive the most luxuriant of gardens. A grove of palms in the midst of the arid desert surprises the visitor. The date gardens near Indio and Mecca are among the wonders not only of the Colorado Desert but of the world.

A Great Engineering Problem

The problem of water for large-scale irrigation on the great plain of the arid lake bottom has been solved. The Colorado River, by which the great desert plain was formed, now supplies water to irrigate its own delta. In 1900 a company was formed to divert the waters of the Colorado for irrigation of the broad flat Imperial Valley just north of the International

Courtesy U. S. Bureau of Soils

FIG. 34. Erosion in stratified sandy loam of Coachella Valley.

Boundary and south of Salton Sink. The engineering feat of diverting the water of the Colorado and conveying it by canals to the plain of the desert was undertaken and carried out with such success that within a few years there had been a great influx of settlers and the development of many fine farms.

In 1904–5 a terrific flood poured down the Colorado River. The Colorado is a tractable and well-behaved stream during most of the year, but becomes a raging torrent of terrific force during seasons of flood. The eroding and cutting power of the accelerated current in times of high water is almost inconceivable. The river broke its bounds and went wildly on its way over its old delta plain. For centuries the river had discharged alternately to the Gulf of California on the south and to the basin of Lake Cahuilla on the north. The silt deposits of the delta are very erodable and the flooded river, having left its original channel, rapidly cut terrific gashes in the soft earth. The river resumed its old channels of New and Alamo rivers by which it had delivered water to Lake Cahuilla. The basin of Salton Sink began to fill with water. The shores of Salton Sea were pushed outward. The tracks of the Southern Pacific railroad which skirted the shores of Salton Sea had to be relaid on higher ground. The salt works which had been in operation on the flat bottom of Salton Sink were submerged and had to be abandoned. Farm lands that had been improved under the irrigation system were inundated and valuable fields destroyed by erosion. The great irrigation system by which the Imperial Valley had been a productive garden seemed doomed.

Despite overwhelming difficulties and obstacles, by the determined efforts of engineers and the persistent outlay of capital by the Southern Pacific railroad, the river in 1907 was brought under control and returned to its former channel leading to the Gulf of California. By successful adjustment of out-takes from the river and the further construction of canals this great desert irrigation project has been brought into successful operation, and the river goes on its way to the gulf.

Lake Cahuilla

Salton Sea increased in area due to the incursion of the Colorado River, till in 1907 it was 45 miles in length, with a maximum width of 17 miles, having at its deepest point a depth of 83 feet, and covered an area of about 410 square miles. It extended from Imperial Junction nearly to Mecca. The evaporation due to the high temperatures is very great. The area of the sea had fallen to 300 square miles in 1915, and is still receding. Had the river not been brought back to its old channel leading to the Gulf, and had it continued to pour its waters into the Salton Sea, this would have meant the return of Lake Cahuilla. This is what did happen in the geologic past, and probably occurred many times as the river meandered over its delta, alternately delivering water to the Gulf and to the lake. Evidently the ancient Lake Cahuilla disappeared by evaporation with the loss of the supply of water from the Colorado.

The inland basin, known as Lake Cahuilla, was at one time filled with water till it covered an area of 2,200 square miles. This is shown by a well-defined beach line around the present Salton Sea, about 40 feet above sea level, 327 feet above the present surface of Salton Sea. The vast basin that lies below this ancient beach, on the lowest part of which is the present Salton Sea, is what is known as the Salton Sink. Water filled the basin to the height of the ancient beach line. Probably this ancient inland sea overflowed to the Gulf, but its ultimate disappearance was due to diversion of the waters of the river southward, and evaporation of the waters of the lake. A guess has been made, based on Indian traditions and such field evidence as can be gathered, that the desiccation of the lake may have been 500 to 1,000 years ago. (This is a mere guess.) The rate of evaporation in this basin has been determined to be 113 inches per annum, or 43 times the average annual precipitation. With the evaporation and disappearance of the waters of Lake Cahuilla the basin bottom became a salt-covered plain. The present Salton Sea is the remnant not yet evaporated of the restored "sea" caused by the influx of the Colorado River. Salton Sea is now disappearing by evaporation, and will probably in a short time (geologically) become again a "dry" salt plain.

The Colorado Desert lies in a long deep valley or trough, the northern extension of the trough in which lies the Gulf of California. The waters of the Colorado enter the Gulf after crossing the delta plain. The extreme northern end of the great valley or trough, San Gorgonio Pass, lies between two mountain ranges, San Jacinto and San Bernardino, 200 miles north of the present Gulf of California. The great trough is due to crustal movement, the subsidence being along fault lines. The character of the topography of the west side of the desert indicates fault lines. The east edge of the Peninsular Range is marked by a fault scarp. The character of the slopes on the east side of mountain salients of the Peninsular Range, Santa Rosa, Carrizo, San Felipe, and Black mountains, indicates a break or fault fracture in the crust of the earth. The San Andreas fault runs through San Gorgonio Pass into the Colorado Desert. At the time of the great earthquake in San Francisco in 1906 there was an earthquake in the Imperial Valley, which suggests the probable continuation of the fault—southward through the valley toward the Gulf of California.

Closely associated with the faults in the desert region are evidences of volcanic activity. In the Salton Sea about 7 miles southwest of Imperial Junction is a row of knobs of obsidian, pumice, scoriaceous lava, and tuff. Near these an interesting group of mud volcanoes existed before the area was flooded by the rising of the lake. Some of these were nearly perfect cones with little craters at their tops. Accompanying these were hot pools, gaseous emanations, sulphur and salt deposits, acidulated waters, and boiling mud pools. A few miles northwest of Imperial, near the bank of New River, is a group of mud volcanoes and boiling pools. A more extensive field of mud craters is found about 40 miles south of the international boundary along the shore of Volcano Lake. These are similar to those just mentioned, but on a larger scale. These mud volcanoes are regarded as representing the last phase of the volcanic activity of which there are many evidences in this desert region.

Chapter X

THE MOJAVE DESERT

An exceedingly interesting region of California is known as the Mojave Desert. The region is traversed for a distance of 100 miles by the Mojave River, from which it gets its name. The area includes Inyo and San Bernardino counties, and eastern Kern, northeastern Los Angeles, and northern and eastern Riverside counties. Death Valley lies to the north. There is no definite line of demarcation separating the desert to the south from the similarly desert region lying to the east of Owens Lake, and including Death Valley and the Amargosa Desert.

Location and Extent

Mojave Desert is separated from the Colorado Desert, which lies to the south, by a series of southeasterly trending mountain ranges. The San Bernardino Range extends southeast from Cajon Pass more than 100 miles, and the Cottonwood, Chuckawalla, and Chocolate ranges extend to the Colorado River. The San Gabriel Range separates the desert from the Los Angeles basin on the south. The Desert is bounded on the west by the southern Sierra Nevada Range and the Tehachapi Mountains. It extends north to the latitude of Mount Whitney, and east to the State line and into Nevada. On the south and east it extends to the Colorado River, which forms the boundary of the State of Arizona. It is a part of the Great Basin region of North America. This vast desert region embraces more than 30,000 square miles, an area almost as large as that of the State of Maine. It is a vast arid region destitute of any drainage streams that reach the ocean. The water supply, such as there is, is obtained from springs and wells. The region is much broken by mountains and hills, often rough and rocky.

The topography is typical of the western deserts, consisting of bare mountain ranges and isolated knobs separated by nearly flat arid belts of varying width. The mountains rise abruptly from the desert, in places almost precipitously. The appearance of the mountains suggests that they are the summits of more massive ranges whose lower slopes are submerged beneath unconsolidated desert deposits. It is thought the irregularly distributed ranges and peaks of the southeastern Mojave Desert are ridges and peaks of a former vast mountain system comparable to the Sierra Nevada, which has been lowered by subsidence of the region, and by erosion, which has resulted in tremendous valley-filling. Alluvial fans occur at the mouths of gullies, and these unite into broad aprons which slope gently toward

Photo by Eliot Blackwelder

Fig. 35. Deeply dissected Afton Basin. An arm of Manix Lake, Mojave Desert, looking north toward Cave Mountain. Black shadows obscure the eroded slopes in foreground.

the centers of the basins. In the center is generally a flat nearly level area known as a playa, dry lake, or alkali flat. Such flats may be covered with water during parts of the year, and they are commonly covered with a white crust of alkali or salt. Toward the west the surface of the desert is generally level. Toward the east it is marked by isolated knobs and short ranges of mountains having no system of arrangement, and separated by broad stretches of alluvial deposits in the form of fans and playas. To the north, in Inyo County, mountain ranges are prominent and are arranged in a somewhat definite north-south system.

A striking feature of the landscape in many parts of the desert is the presence of flat areas ranging in extent from a few acres to many square miles, which are entirely devoid of vegetation. This intensely arid region, lying between the Sierra Nevada Range and the Colorado River, is in extreme contrast with the region lying west and south of the San Gabriel Range, in Los Angeles and Orange counties. However, wherever sufficient water can be obtained in the desert ranches have been developed, and their bright green is a welcome sight to the traveler weary of the interminable desert waste and the dark, forbidding mountains. Many of the valleys or basins that separate the mountain ranges are absolutely desert, totally destitute of water, and treeless for distances representing many days' journey, gray sage brush alone giving life to the landscape. In the larger basins the land slopes toward a central depression into which an intermittent stream may convey water during rainy seasons, forming playas or mud plains. Some larger valleys have permanent lakes, and these are saline or alkaline. The shores of such lakes are devoid of all forms of life except salt-loving plants.

Arid Conditions Due to Mountains

The great Sierra Nevada mountain system is the factor which determines the climate of the desert region. The moisture-laden winds from the Pacific Ocean shed their moisture upon the high mountains, and the lands to the east are left literally "high and dry."

Death Valley Region

An outstanding feature of this great desert region is Death Valley. This remarkable sink of the earth's crust is located about 50 miles east of the Sierra Nevada Range, 6 to 35 miles west of the Nevada State line. This depression of the earth's crust has a length of more than 80 miles, and in width ranges from two to eight miles. It is 60 to 70 miles east of Mount Whitney, the highest point in the United States. The lowest point in Death Valley, according to the U. S. Geological Survey, is 296 feet below sea level. This point is three miles east of Bennett's well, about 30 miles in a direct line west from Death Valley Junction on the Tonopah & Tidewater railroad, and about the same distance northwest from Saratoga Springs, following the road down the valley. The rainfall does not exceed two to three inches annually, with no precipitation at all some years. Mountain ranges on either side of the Valley rise nearly to the line of perpetual snow. Funeral Mountains and Black Mountains, of the Amargosa Range, rise on the eastern side of the Valley to altitudes of 5,000 to 7,000 feet, while on the west the Panamint Range reaches a height of more than 10,000 feet.

High Temperature and Low Humidity

The most marked feature of the desert climate is the unusually high summer temperature and the low relative humidity. Temperatures in this arid region rise to 125° to 130° during the summer months, and seldom during these months fall below 70°. The humidity is low so that conditions are more endurable than would be the case under such conditions of heat in regions of higher humidity. The highest officially recorded temperature of any place in the world is that of 134° at Greenland ranch in Death Valley. This is said to be the dryest and hottest place in the United States. A low temperature of 15° F. has been recorded at Greenland ranch. The difference between the highest and lowest recorded temperatures however is not as great in this desert region as in some parts of the United States. In the Dakotas and Montana differences of 150° have been recorded. In the desert region sunstroke is almost unknown, due to the low humidity. Because of the dryness of the air the moisture given off by the body quickly evaporates producing a cooling effect. Travelers in the desert should be provided with a sufficient water supply. One should never go far from a source of water, in winter or summer, without enough water to last until another supply can be reached. Travelers should carry at least two to four gallons of water per person for each 24 hours.

Three Rivers that Do Not Reach the Sea

Three rivers enter upon the vast domain of the Mojave Desert from high mountain ranges, but none delivers any water to the ocean. These are the Mojave, the Owens, and the Amargosa rivers. The rivers originate on high mountain ranges, fed by melting snows that gather upon the high ranges and peaks, and by rains that are condensed from the wind-borne clouds at high altitudes. These all start as rapidly flowing turbulent torrents. They continue for many miles as intermittent streams, but ultimately disappear by evaporation after passing into the porous soils and sands, detritus from the erosion of the mountain slopes. Other streams that flow as mountain torrents to the great desert plain sink at once into the sands and are "lost" as streams.

The Mojave is a typical desert river. It rises in the high San Bernardino Mountains, in southwestern San Bernardino County. The waters gather in the mountains and form a perennial stream. Within a short distance it emerges upon the desert plain, and much of the water sinks into the porous alluvium. The course of the stream is in a northerly direction to Barstow, where it turns to the northeast. In times of flood the water may be carried 40 miles east of Daggett to Soda Lake. Water sometimes flows into Silver Lake, another playa a mile or two to the north of Soda Lake. During many years no water from the river reaches the playas, but in years of extreme flood the water may be several feet deep in the playas and remain for several months. The water that reaches the playas disappears by evaporation. The river ends in these depressions. The region of these playas has been called "the Sink of the Mojave."

Owens River is the principal stream occuping Owens Valley. Owens Valley is a long narrow depression lying between the Inyo Range on the east and the Sierra Nevada Range on the west. Between these two ranges Owens River flows south to its end in the saline sea called Owens Lake. The valley is thought to have originated as an enclosed and undrained basin through profound faulting of the crust of the earth. The origin of the valley is thought to be similar to that of Death Valley and most of the enclosed undrained areas of the Great Basin. This great structural valley extends from the great bend of Owens River north of Bishop southeast to the southern end of Owens Lake, a distance of 100 miles. It is wholly in Inyo County.

Owens River rises in the Sierra Nevada Mountains near San Joaquin Pass and descends the rugged eastern slopes as a turbulent stream. The river emerges from a deep canyon cut in a table-land of volcanic lava north of Bishop and enters upon the level floor of Owens Valley, whence it pursues a meandering course southeastward to Owens Lake. It is one of the few perennial streams of the Great Basin. Owens Lake, into which the river empties, lies in an undrained depression at the south end of the valley, from which the water disappears by evaporation. The waters of the lake constitute a dense brine containing common salt, sodium carbonate, potassium sulphate, borax, and other salts. The recovery of sodium carbonate is an important chemical industry established near Keeler. About 40 miles above the point where the river enters Owens Lake, near Big Pine, the pure mountain water is diverted through the Los Angeles Aqueduct and conveyed to that city.

Fresh Water of Owens River forms Saline Lake

The waters that gather from the mountains to form Owens

River are "pure" as surface waters go. Even the pure clear sparkling waters of mountain streams contain some mineral matter dissolved from the rocks. By long continued evaporation from Owens Lake the contained mineral matter becomes concentrated so that the waters of Owens Lake are strongly saline. The river waters diverted by the Los Angeles Aqueduct are essentially pure. The salts now contained in solution in Owens Lake were undoubtedly derived by the slow accumulation and concentration of the river waters entering the basin.

In the geologic past Owens Lake overflowed and supplied water to a series of lakes in Indian Wells, Searles, and Panamint valleys. On the bottoms of these lakes deposits occurred consisting principally of clay, with minor amounts of sand and almost no gravel. In most places they include some chemically deposited salts. In a few places these salts are of economic value.

Amargosa River rises in a group of springs about 17 miles northeast of Bullfrog, Nevada. It is dry the greater part of the time throughout much of its course. It is about 140 miles long. Its course is east of south through Franklin Dry Lake, thence south through a canyon about 10 miles long to the southern end of Death Valley. Here it turns westward to Saratoga Springs, where it flows northwestward to the sink of Death Valley. The northern end of Death Valley lies nearly due west of the head of the river, so that the depression which is occupied by the Amargosa River as a whole is in the form of a long and narrow U. Ordinarily there is water at only a few places along the course of the channel, but when a cloud-burst occurs it may become a raging torrent for a few hours. For many years the river has not been known to carry enough water to flow on the surface as far as the lowest depression of Death Valley. The waters of the Amargosa are briny along its lower course. Where it spreads out into the large playa at Resting Springs Dry Lake it leaves fields of salt as well as of borax and niter. Hot springs discharge into it at a number of places.

Playas or "dry lakes" are widely distributed throughout the desert region. It is somewhat paradoxical to speak of a "dry" lake. Often flat dry surfaces of saline mud are ripple-marked from the wind before the water disappeared. Seen from a distance such "dry lakes" may deceive the traveler, the dry flat bottom having the appearance of a water surface. The term "dry lake" seems therefore not entirely inappropriate. In the desert region the rainfall is very light, but sporadic. Mountain torrents tear down the slopes with great erosional force after sudden rains. Broad basins between mountain ranges are generally filled, often to depths of hundreds of feet, with alluvial wash from the surrounding mountains. In the lowest parts of such basins water may gather after storms, and large areas may be covered by shallow sheets of water for a time. Soon, however, the waters disappear by evaporation, and the lowest part of the basin becomes a salt-incrusted flat pan, or dry lake.

Salt Deposits Accumulate on Lake Bottoms

Scores of dry lakes or playas range in size from a few acres to lake beds several miles across. One of the largest and most important playas is Searles Lake, which has an area of about 60 square miles. This playa is important because of the extensive deposit of crystalline salt in the central part of the broad basin. Solid salt beds embrace an area of 11 or 12 square miles, and extend to depths of 60 to 100 feet. It is unique in that the salt is nearly pure crystalline mineral (sodium chloride), and not interbedded or mixed with dust or clay, as is the case in many playas where saline deposits occur. This deposit of salt is free from earth sediments, it is thought, because of settling basins in Indian Wells and Salt valleys through which waters passed from Owens Lake during Quaternary (Pleistocene) time when waters from Owens Valley evaporated here.

Death Valley contains an immense salt field. It extends fully 30 miles south from the old borax works. It varies in width from two to four miles. Borax was once manufactured two or three miles north of the point where Furnace Creek emerges from the hills of the west slope of Black Mountains (Amargosa Range).

Soda Lake, southwest of Baker, is one of the largest playas in the desert, having an area of approximately 60 square miles. It is here that Mojave River ceases as a stream. To the north, and separated by a low divide, is the playa of Silver Lake. The great structural trough in which these playas lie is continuous with the trough of Death Valley, and it is thought that waters from the Mojave Valley in Pleistocene time moved northward and joined the Amargosa, and then flowed into Death Valley. Strand lines or beaches high above the valley bottom show that a large body of water once filled Death Valley.

Antelope Valley, lying north and east of the San Gabriel Mountains and south and east of the Tehachapi Mountains, is a closed basin, having no outlet for its surface waters. The rainfall is so slight and the evaporation is so great that not enough water reaches the bottom of the valley to form a lake. Several playas occur, the largest of which are Rosamond, Rogers, and Buckhorn. It is thought that at one time (Pleistocene) all three formed a single large playa. The rainfall in Antelope Valley ranges from 3 or 4 inches to 10 inches annually, varying widely different years. The greater part of the annual precipitation occurs during the winter months of January, February, and March. The summer rainfall is so slight and so irregular that it is not of much value to agriculture. Irrigation is therefore important. The greatest development of agriculture in the Mojave Desert region has been in the Antelope Valley, where it is claimed 10,000 to 15,000 acres are under cultivation. Water for irrigation is obtained from mountain streams.

Geology of the Region Very Complex

The geology of Mojave Desert and the Death Valley region is very complicated. The region embraces the southwestern portion of the Great Basin plateau. In the north, in the Death Valley region, mountain ranges trend in somewhat parallel lines in a generally north-northwest and south-southeast direction. Faults in many cases mark the boundaries of the ranges and valleys. Death Valley, lying west of the Amargosa Range (Funeral and Black mountains), is a sunken basin in which the floor dips to the east and north toward the great fault scarp which marks the mountain side. The structure of Panamint Valley, lying west of the Panamint Range, suggests that it is a down-faulted block with the greatest depression on the east side of the valley. What is thought to be a fault-plane appears in the abrupt wall of the mountain range on the east. Hot springs at the north end of the valley, and the springs near Ballarat, indicate a zone of faulting along this edge of the valley. The parallel arrangement of the mountains and valleys is generally believed to be due to a series of parallel faults, the valleys representing large blocks that have been lowered relatively with respect to the blocks that have been elevated or tilted to form the mountains.

Very ancient rocks, granites probably of Archaean age, occur in some of the mountains. Whatever rocks may have been deposited over them have been removed by erosion. During the early part of the Palaeozoic era (Cambrian period) some parts of the region were submerged beneath the sea. This is shown by beds of limestone and other sea sediments in which fossils have been found. If the sea covered the entire region during Cambrian time the formations that were laid down have been removed by erosion from most of the region. During the long Ordovician, Silurian, and Devonian periods it is thought that the region was land, as no fossils of these ages have been found. Small patches of rocks containing fossils of Carboniferous age have been found, showing that the sea covered parts of the region at least during Cambrian time. Throughout the Mesozoic era the region is thought to have been land, and was greatly eroded. In the early part of the Tertiary period volcanic outbursts occurred and great lava flows spread over large areas. Throughout the long time of the Tertiary and Quaternary periods erosion was actively going on. A large part of the Tertiary lava flows and other rocks were worn away until now only remnants of once continuous formations are left. Disturbance of the rocks by faulting completed the work of deformation and resulted in the present relief.

Geological conditions have resulted in the accumulation of mineral deposits. These constitute the greatest resource of the region, and have been the incentive for the early exploration and much of the later industrial development. Of metallic ores those of gold, silver, copper, and iron have been principally mined, but lead, zinc, quicksilver, and many rarer metals also have been found. Non-metallic minerals, as salt, potash, niter, borax, and gypsum occur in many places, some in commercially important quantities.

Much literature relating to the minerals and geologic features of the region is available. (See Appendix.)

Chapter XI

THE GREAT VALLEY

A Structural Valley or Syncline

The great basin of central California is one of the world's outstanding valleys. Its floor embraces an area of approximately 16,000 square miles, about 3,000 square miles of which lies less than 100 feet above sea level. Bounded on all sides by mountain ranges it is both shut off from rainfall by them, and watered by inflowing streams that bring back the melted snows from those mountains. This great inter-mountain depression or basin extends from the Tehachapi Range and the San Emigdio Mountains on the south to the vicinity of Mt. Shasta on the north, 500 miles in a generally north-northwest south-southeast direction, varying in width from 20 to 50 miles. On the east is the great Sierra Nevada Range, rising to altitudes of more than 14,000 feet. On the west lie the complicated ranges of the Coast Range system. At the south the great depression ends abruptly with the Tahachapi Range and the San Emigdio Mountains, which ranges form a connecting link between the Sierra Nevada and the Coast Ranges. At the north Mt. Shasta and Lassen Peak fill the great hiatus between the Sierra Nevada and Coast Ranges, these marking the southern end of the Cascade Range. From the southward sloping lava-covered plateau of far-northern California flow the Sacramento and its tributaries. From the far south comes the San Joaquin River bringing the waters of large tributaries which descend the western slope of the great Sierra Range from the snow-capped crests of the high mountains. The Sacramento flowing south and the San Joaquin flowing north meet east of San Francisco Bay and reach the ocean through the Golden Gate.

This vast area, drained by two great rivers flowing in opposite directions, is a synclinal basin hemmed in by mountain ranges and having a bottle-neck outlet through the Golden Gate to the sea. It is a great rock basin or structural valley, and not a valley formed by the erosion of streams. The floor of the basin is essentially flat, with its deeper basement floor of rock formations buried under many feet of alluvial materials borne by streams from the surrounding mountain ranges. During late Tertiary time the basin was filled with water which connected with the sea, and thus marine sediments covered its

Courtesy Tracy Chamber of Commerce

FIG. 36. Cherry Orchard in San Joaquin County, in the Great Central Valley of California.

floor. Later deposits, during Quaternary and Recent time, have further filled the basin. What are now the surface formations, from which the present soils have been formed, are the alluvial deposits that have been carried by streams and deposited either in lakes or spread out as fans upon the flat plain. Fresh-water lake sediments and fluviatile deposits, river-wash, cover the axial part of the great basin. These materials merge below into the loosely consolidated deposits of the Tertiary sediments.

The basin is surrounded by mountain ranges. The cores or axes of the mountain ranges are granite. The mountain ranges represent great upheavals of the crust of the earth. In late Tertiary time the mountain ranges both east and west of the Great Valley were further uplifted, and it is thought that the axial portion of the basin was depressed. This is shown by the fact that the Tertiary strata on either side of the valley are bent upward so that they lap upon the mountain sides.

The Great Valley Once an Arm of the Ocean

A land mass that is now beneath the sea probably existed farther west than the present coast line. The Farallone Islands and Point Reyes peninsula are thought to be high points, mountain tops, of that now submerged land. What is now the Great Valley was then an arm of the sea or bay. Sediments were probably washed from the western land and deposited in the bay and now make up a part of the deep floor of the Great Valley.

Deposits of great thickness were laid down on the floor of the Great Valley. It is thought that the floor of the bay sank as the sediments continued to be laid down. At the same time the mountain ranges were further uplifted. Tertiary shales, sandstones and conglomerates outcrop now in the foothills that rise abruptly on the flanks of the mountains that surround the basin. That here was an inland sea for a long time, and that sedimentation in deep still water was continuous for long is attested by the occurrence of shale deposits many thousands of feet in thickness. That the deposits were made in deep still water is evidenced by the fact that the shales are organic shales, that is, they are made up largely of the remains of organisms, diatoms, microscopically minute animals encased in siliceous shells. It is from this shale, the Monterey group of formations, that the greater part of the wealth of California oil has been obtained.

Formations Disturbed by Earth Movements

During Tertiary time violent and widespread disturbances occurred. Sediments that had been deposited in the bay or arm of the ocean that during this time filled the great basin have

Courtesy Fresno County Chamber of Commerce

FIG. 37. Part of a 10,000-acre fig orchard in Fresno County.

been broken by faulting, upheaved, bent, and folded. Outcropping on the flanks of the bounding mountain ranges, both on the east and west sides of the great basin, Tertiary rocks form the foothills of the ranges. The foothills are the outcropping edges of the uplifted Tertiary formations. The strata dip or incline toward the axis of the basin, those on the Sierra side dipping toward the west-by-south and those on the Coast

Range or western side dipping toward the east and north. The axis of the Great Valley is thus the line of greatest depression, or the bottom of the trough. The broader side of the trough or valley floor is on the Sierra side, the uplift of the great Sierra Range carrying with it the wider portion—about two-thirds—of the basin floor. The bottom or floor of the basin is not uni-

Photo by Hitt. Courtesy Tracy Chamber of Commerce

Fig. 38. Dairy herds in San Joaquin County, in the heart of the Great Central Valley.

form, but has been disturbed by upheavals that reached out from the mountain ranges. In some cases upheavals branching out from the adjacent mountain ranges resulted in humps or anticlines. Such anticlines are the "structures" which have determined the great petroleum oil fields. Such anticlinal folds in the rocks are the Coalinga anticline, Antelope Hills, the groups of anticlines in the Elk Hills and the Buena Vista

Hills, the Wheeler Ridge, and the Tejon Hills. Sometimes the disturbance resulted in the faulting or breaking of the rocks, blocks being elevated or depressed, deeper and older formations being uplifted alongside of younger strata, or younger strata depressed alongside of older. This faulting or breaking of the formations and their displacement has resulted in oil from

Courtesy Fresno County Chamber of Commerce

FIG. 39. Raisin drying in Great Central Valley, Fresno County.

organic shales being drained from its original source and accumulated in porous sandstone formations, and these, when tapped by the drill, have furnished the oil for which many fields are noted.

Alluvial Fans Furnish Artesian Conditions

Porous sandstones which outcrop around the edges of the basin absorb water from rains and melting snows. Under pressure due to the greater altitude the waters descend toward the lower valley floor, thus making artesian or flowing wells possible. Porous alluvial deposits, fans, formed by streams that flow from the mountain ranges, absorb the mountain waters and become a source from which artesian flowing wells and pump wells are obtained at lower levels. Large perennial streams flow from the high Sierra Range over the broad slope toward the valley. Shorter streams, more torrential due to the shorter and steeper slopes, enter on the Coast Range side of the valley. These streams from both sides of the valley have built alluvial fans or aprons, delta-like, at their mouths. These fans spread out over great areas on the basin bottom. The fans on the west side of the valley are shorter and more abrupt, due to the torrential character of the streams from the Coast Ranges. On the east side of the basin the fans extend far out upon the valley floor, their sides often coalescing so as to form a continuous plain. Streams flow across the deltas or fans built at their own mouths, their waters sometimes soaking into the porous soil and sometimes the fans are channeled by the streams that have built them to a depth as great as 100 feet. Coarser rock debris, gravel and even boulders of considerable size, are thrown down, first on the flanks of the foothills as the streams emerge upon the plain, and the finer sands and silt are carried farther toward the axis of the valley.

Streams Disappear in Sands of Valley Floor

In the southern part of the Great Valley, south of the big bend of the San Joaquin River, rivers from the Sierra Range spread out upon their own deltas and the waters sink into the porous soils. Kings River, coming from the crest of the Sierra Range, and Los Gatos Creek, coming from the Coast Range on the west, have each built a delta or alluvial fan into the Valley, and these have extended from opposite sides of the Valley till they have met, and so form a ridge of porous water-borne debris entirely across the Valley. Thus a dam has been formed by which the waters from the southern end of the Great Valley are prevented from flowing north to join the great San Joaquin River, which carries the waters of the rivers from the Sierra Range farther north northward to finally reach San Francisco Bay and the Golden Gate.

Kings River rises in the high Sierra near Split Mountain, and has carved a tremendous canyon in its descent to the plain of the Great Valley bottom. In times of exceptional floods, when levees break, its waters may reach the San Joaquin. Normally its waters, which do not disappear in the porous

Courtesy Kern County Chamber of Commerce

FIG. 40. Olive orchard near Bakersfield in Great Central Valley.

sands, enter Tulare Lake. Tulare Lake is connected by a slough with Buena Vista and Kern lakes to the south. The waters of Kern River that survive the porous sands enter the basin in which Buena Vista and Kern lakes spread out. Tulare, Buena Vista and Kern lakes thus lie in a closed basin within the

Great Valley, a gathering place for waters which have withstood the arid conditions and have not been entirely taken up by the porous sands which form the southern Great Valley floor. There is no drainage outlet to the ocean and the waters disappear by evaporation or sinking into the sands.

Down the Sierra slope between Kings and Kern rivers flow the Kaweah, Tule and White rivers and Cameron, Deer and Poso creeks. These come from near the crest of the great Sierra Range, from Sequoia National Park, and the vicinity of Mt. Whitney, Mt. Tyndall, Bald Mountain, and Sugar Loaf. They descend toward the Great Valley as turbulent mountain streams, all to disappear in the sands of their own delta fans which they have built upon the Great Valley floor. Here under the drying arid conditions they cease and determine as streams.

Outlet to the Sea via the Golden Gate

The drainage of the Great Valley is unique. It has been stated that the outlet for the waters of this great basin is the Golden Gate. The San Joaquin and Sacramento rivers meet and their waters, met by tidal waters from the ocean, pass through Carquinez Straits and the Bay of San Francisco, finally entering the Pacific through the Golden Gate. The rivers that come from the Sierra Range and join the San Joaquin are, from south to north, the Fresno, Chowchilla, Merced, Tuolumne, Stanislaus, Mokelumne, and Cosumnes. These are mighty rivers, that flow perennially from near the crest of the Sierra Nevada Range. In their flow down the western Sierra slope they have cut tremendous canyons. In their lower courses they cut through their own delta fans entering the San Joaquin. Only insignificant streams, insignificant by comparison, enter the San Joaquin from the west or Coast Range side of the Great Valley. Some of these from the west become lost in their own sandy deltas and their waters never do reach the San Joaquin.

The great Sacramento River, bringing the turbulent waters of its great tributaries, the American, Yuba, Feather, and Pit, meets the San Joaquin east of San Francisco Bay. The floor of the Great Valley extends far north of the latitude of San Francisco Bay. The vast structural basin which embraces the area between the two great mountain systems, the Sierra Nevada and the Coast Ranges, extends far to the north. The Sacramento, which technically begins in the foothills of Trinity Mountains southwest of Mt. Shasta, may properly be said to include Pit River, which emanates from Goose Lake on the boundary between California and Oregon, east of the crest of the Sierra Nevada. What is termed the Great Valley of California includes the Sacramento Valley as far north as Redding, or nearly to the point where Pit River joins the Sacramento. The Sacramento Valley is a broad flat plain extending from Carquinez Straits north 160 miles. It is about 50 miles broad at the south and narrows to about 20 miles at Redding.

Axis of the Valley but Little above Sea Level

The lowest part or bottom of the Great Valley is but little above sea level. The city of Stockton is less than 20 feet above sea level. Sacramento is 30 feet, and Davis, where is located the State Agricultural Experiment Station, is 42 feet. The valley bottom where the San Joaquin turns north after descending the Sierra slope is about 150 feet above tide water. Lower in its course the river meanders over the flat plain forming islands and sloughs. By means of harbor improvements and cutting a canal through the winding lagoons Stockton is made a seaport, and boats from the San Francisco harbor tie up at its docks. Where the two great rivers, the San Joaquin and the Sacramento, join to enter Carquinez Strait they are met by tidewater from the ocean. In times of flood the water from these great rivers is not able to reach the ocean and large areas along the lower courses of both rivers are overflowed. When it happens that the two rivers are at flood at the same time the levees which have been constructed along the banks are not able to hold the waters within bounds and destructive inundation may result. Many miles of levees have been built along the stream banks and the cultivation of fertile bottom lands has thus been made possible. Yolo Basin is a level expanse extend-

Courtesy Stockton Chamber of Commerce

FIG. 41. Black bottom lands of Great Central Valley, San Joaquin County.

ing some 30 miles along the Sacramento River south of Sacramento that is subject to annual overflow on which only swamp tules and coarse grasses grow.

Agriculture an Important Industry in the Valley

Agriculturally the Great Valley is an important part of California. The determining factor is water. As has been stated, high mountain ranges surround the Great Valley. The Coast Ranges, which lie between the Valley and the sea, intercept the moisture-laden winds, and air-currents carry clouds high above the Valley to be condensed and fall as snow and rain upon the higher slopes and crest of the Sierra Range. From these high snow-capped mountains waters in perennial streams flow back to the valley floor. Porous deposits take up the waters that flow upon them. Many streams on alluvial slopes spread out and sink into the porous soil. Thus irrigation waters are made possible through artesian or pump wells. Irrigation ditches carry water by gravity from the mountain streams. Lands that are normally arid are rendered productive where water can be supplied, either by gravity canals from streams or from wells either artesian or pumped.

Chapter XII

SAN FRANCISCO BAY AND GOLDEN GATE

A Great Natural Harbor

One of the world's greatest natural harbors is at San Francisco. Ships from the Seven Seas enter and depart through the Golden Gate. The sea-level waters of San Francisco Bay lie in a basin athwart the Coast Range of mountains. Through a notch in the mountain range the commerce of the world comes and goes to and from the great port. The waters of the great rivers that drain the large central valley of California, the San Joaquin and Sacramento, and these include the vast number of streams that flow down the western slope of the great Sierra Nevada Range, reach the ocean through the narrow pass of the Golden Gate. In turn the tides from the ocean surge in, mingling the salt waters of the sea with the fresh waters of the streams. To and fro ebb the tides, and thus intermittently the waters of the San Joaquin and Sacramento reach the sea. If a dam were imagined to be constructed across the Golden Gate, the narrow pass between the Presidio and the Marin Peninsula promontory, or if the mountain range were imagined to be not broken in two, a vast lake of fresh water would be impounded over San Francisco and far north and south covering Sacramento and Stockton, and perhaps finally discharging to the ocean through Monterey Bay.

Such a flight of the imagination is not entirely visionary. The sea has been far over the land where San Francisco is now, and over a vast region to the north and south. This is shown by the formations that mantle the coast ranges to the north and south, now partially eroded away. If on the other hand the region about San Francisco Bay were depressed a few hun-

Photo by G. K. Gilbert, U. S. Geol. Survey

Fig. 42. Thin-bedded chert and shale. Claremont (Monterey) formation, in Berkeley Hills.

dred feet the large valleys, as Napa, Santa Rosa, and Santa Clara, would become bays similar to Richardson, San Rafael, and San Pablo. The higher hills and ridges would become islands similar to Angel Island and Goat Island, and high ridges between the present valleys would become promontories similar to Tiburon Peninsula, Hunter Point, and San Pablo Point.

What is the explanation of San Francisco harbor? During the great lapse of time from Jurassic to Pleistocene the land was

Photo by G. W. Stose, U. S. Geol. Survey

FIG. 43. Minutely folded radiolarian chert (Franciscan) Golden Gate Park, San Francisco.

depressed and covered by the sea several times. Over what is now the Coast ranges sea sediments of great thickness were laid down. Cretaceous deposits north of San Francisco that have not all been removed by erosion reached the astounding depth or thickness of 5 or 6 miles. Erosion since the land was elevated has removed much of the Cretaceous formations, and in places the underlying granitic rocks of the basement complex are exposed. Not only Cretaceous formations have been deposited over wide areas to the north and south of San Francisco Bay, but rocks of Tertiary and Quaternary ages occur. Intervening periods of withdrawal of the sea and elevation of the land are revealed in the succession of rock formations. The intervals of erosion between formations mark unconformities. Unconformities exist about San Francisco Bay, showing that the sea has repeatedly encroached upon the land and the land has been repeatedly uplifted. Not only have there been repeated upheavals and subsidences of the land but the formations have been broken by violent disturbances. Rock formations have been broken or "faulted," and by heat and pressure the character of the rocks has been changed (metamorphosed). Upheaval and subsidence of the land, breaking of the formations by earthquake stresses resulting in vast rock displacements by faulting, and bending, folding, crushing, and crumpling of the rocks, have resulted in the great harbor at San Francisco.

The dominating feature of San Francisco Bay and harbor is three great fault blocks. These three blocks extend across the region in a northwest-southeast direction. These blocks are segments of the earth's crust that have been formed by breaking of the crust of the earth along fault lines and the uplifting and tilting of these segments. They are each uplifted on the southwest side and depressed on the northeast side, that is, they are each tilted toward the northeast. The surface of each block slopes more gradually toward the northeast from the crest and abruptly toward the southwest. The three blocks are designated the Montara, the San Francisco-Marin, and the Berkeley. (See Fig. 44.)

Originally the basin in which San Francisco Bay lies was a river valley through which the drainage of the great interior valley of California reached the sea. The outlet to the sea was where the Golden Gate is now. When the great San Francisco-Marin fault block was uplifted the outflowing waters cut down into the crest of the uplifted block, and continued to flow through the channel, cutting down its bottom as the faulted block was uplifted. The channel of the ancient stream is thought to have been between Angel Island and Tiburon Peninsula, where now, in Raccoon Strait, there is a deep channel. It is thought that this river was a superimposed stream, that is, its course was established when the region was covered with soft formations of Pliocene age, which have since been eroded away. Outside of the Golden Gate is a submerged embankment composed of fine silt which it is thought may represent a delta of the ancient stream which flowed through the

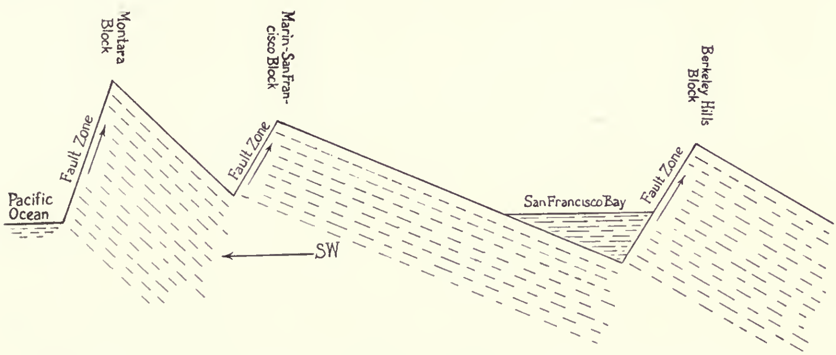


FIG. 44. Generalized cross section diagram of the three great fault blocks in the San Francisco Bay district. The arrow SW indicates the directions of crustal movement from northeast to southwest. The other arrows indicate upward movement of the fault blocks.

Golden Gate before the region was depressed. The embankment extends beneath shallow water for 30 miles to the Farallone Islands. Fine silt is carried through the Bay of San Francisco during flood seasons, and the embankment has been probably in part thus built up.

It should be borne in mind that the uplifting of the great fault blocks was not a sudden or cataclysmic upheaval but went on slowly and for a long time, so that the river continued to flow across the crest of the uplifted side of the block and cut its channel into the hard rock. The depth of the present channel, known as the Golden Gate, is more than 400 feet. San Francisco Bay lies chiefly on the northeastern slope of the San

After A. C. Lawson, U. S. Geol. Surv.

FIG. 45. Map of San Francisco Bay and vicinity, showing tilted fault blocks. The eastern boundary of the Berkeley Hills is not clearly defined. It lies east of the Berkeley Hills and west of the Mount Diablo thrust block. The bar outside the Golden Gate was formed as a delta by the stream which flowed in the old valley of San Francisco Bay before the valley was submerged.

Francisco-Marin faulted block, extending over the Montara block in part, and to the uplifted southwest side of the Berkeley block. A long time elapsed after the uplifting of these great fault blocks, during which time erosion of the land surfaces of these blocks went on. The river, which had been established before the uplifting of the great blocks, continued on its course during the slow rising of the blocks.

The Region Sank and Later Uplifted

At a later time the region about San Francisco Bay subsided so that drainage from the great interior valley to the sea was interrupted. The land sank and the sea came in. The great rivers, San Joaquin and Sacramento, continued to discharge their waters into the basin, but sea waters now entered the basin through the channel of the Golden Gate, and the Great Valley through which most of the drainage of the State had reached the sea was blocked. The intermingled waters from the rivers and those from the sea were ponded. Thus the region of San Francisco Bay became a vast drowned valley. Richardson Bay and San Rafael Bay are drowned valleys of streams that flowed into the basin of San Francisco Bay. San Pablo Bay and Suisun Bay, and indeed the southern end of San Francisco Bay, should be regarded as the submerged lower portions of the valleys that lie above them, viz., Napa, the Sacramento, and the Santa Clara.

Stream Courses Changed

By the uplifting of the land the courses of streams entering the basin have been modified and changed. On the Marin Peninsula a valley having steep sides extends from the head of Richardson Bay on the east across the mountain range of Mt. Tamalpais to the ocean at Tennessee Cove. At the present time two small streams occupy this valley, one flowing to the northeast into Richardson Bay and the other to the southwest to the ocean. The "divide" is about midway of the original valley on an alluvial bottom about 200 feet above sea level. The valley was originally occupied by a stream which flowed to the ocean from the northeast. With the uplifting of the mountain range, which is the high southwest side or crest of the San Francisco-Marin faulted block, the stream was interrupted or cut in two, a stream now flowing each way, one down the east slope of the uplifted block to Richardson Bay and the other down the west slope to the Pacific Ocean.

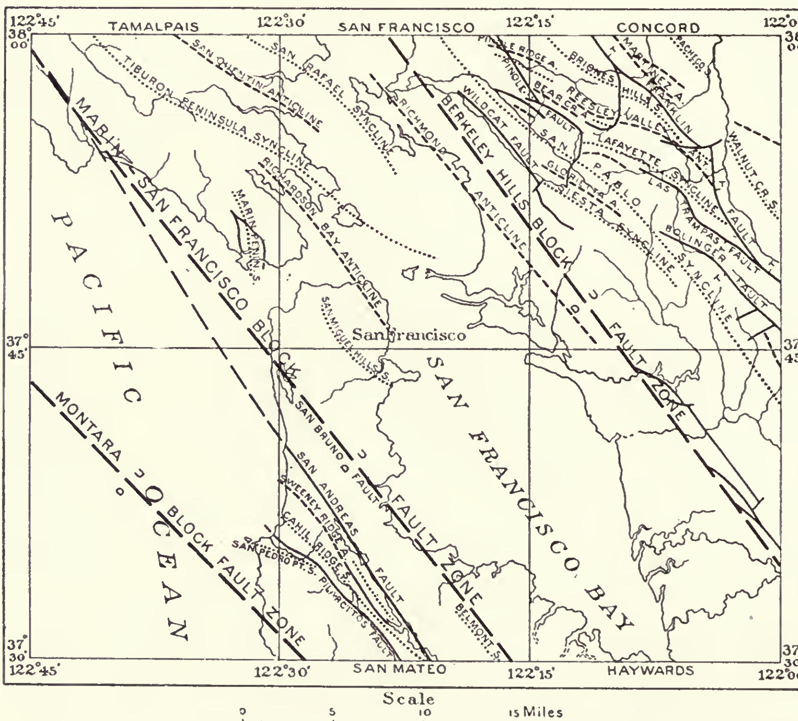
Photo by G. W. Stose, U. S. Geol. Survey

Fig. 46. Steeply tilted rockes. San Pedro Point, west of San Francisco Bay. Martinez (Eocene) formation.

The steep slope on the east side of San Francisco Bay is the fault plane which marks the southwest side of the Berkeley block. Streams that flow down from the crest of the Berkeley Hills, the culminating crest of the Berkeley faulted block, are "consequent" streams. They flow directly to the Bay in courses that were determined by the steep slope. The streams that flow down the northeast slope of the faulted block are "subsequent" streams. Their courses have been determined by rock structure rather than by normal slope. Drainage is toward Suisun Bay. The streams follow lines of faulting rather than that of the general slope of the land surface. The Berkeley block is shattered by many faults. These breaks in the rocks offer easy paths for the waters which flow from the crest of the block northeastward. Since the courses of the streams have been determined by rock structures, breaks or weak places in the rocks, after or subsequent to the uplifting of the great block, they are called subsequent streams.

Alameda Creek enters San Francisco Bay near its southern end. Its headwaters come from the slopes of Mt. Hamilton on the south and Mt. Diablo on the north, and drain broad low-lying valleys east of the Berkeley Hills. It crosses the hilly country of the east slope of the Berkeley uplifted block. The course of the stream across these hills was evidently established before the uplifting of the block, and the stream has continued across the rising mountain block cutting its rugged canyon deeper and deeper into the hard rocks as the block was uplifted. It is an example of an "antecedent" stream, because its course had been established before the uplifting of the block, that is, antecedent to the uplifting, and has held its course while the uplifting of the block was in progress. An antecedent stream is one whose course was established before an obstacle arose across its path and has persisted in its course despite the obstacle.

Due to changes in elevation that affected the region south of Mount Diablo the waters from Livermore Valley, which formerly had reached Suisun Bay through the broad San Ramon and Ygnacio valleys, were diverted to Alameda Creek. The uplifting of the land between the San Ramon and Ygnacio valleys on the north and the drainage basin of Alameda Creek on the south enabled the tributaries of Alameda Creek to push their heads back and tap the streams that had flowed north. The divide between the head of San Ramon Creek and the drainage basin of Alameda Creek is on the nearly level floor of Livermore Valley (called also Amador Valley). This flat plain was the floodplain of San Ramon Creek before it was beheaded. By stealing the waters that had flowed north to Suisun Bay the drainage basin of Alameda Creek was more than doubled. This



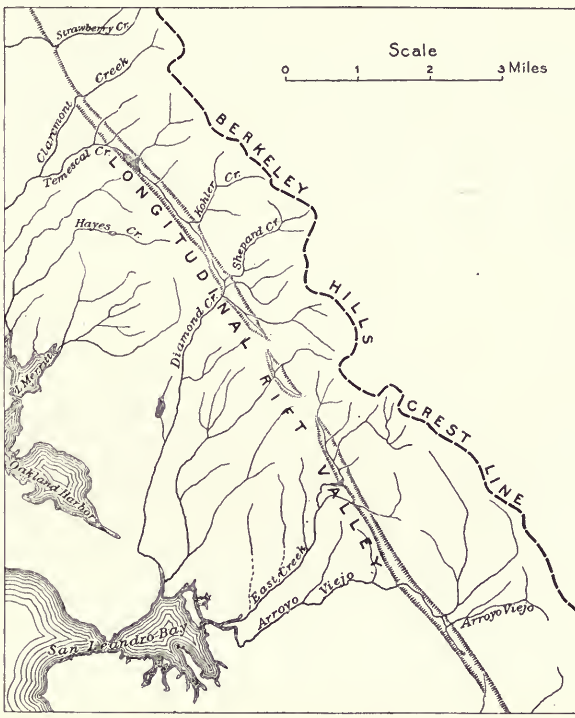
After A. C. Lawson, U. S. Geol. Survey

Fig. 47. Outline map showing the limits of the great Fault Blocks and the larger faults. The limits of the major fault blocks are shown by heavy dashed lines; faults by continuous lighter lines (broken in the ocean). T indicates the thrust side of an overthrust fault; U the up-raised side of a fault block; D the down-throw side of a fault block.

is called "piracy," or the stealing of one stream by another. The broad flat-bottomed valleys of San Ramon and Ygnacio are thus explained. These broad plains mark the lower course of what was a much larger and longer stream. Walnut Creek now flows over the broad alluvial bottom of the lower half of the original valley, the upper half having been diverted or pirated to another stream.

Drainage Affected by Faulting

How the courses of drainage streams have been affected by faulting of the rock formations is strikingly shown by a long



After A. C. Lawson, U. S. Geol. Survey

FIG. 48. Outline map of western slope of the Berkeley Hills, showing the deflection of the streams by the longitudinal rift valley of the Haywards fault zone.

rift valley, the Haywards fault, which extends for several miles parallel to the crest line of the Berkeley Hills (the Berkeley uplifted block). This is shown in figure 48. It should be noted that this fault is not the one that marks the boundary of the Berkeley uplifted block, but occurred after the uplifting of the main block, and after the streams that flow down this steeper southwestern slope had been established. How the Haywards fault affected the consequent streams is shown in figure 48. Along the foothills between Claremont Creek and the Arroyo Viejo lies a long narrow interrupted valley which is parallel to the range of the Berkeley Hills, which marks the crest line of the Berkeley faulted block. Most of the consequent streams which flow down the steep southwestern slope

Courtesy Redwood Empire Association

FIG. 49. Muir Woods. Redwood Forest. Fourteen trees are growing from one horizontal trunk.

of the block, which valleys were intersected by the longitudinal valley of Haywards fault, are diverted for short distances before they pass southwestward through breaches in the fault wall. The consequent drainage of the southwest slope of the Berkeley Hills (Berkeley block) was established before the Haywards fault occurred. The tendency of streams to follow the paths of least resistance caused the diversion of the consequent streams along the path offered by the Haywards fault, and they thus become subsequent streams till they break through the wall of the fault valley and again become consequent streams. The Haywards fault occurred after the development of the main fault between the Berkeley Hills block and the San Francisco-Marin block. In a similar way the San Andreas fault is related to the earlier San Bruno fault. The San Bruno fault marks the southwest boundary of the San Francisco-Marin block. The San Andreas fault occurred at a later time. The San Andreas fault marks a long straight valley for many miles across the Marin Peninsula north of San Francisco. The long series of lakes along the San Andreas rift valley represent the interrupted drainage down the steep southwestern slope of the San Francisco-Marin uplifted block, the Buriburi Ridge. North of the Golden Gate the San Andreas fault joins the San Bruno fault, which latter forms the southwestern steep wall of the San Francisco-Marin fault block. The San Andreas fault is separated from the San Bruno fault west of San Francisco. It is traced for 300 miles to the southeast. Earth movements along the San Andreas fault caused the earthquake of 1906.

Chapter XIII

MOUNT DIABLO

An Up-Thrust Folded Mountain

An outstanding geologic feature of central California is Mount Diablo, about 20 miles east of San Francisco Bay. It is located at the northern end of the Mt. Diablo Range, the central group of the Coast Ranges, between the great Central Valley of California and the Pacific Coast adjacent to San Francisco. Rising from near sea level to an elevation of nearly 4,000 feet (3,849 feet), Mt. Diablo is a conspicuous landscape feature. It is in view from the eastern slopes of the Sierra Nevada Mountains to the Golden Gate. From a geologic standpoint the mountain and its immediate vicinity constitute what is pronounced the most conspicuous structural feature in middle California.

Following the end of Tertiary time Coast Range mountain building became more active, with increased uplifting, folding, and faulting. At this time the Mt. Diablo uplift began, and during its progress, which continued probably into late Quaternary time, the Franciscan complex was thrust up through the Cretaceous in the apex of the structure. The Franciscan mass of Mt. Diablo is the remnant of this upthrust complex remaining after the erosion of the Cretaceous from above and about it.

Two distinct structural features stand out in Mt. Diablo. First, there is the great anticlinal fold, the Mt. Diablo uplift, which may be termed the "great Mt. Diablo anticlinal fold," developed at the close of Tertiary time. Second, there is the Mt. Diablo upthrust of an igneous and metamorphic complex through the upper Jurassic and Cretaceous strata in the center of the great anticlinal fold. The structure of the Mt. Diablo anticline involves the entire sedimentary series below the top of the Tertiary, aggregating not less than 43,000 feet. The extent of the protrusion of the Franciscan upthrust mass through later Cretaceous and Tertiary strata it is not possible to state because these strata, totaling upward of 20,000 feet, have been removed from the central part of the anticline around the mountain, and an unknown amount of the Franciscan rocks has been worn away.

What is called the Mt. Diablo anticlinal fold extends from the edge of the San Joaquin Valley south of Tracy more than 50 miles in a northwesterly direction through Mt. Diablo, across Carquinez Strait, and includes Sulphur Springs Mountains near its north end. The upheaval and overthrust of Mt. Diablo occurs about midway of this great fold or anticline. The mountain proper is an ovate mass of metamorphic and igneous rocks 15 square miles in area thrust up and protruding through the center of the great anticlinal fold. Structurally the mountain is an overturned and overthrust anticline, that is, an uplifted bent and folded segment of the earth's crust, thrust upward and forward by the force of a molten mass injected from below, and the fold overturned. The injected mass of igneous and metamorphic rocks was thrust upward through the upper Jurassic and Cretaceous strata in the center of the anticlinal. The mountain mass proper is what is geologically termed a "horst," a segment of the crust of the earth uplifted and bounded on all sides by faults.

Great Thickness of Rocks Eroded During Uplift

The central mass of Mt. Diablo is a "plug" of rocks four miles in diameter of the old underlying Franciscan formation. Rocks of Cretaceous age, which were thrust into and uplifted, have been eroded away, so that the old Franciscan rocks are now exposed and form the outstanding mass of Mt. Diablo. Cretaceous and Tertiary rocks having a total thickness of as much as five miles were laid down over what is now Mt. Diablo, when the sea covered the region at different times, and these have been carried away by erosion during the long time during which the upheaval of the mountain was going on. During the time from late Jurassic to the end of the Cretaceous there were five epochs of submergence and sedimentation throughout the Mt. Diablo area, and during Tertiary time the region was submerged beneath the sea at two different times. It is thought that 20,000 feet of Cretaceous and Tertiary rocks have been removed from the top of Mt. Diablo, and how much of the upthrust Franciscan rocks have been worn away it is impossible to tell. Mt. Diablo as a topographic feature has developed during the long time during which 20,000 feet, more or less, of Tertiary and Cretaceous rocks were being eroded from the conical mass of Franciscan rocks which had been thrust up through the axial zone of the great Diablo anticline.

Mass Forced Upward as Vast Fault Plug

It requires some exercise of the imagination to picture to the mind such a gigantic thing as the Mt. Diablo overthrust. When the region of Mt. Diablo was submerged beneath five miles of sediments, as it was at the end of Tertiary time, and was subjected to mountain-building stresses deep seated in the earth, the rocks moved as a plastic mass in the direction of least resistance. A mass of Franciscan rocks four miles in diameter was forced upward as a fault plug into the younger rocks above, and was thrust forward a distance of 10 miles over younger rocks below and under still younger rocks above. The mountain as it is today is a conical mass of eroded and weathered igneous, metamorphic, and sedimentary rocks of Franciscan age standing high above the San Joaquin Valley on the east and San Ramon Valley on the west. Cretaceous and Tertiary rocks flank the anticline in eroded parallel ridges northeast and southwest of the mountain.

The Franciscan rocks of Mt. Diablo are intensely folded, crumpled and fractured. They may be grouped roughly into three areas: (a) The metamorphic sedimentary complex, about ten square miles, includes the main Mt. Diablo Peak and North Peak. Here are found all the forms of metamorphic sedimentary rocks that occur in the San Francisco Bay region.

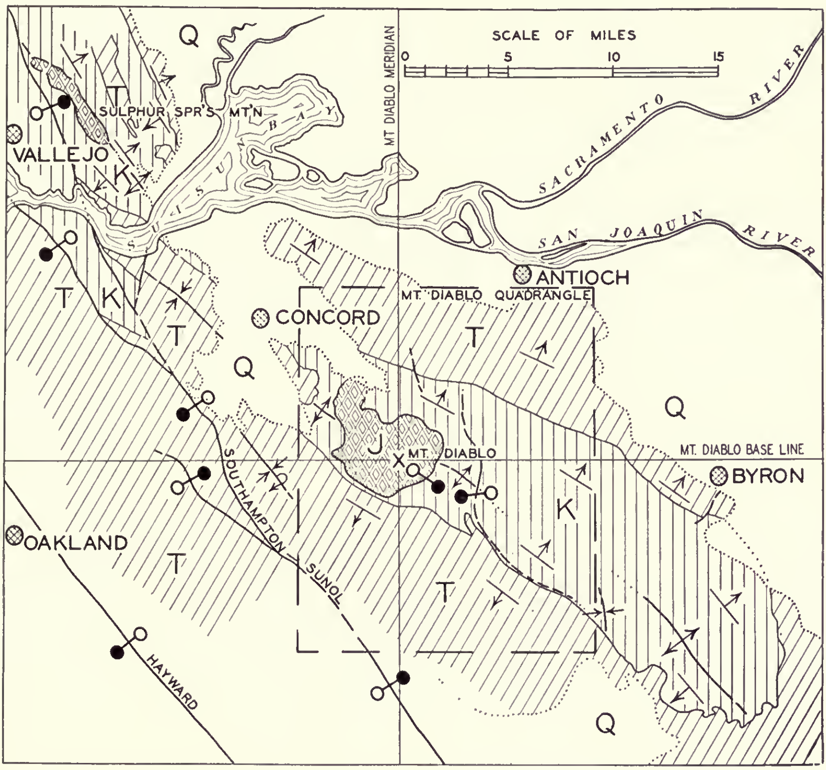


FIG. 50. Structural map of Mount Diablo, showing upthrust mass of Franciscan rocks through Upper Jurassic and Cretaceous formations. J, Franciscan; K, Upper Jurassic and Cretaceous; T. Tertiary. Beginning in late Jurassic time and ending at the close of the Cretaceous there were five epochs of subsidence and sedimentation throughout the Mount Diablo area. (J. A. Taff.)

(b) Massive diabase and basalt, igneous rocks, occupy about five square miles in the northwestern part of the mountain. Included in this area are Mount Zion, Black Point, and Eagle Point. (c) Metamorphic igneous rocks extend diagonally across the mountain as a large intrusive mass between the metamorphic sedimentary main mass of the mountain and the diabase basalt area of Mt. Zion, Eagle Point, and Black Point.

Tilted Rocks Visible on Ride to Top of Mountain

A ride to the top of Mt. Diablo is one to be remembered. The fine highway makes the ride enjoyable, and the view from the top is in itself compensation for the climb. One does not have to be a geologist to enjoy seeing what nature has done. All the upturned rocks that are passed going up may not be distinguished as Cretaceous or Tertiary, as metamorphic or igneous, but tilted beds of chert, shale and sandstone will be interesting. The complex metamorphic sedimentary and igneous rocks that make the central mass of the mountain, though weathered and mantled with soil at the top, where exposed in eroded gullies or in highway cuts, will fascinate and hold the interest of layman or geologist.

Formations Vertical and Overturned Exposed in Faults

The Riggs Canyon fault cuts across the southwestern base of the mountain. For several miles to the southeast of the base of the mountain the fault is covered by the Cretaceous deposits above the Diablo thrust. The formations along the south side of the Riggs Canyon fault zone stand vertically or are overturned. In the immediate vicinity of Mt. Diablo beds of Knoxville (Lower Cretaceous) age border the fault. An anticlinal fold, which strikes into the fault at right angles, occurs in the Knoxville beds on the north side of the fault and exposed in a cut on the road that leads up the mountain from the west side. This is north of Pine Canyon and a little southeast of Arroyo del Cerro. Just south of Windy Point, to the east, lower Chico (Cretaceous) sandstones and shales are folded into a syncline with steeply dipping beds on either side. In a broken flexure in this syncline the beds stand vertically. The Tassajero flexure is on the east side of Riggs Canyon and on the north side of the main Riggs Canyon fault a little farther to the east. It is on the surface an overturned syncline, the rocks of which are composed of upper Cretaceous shales and Eocene (Tertiary) deposits. The Eocene rocks in the flexure have been doubled back upon themselves. The Eocene deposits west of the flexture stand vertically, and in the area south of it they are overturned. The curved fault around the flexure is not easily seen in the field because it is in shale and exposures are poor.

The Mt. Diablo upthrust cuts through Cretaceous strata on all sides. The contact of the uplifted Franciscan Complex is that of a fault plane with Cretaceous rocks on one side and the heterogeneous mass of the intruded complex on the other. The contact of the Franciscan rocks and the surrounding Cretaceous deposits wherever exposed is that of faulting. On all sides of the mountain rocks have broken and moved in landslides, these extending in many places over the edges of the adjacent Cretaceous formations. On the southwest side of Mt. Diablo and on the north side of North Peak particularly, gravity landslides of very large proportions have extended to the base of the mountain. The road that approaches the mountain from the west crosses such landslides for several miles, as does the road approaching the mountain from the south for a lesser distance.

Chapter XIV

THE SIERRA NEVADA RANGE

One of the outstanding mountain ranges of the United States, and indeed of the world, is the Sierra Nevada Range. It embraces the entire eastern portion of the State of California. It dominates the State of California, and indeed the western United States. It is a single unbroken mountain range, comparable in size to a mountain system. It is nearly as extensive as the French, Swiss, and Italian Alps combined. It extends from the Tehachapi Pass on the south to the vicinity of Lassen Peak on the north, a distance of 430 miles, and varies in width from 40 to 80 miles.

Highest Mountain Range in United States

In height the Sierra Nevada outranks all other mountain ranges in the United States outside of Alaska. Mount Whitney, in the southern portion of the range, is the highest point in the United States. Many summits of the Rocky Mountains stand at heights of 14,000 feet or more, nearly as high as Mount Whitney, but the Great Plains stand at an altitude of about 5,000 feet at the foothills, and the high peaks of the Rockies are thus about 9,000 feet above their bases. The Sierra Nevada stands 11,000 feet above Owens Valley on the east, and 14,000 feet above the Great Valley of California on the west.

The peaks of the northern part of the Sierra Range reach altitudes of above 7,000 feet, but increase in height toward the south. Lassen Peak reaches an altitude of 10,453 feet; Crater Peak, a few miles to the north of Lassen Peak, 8,724 feet; Butte Mountain to the south, 7,831 feet. In the vicinity of Lake Tahoe, northeast of Sacramento, the peaks of the main crest of the range reach heights of 9,000 to 10,000 feet; in the Yosemite National Park, 12,000 to 13,000 feet; and Mount Whitney, the highest of all, 14,501 feet. The vicinity of Mount Whitney is the culminating part of the range. To the south of Mount Whitney altitudes of the highest peaks decline to 12,000, 9,000, and 6,000 feet. Cache Peak, north of Tehachapi Pass, is 6,705 feet.

East and West Slopes Compared

The east front of the Sierra Nevada Range is among the greatest mountain escarpments in the world. It is less imposing toward the north where it is broken by minor ridges. East of Yosemite National Park it has a height of 6,000 feet

Photo by Adolph Knopf, U. S. Geol. Survey

FIG. 51. Summit region of the Sierra Nevada, west of Mount Whitney.

above the basin of Mono Lake. Farther south, west of Bishop and Big Pine, it stands abruptly at 10,000 feet, and east of Mount Whitney and west of Owens Lake, at the culminating part of the range, it is nearly 11,000 feet, or about two miles, above the plain of Owens Valley. The east slope of the Sierra Range is an abrupt wall extending for 300 miles from Honey Lake, in Lassen County, to Owens Valley, in Inyo County. The fault wall that thus marks the eastern front of the range is a great continuous fault by which the country to the east—the Great Basin of Nevada and Utah—has been dropped or thrown down from 3,000 to 10,000 feet relatively to the high mountain range.

The western slope of the Sierra Nevada Range is 40 to 70 miles in width, sloping from the crest of the range to the Great Valley of California. The Great Valley is a flat nearly feature-

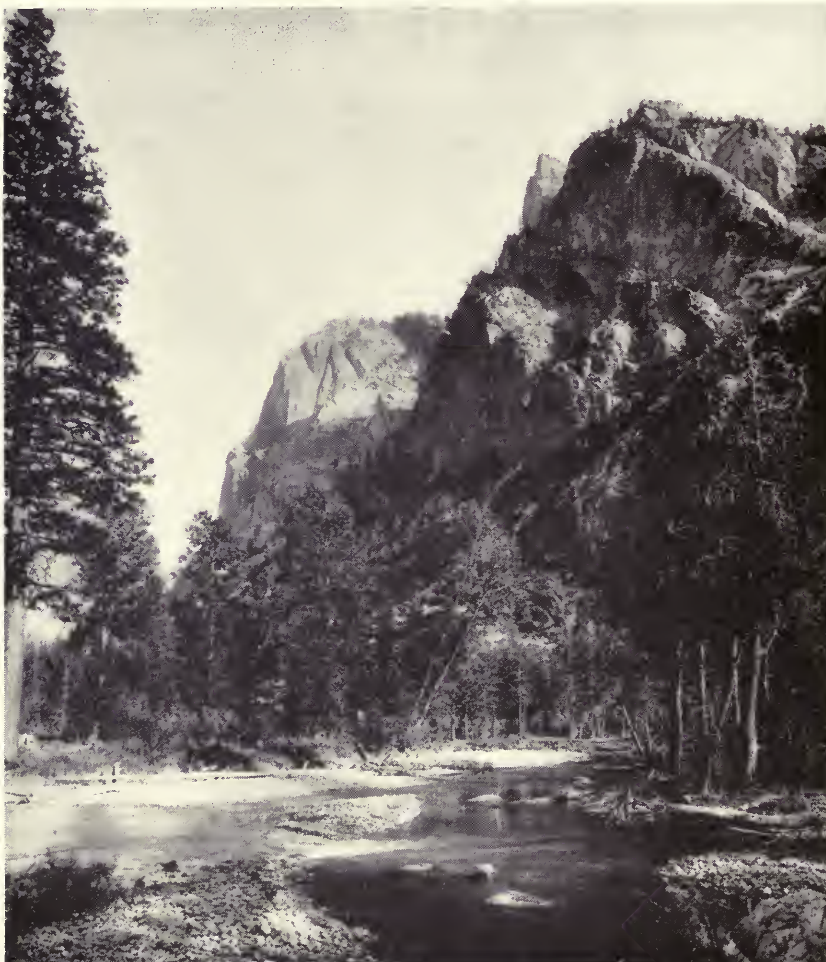


Photo by Hillers, U. S. Geol. Survey

Fig. 52. Cliffs on South Fork Kings River, near mouth of Copper Creek. A bridge crosses the canyon at an elevation of 3,000 feet above the canyon bottom.

less plain, one-third of its area, nearly 3,000 square miles, being less than 100 feet above sea level. The west slope is traversed by a number of long rivers. The east slope, which is extremely abrupt and tremendously rugged, is traversed by comparatively short streams. Both slopes are deeply sculptured. The main streams of the wider western slope run through canyons several thousand feet deep. The canyon of the Merced (Yosemite Valley) is 3,000 to 4,000 feet in depth. The Tuolumne and Kern rivers have canyons between 4,000 and 5,000 feet deep. Kings River and its main branches have canyons between 6,000 and 8,000 feet in depth. The main canyons of the west slope lie mostly at right angles to the crest line of the range.

Crest Line an Obstacle to East-West Travel

The crest line of the Sierra Nevada offers a formidable obstacle to east-west travel across the continent. There are few available gaps or notches that afford passes across the high rugged range. Donner Pass, through which the Southern Pacific Railway crosses the crest of the range, has an altitude of 7,000 feet. The annual snowfall as recorded at stations on this part of the Southern Pacific system is 30 to 40 feet, and in some winters as much as 60 feet. Tioga Pass, the route between Mono Lake and Yosemite National Park, has an altitude of 9,941 feet. It is rarely free of snow before July. The next pass to the south that is suitable for vehicular traffic is Walker Pass, 180 miles south of Tioga Pass. In all this distance there are only steep and laborious pack trails which climb to altitudes of 11,000 feet, and even over 12,000 feet.

Barrier Separates Arid Great Plain from Central Valley

The contrast between the regions lying to the east and west of the great Sierra Range is very great. To the east lies the Great Basin of Nevada and Utah. To the west is the Great Valley of California. The Great Basin to the east is a vast province of sagebrush plains intersected by high mountain ranges. Upon this plain waters that descend the steep eastern slope of the Sierra range disappear by evaporation in the desert. Most of the streams terminate in saline lakes, there being no outlet to the sea. The elevation of the Great Basin is from 3,000 to 6,000 feet above sea level. The lowest parts of the Great Valley of California to the west are practically at sea level. The great Sierra Nevada range is thus seen to be a vast mountain barrier separating lower lands on either side. The eastern slope is short, very abrupt, steep and rugged. The western slope is comparatively broad, nearly 10 times the width of the eastern slope.

Sierra Range a Weather Maker

The Sierra Nevada Range is the weather-maker for the western portion of the United States. Moisture-laden winds from the Pacific Ocean rise over the Coast Ranges and passing over the Great Valley give up their moisture as they pass upward through the colder zones of the Sierra Range. The basin of the Great Valley is semi-arid. On the foothills of the Sierra grow thin grass, brushy chaparral, scattered live oaks, and digger pines. Less than half way up the western slope, at altitudes around 4,000 feet, is the great forest belt. Here are stately forests of yellow pine, sugar pine, incense cedar, Douglas fir, and white fir. In this zone are scattered groves of giant sequoias or big trees. Farther up the slope, above 6,000 to 7,000 feet, occur lodgepole pine, Jeffrey pine, and red fir. At about 9,000 feet silver pine and mountain hemlock make their appearance. This is the "timber-line," where only the hardiest species of trees can survive. At 10,000 to 11,000 feet the white bark pine occurs in curious twisted and recumbent forms. Above the timber-line, from altitudes of 11,000 feet and upward, the mountain sides and peaks are essentially bare of vegetation. Such precipitation as there is is mostly in the form of snow. Snow drifts remain until midsummer, and small glaciers linger in steep-walled recesses among the higher peaks.

What manner of mountain range is the Sierra Nevada? The present range is the latest in a series of mountain ranges that have existed where the Sierra Nevada now is. Mountains are popularly thought of as fixed features of the world landscape. "As old as the hills" is a common expression. As young as youth would probably be more nearly correct. The Sierra Nevada range is young—only probably about a million years old. The crest of the High Sierra remains today much as it was in the "beginning." Its "beginning" was after other great mountain systems had come and gone in the same locality.

The mountain systems that previously existed where the Sierra Nevada is now must have been in existence for very long periods, for each mountain system was reduced by erosion of streams and the weathering agencies to ridges and hills of only moderate height. The time required for the wearing down of these mountains it is estimated must have been between 50,000,000 and 100,000,000 years.

The Story Is Somewhat Complicated

The geologic history of the Sierra region is somewhat complicated, and the story goes far back in geologic time. The record is long. The history and character of two of the ancestral mountain systems that have come and gone where the great Sierra range is now are quite definitely known. The facts as to the character of these mountains have been determined from study of the rock formations which form what may be called the roots of the ancient mountains, and are now a part of the present range. The approximate time when these earlier mountains came into existence is indicated by fossil remains preserved in the rocks. Each geologic epoch is known by its characteristic life forms.

Present Range the Latest of a Series

The first of two ancestral mountain systems that existed before the Sierra range was formed came into being near the close of Palaeozoic time, more than 200,000,000 years ago. The roots of these ancient mountains are recognizable by the character of the rocks and the fossils remains that are preserved in them. This ancient mountain system was formed by the uplifting and folding of a great series of layers of slate, shale, and sandstone—originally mud, silt, and sand, derived from land which lay mostly to the west of the present border of the continent—laid down in an arm of the Pacific Ocean. These beds aggregated thousands of feet in thickness.

During the long lapse of time that followed the wrinkles and folds in the earth's crust thus produced were in large part worn away, and finally the region sank below sea level and again became a place of deposition of sediments borne from adjacent land surfaces. For millions of years layers of mud, silt and sand, together with beds of volcanic material, accumulated upon the submerged remnants of this earlier mountain system, and then, at the end of the Jurassic period, about 130,000,000 million years ago, another upheaval occurred, and the sediments which had been deposited upon the submerged remnants of the former mountain system were folded and crumpled, and were invaded by molten granite from below. Thus there arose a second system of mountain ranges that occupied most of eastern California, and indeed large areas in adjoining States. Throughout the Cretaceous period, which followed the Jurassic, this second mountain system was gradually worn down until by the beginning of the Tertiary period only ridges and hills of moderate height were left.

The present Sierra Nevada range was not formed until a long time later. It assumed its present height and form about the dawn of the Quaternary period. Throughout the preceding Tertiary period, especially in the later half, the region was the scene of repeated disturbances and minor mountain-building movements that finally led up to the culminating uplift at the beginning of Quaternary.

History of the Sierra Nevada

The accompanying table of successive events of the history of the Sierra Nevada Range is from U. S. Geological Survey, Professional Paper No. 160, by François E. Matthes.

"In the table of geologic time divisions the outstanding events in the geologic history of the Sierra Nevada region are set forth in chronologic order, each referred to its proper era, period, and epoch as definitely as the knowledge at hand permits. The figures for the duration of the successive time divisions are taken from the table which the late Professor Barrell compiled from calculations of the age of uranium minerals from different parts of the world.* The age of these minerals is computed from the ratio of lead to uranium present in them, the ratio at which uranium breaks down and is reduced to lead by atomic disintegration being accurately known. The measures of geologic time are much greater than those which have been current among scientists in the past, but they doubtless afford much closer approximations to the truth than the shorter measures, for they are of an order of magnitude that is consistent with many geologic facts, notably with the extremely slow rate at which mountains are worn down."

The Sierra Range a Massive Tilted Block

Most mountain ranges are carved from great wrinkles or folds in the outer crust of the earth, produced by the buckling of originally flat strata. Both of the ancient mountain systems that formerly occupied the site of the Sierra Nevada Range were of that folded type, but the present range consists essentially of a single massive block of the earth's crust that has been dislocated and tilted toward the southwest without appreciable bending or warping. (See fig. 53.) The Sierra Nevada is therefore properly termed a "block range." Great master fractures (faults) extend along the eastern base of the range

* Barrell, Joseph, "Rythms and the Measurement of Geologic Time," Geol. Soc. of America Bull., Vol. 28.

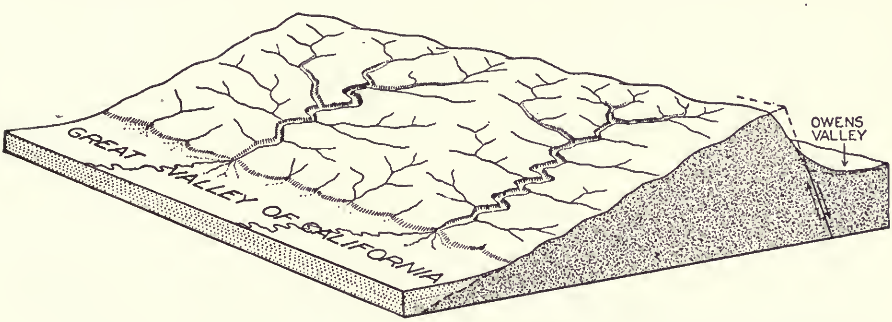
Sequence of mountain-building events in Sierra region

[Read from bottom up]

Era	Period	Epoch	Nature of events	Duration in years
Cenozoic	Quaternary.	Recent.	Postglacial time. Return to normal climatic conditions.	20,000
		Pleistocene.	The great ice age. The higher parts of the range are repeatedly mantled by glaciers. Renewed vigorous tilting, accompanied by strong faulting movements along its eastern margin, cause the Sierra Nevada to stand forth as a lofty block range with steep eastern front.	1,000,000
	Tertiary.	Pliocene.	Period of relative stability. Occasional minor crustal movements and volcanic outbreaks. The region is tilted to the west and assumes mountainous height at its eastern margin.	7,000,000
		Miocene.	Volcanic eruptions begin anew, and the northern half of the region is covered by successive flows of andesitic lava and mud. Prolonged interval marked by minor warpings of the earth's crust, up and down. The land is subject to continued erosion and the rhyolitic materials are mostly worn away.	12,000,000
		Oligocene.	The region, together with the country to the east of it, is slowly up-warped to moderate heights. Volcanoes burst forth in the northern part and cover the land repeatedly with rhyolitic lava, mud, and ash.	16,000,000
		Eocene.	The mountain ranges are worn down gradually and the region as a whole is reduced to a lowland. The bulk of the sedimentary rock, several thousand feet in thickness, is carried away by the streams, and the granite is uncovered over large areas.	23,000,000
Mesozoic	Cretaceous.			75,000,000
	Jurassic.		The new sediments, together with remnants of the old, are folded and crumpled into parallel, northwestward-trending mountain ranges. Molten granite invades the folds from below. More sediments are laid down as the sea bottom progressively sinks.	40,000,000
	Triassic.		The mountains are slowly worn down to hills. The land finally sinks below the sea and new sediments are deposited.	40,000,000
Paleozoic	Carboniferous.	Permian.	The sediments are uplifted and folded into the form of mountain ranges.	415,000,000
		Pennsylvanian. Mississippian.	Sediments, mainly outwash from the continent, accumulate to thicknesses of thousands of feet on the floor of the Pacific Ocean.	
	Devonian.			
	Silurian.			
	Ordovician.			
	Cambrian.			
Proterozoic	Algonkian.		Nothing definite known.	
	Archean.			

and around its curving southern part. The Sierra block was uplifted and tilted toward the southwest, and the block adjoining it on the east sank relatively. The relative movement is shown in the idealized drawing (fig. 53). The magnitude of the displacement, called the "throw," may be inferred from the great height of the eastern escarpment. This in the vicinity of Owens Lake reaches a maximum of not less than 8,000 feet.

The great dislocation at the eastern base of the Sierra Nevada should not be regarded as an isolated case. Most of the mountain ranges that traverse the Great Basin are bounded by somewhat similar faults or fractures. The Sierra Nevada is but



After F. E. Matthes, U. S. Geol. Survey

FIG. 53. Generalized diagram of tilted Sierra block. The great fault fractures that separate the Sierra block from the Owens Valley block on the east are shown by a single line, and the relative directions in which the two blocks have sheared past each other are indicated by arrows.

one, the westernmost, of a vast number of more or less closely related block ranges. The Sierra Nevada is, however, far and away the longest and highest of them all. It is one of the greatest block ranges in the world.

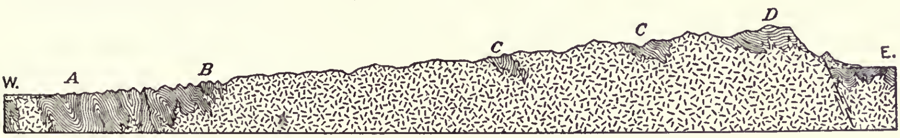
The reader may naturally wonder what is the cause of so profound a phenomenon as the uplifting of a great mountain range. The cause is not known. What has happened we know. The effects are seen in the rocks. Deep-seated forces of tremendous power from the depths of the earth's interior apparently found expression in the upheaval of large segments of the earth's crust, and molten rock in immense volume was forced from below toward the surface and sometimes was poured out upon the surface in the form of molten liquid lava. The nature of the interior of the earth is but little known. The causes of the uplifting of the Sierra block and of the down-faulting of the valley blocks adjoining it on the east—indeed the causes of the upwarpings and faulting movements that have affected the whole of the Great Basin—are not fully understood. A block such as that of the Sierra Nevada must have a tremendous depth, and the main fractures that bound it must reach far down into the earth. That the forces involved were deep-seated and of great power is apparent.

The Main Mass of the Sierra Range a Great Batholith

Of what manner of rock materials is this huge earth block constituting the Sierra Nevada range built up? It is essentially a block of granitic rocks (Fig. 54). The block was once covered with sedimentary rocks, which have been mostly removed by erosion. Only on the lower part of its western slope and in some places on its crest are there considerable bodies of other rocks, such as slate, quartzite, limestone, and lava.

The main mass of the Sierra Nevada range is a vast body of granitic rocks known as a batholith, a term which means "deep rock." A batholith is formed by the welling up from the depths of the earth of highly heated molten rock toward the surface but stopping before reaching it. It thus forms a reservoir of molten liquid rocks below the surface that has over it a roof of rock formations under which the molten mass is forced from below, but which remained as a cover or roof over the molten rock.

The granite rocks have been forced up from the depths of the earth in a molten state and have crystallized as they cooled. In the Sierra block occur many different kinds of rocks, as granites, monzonites, granodiorites, diorites, and gabbros. (See Glossary.) For the general reader the granitic rocks may all be referred to as granite, though this is not strictly accurate. The aggregate of these granitic rocks forms a great complex mass which is spoken of in geological literature as the Bed Rock Series, or Basement Complex.



After F. E. Matthes, U. S. Geol. Survey

FIG. 54. Idealized cross section of Sierra block showing the composition of the interior. The folded beds in the foothill belt (A, B) and different points on the western slope (C, C) and on the crest (D) are the remnants of a formerly continuous roof of (mostly) sedimentary rocks. Under these the granitic materials of the great batholith welled up in a molten state. They are the "roots" of the mountain systems that occupied the place of the present range in time past.

Batholith Confined under Roof of Sedimentary Rocks

The outstanding fact regarding this granitic batholith is that it is now exposed at the surface of the block over large areas, despite its deep-seated origin. Granitic rocks form the surface almost everywhere in the High Sierra region. Most of the prominent peaks, domes and cliffs are carved from such rocks. Yet it is clear from their crystalline structure that these igneous materials did not flow out upon the surface but cooled very slowly, under the pressure of a confining crust or roof of other rocks. The explanation is that they have become uncovered—that they now appear at the surface because the roof under which they crystallized has been in large part removed. The slate, quartzite, and limestone mentioned are the materials of which the ancient roof was made. The old roof rocks were originally thousands of feet thick, but in the course of the ages since Jurassic time, they have been gradually worn away. It is thought that as much as 5,000 feet of rock formations have been removed from the great dome of the Sierra range.

Among the high peaks that mark the crest of the High Sierra, and in isolated patches below the crest, occur remnants of the rock formations that were uplifted by the great batholith and which formed the roof of the great mountain dome. The first mountain crest above the Yosemite region is the boldly sculptured Clark Range, which terminates in Mount Clark (11,506 feet), on the south side of the Merced. About eight miles farther northeast, between the Merced Basin and the Tuolumne Basin, stands the still bolder Cathedral Range, which extends from Mount Lyell (13,090 feet) northwestward to Cathedral Peak (10,933 feet). The main crest of the Sierra Nevada is surmounted by Mount Dana (13,050 feet) and a long row of other peaks between 12,000 and 13,000 feet in altitude that overlook Mono Lake and the deserts at the east base of the range.

The largest mass of the ancient roof rocks extends along the western foothills and the lower slope of the range. It is in the remnants of this ancient rock roof that are recognized what have been termed the "roots" of the earlier mountain systems. The rocks are seen to be composed almost wholly of upturned beds of slate, quartzite and marble, inclined at high angles. The slate, quartzite and marble are really shale, sandstone, and limestone—originally deposited as mud, sand, and lime—that have been metamorphosed by pressure and heat as the beds were folded and pressed together and baked by the intruded molten granite. Intercalated with them are ancient lavas that have been metamorphosed out of all semblance to their former selves. It is interesting to note that cutting northwestward through this belt of metamorphic rocks is a group of gold-bearing quartz veins, the famous Mother Lode of the "days of '49."

These upturned beds of the lower Sierra slope represent the remnants of a series of closely compressed folds or wrinkles of the ancient rock roof. Strongly bent, folded and closely crumpled strata occur in the canyon of Merced River below the entrance to Yosemite National Park. The river cuts across a series of thin beds of chert (metamorphosed siliceous sea-bottom ooze) and shale that are compressed into astonishingly intricate labyrinthine wrinkles. On the scoured and polished rocks in the river bed these wrinkles conspicuously appear (Fig. 55). In the granitic areas above the lower Sierra slope occur here and there small bodies and individual slabs of metamorphic rock, remnants of the ancestral rock roof. Larger masses of

Photo by F. C. Calkins, U. S. Geol. Survey

Fig. 55. Upturned beds of slate and schist. In lower Merced Canyon.

metamorphic rock, including white marble, occur near May Lake at the base of Mount Hoffmann, and also in the rugged headwater basin of Yosemite Creek. Next to the broad belt on the lower slope of the Sierra Nevada the masses of metamorphic rock, remnants of the ancestral rock roof, situated near the crest of the range are the most extensive. They make up the bulk of Mount Dana, Mount Gibbs, and Parker Peak, and of that jumble of mountains north of Tioga Pass, the central summit of which is Mount Warren.

Roof Rocks Reveal History of Ancient Mountain Systems

"The age of the metamorphic rocks of the Sierra Nevada is not easily determined owing to the scarcity of fossil remains preserved in them. A few fossils, however, have been found, particularly in the limestone and sandstone of the lower belt. From a study of these fossil remains it has been determined that the rock strata of that belt fall into two distinct series, one of which is much older than the other. The older, known as the Calaveras formation, is of Palaeozoic (Carboniferous) age; the younger, known as the Mariposa formation, is of Mesozoic (Jurassic) age. The older rocks make up approximately the eastern half of the belt; the younger rocks the western half, extending down to the foothills.

"In the strongly deformed structure of these two distinct series of strata there is clear evidence of the former existence of two successive mountain systems. The general character of these ancient mountain systems is indicated by the forms, mode of arrangement, and trends of the folds. The tops of the up-folds doubtless were worn away at an early stage during the slow progressive upheaval. Stumps of resistant upturned strata remain."*

Thus it is seen that the Sierra Nevada Range is an uplifted block, pushed up to a great height by the up-welling from the depths of the earth of molten rock. The molten rocks of the intruding batholith slowly cooled and crystallized beneath an overlying roof of sedimentary rocks. In the lapse of time since the intrusion of the molten rock the rocks that were uplifted and formed the roof of the great uplifted dome have been eroded away, and the molten rocks, cooled and crystallized, are exposed and form the greater part of the surface of the present range.

* François E. Matthes. *Op. cit.*

Sierra Range Young, Yet Dates Far Back

The history of the uplifting of the Sierra Nevada Range embraces a long span of time. In terms of geologic periods the present Sierra Nevada Range is young. In the genealogy of the mountain systems of the world it may be said to belong to the latest generation. It was "finished" as a mountain range in the geologic period just preceding the present. Indeed it is not known but that it may still be in the process of being uplifted.

While the range is geologically young yet its birth or beginning dates back requiring nine figures to express the time in years. The earlier of the two ancestral mountain systems dates back to Palaeozoic time, estimated to have been 200,000,000 years. The folded, crumpled and metamorphosed rocks that now lie on the western slope of the range properly belong in the ancestral lineage of the Sierra Range.

Toward the end of the Eocene (early Tertiary) epoch—about 40,000,000 years ago—there commenced a period of volcanic outbreaks. Volcanoes on the eastern border of the Sierra region poured out streams of (rhyolite) lava and mud. These flowed down the valleys burying the river channels. During this time, by gradual uplifts the Sierra region was raised and tilted to the southwest. The disturbances finally died out, and during a long interval of relative quiet most of the rhyolite and much other rock waste were removed by erosion. Then during the Miocene epoch (middle Tertiary)—about 12,000,000 years ago—volcanic activity and earth movements began again on a vast scale. Eruptions of lava of a different type (andesite) flowed down and filled the valleys. These lava flows accumulated to thicknesses of thousands of feet. The crustal movements of the earth increased the height of the Sierra region thousands of feet. Strong faulting occurred along some parts of the eastern border, and the great depression in which Lake Tahoe is situated was formed by subsidence of its basin. During the Pliocene epoch (late Tertiary) there followed a lengthy interval of quiet. The waters on the lava-covered parts of the range established new courses, and cut canyons some of which reached depths of 1,000 feet or more. Vegetation established itself, and forests of Sequoias, ancestors of the big trees of the present time, flourished throughout the region.

Final Uplift of Sierra Range a Late Geologic Event

At the beginning of Quaternary time—about 1,000,000 years ago—commenced those great upheavals and tilting movements that gave to the Sierra Nevada its present great altitude. The summit peaks were raised to almost double their previous height, Mount Lyell being lifted to more than 13,000 feet above sea level. At the same time fracturing and faulting occurred on an enormous scale. Owens Valley and other desert regions adjoining the range on the east and south were depressed, and so the Sierra Nevada came to stand out in its present imposing form, with gentle westward slope, sharply defined crest, and abrupt eastward-facing escarpment.

After the grand climax of mountain-building movements that ushered in the Quaternary period earth stresses abated in intensity. Upheaval and down-faulting occurred less frequently, and the Sierra Nevada has suffered no marked further changes in height or in general form. Minor movements, however, have continued to occur at intervals into historically recent times.

One notable dislocation has taken place at the eastern base of the Sierra Nevada within historic time. It gave rise to the famous Owens Valley earthquake of March 26, 1872. The fault scarps produced by this earth movement are still conspicuous, and are easily traced for distances of several miles. They vary from 8 to 25 feet in height. The tremors produced by this earth movement were so strong that even in the Yosemite Valley, more than a hundred miles away, great avalanches of rock fell from the cliffs, and one notable pinnacle was demolished, as has been graphically told by John Muir, who was an eye witness of the scene.

Since this great earthquake no further strong tremors have been felt in the Sierra Nevada nor in the lowlands immediately to the east of it. Evidently earth movements are infrequent in these areas—certainly infrequent compared with those in the coastal belt—and it may be concluded therefore that the Sierra block and its neighbors are in fairly stable adjustment. (F. E. Matthes.)

Chapter XV

AN UNIQUE REGION

California geology is exceedingly complex—and therefore interesting. To speak of any particular region of the State as "unique" might easily lead to the question *which* region! There is indeed more that is unique—that is, unusual—in California probably than in any other State of this great United States. That Owens Valley, with its environs, is entitled to be called unique it is the writer's opinion will not be questioned by any one who has seen and studied this region, among all the "unusual" localities and all the complicated features of the State.

The Highest, the Lowest, the Hottest, and Perpetual Snow

Owens Valley is in Inyo County. Inyo County embraces a vast empire between the crest of the great Sierra Nevada range and the State line of Nevada, and includes the northern portion of the Mojave Desert and the famed Death Valley. Not the least noteworthy fact about this remarkable region is that the highest point of land in the United States—Mount Whitney, altitude 14,501 feet—and the lowest, Death Valley, 296 feet below sea level, are within Inyo County and are separated by a distance of about 60 miles. On the west of Owens Valley is the highest and steepest part of the eastern escarpment of the uplifted block which comprises the Sierra Nevada range, the highest mountain escarpment in the world. To the east of the Valley is the great faulted block of the Inyo Mountains (including White Mountains), the first mountain range of the Great Basin to the east of the Sierra Nevada range. To the south is the Mojave Desert and Death Valley, the most abject of abject deserts, the hottest and most arid place in the continental United States. In the southern part of Owens Valley lies Owens Lake, a sheet of saline water so highly charged with mineral salts that commercial use is made of them at Keeler, on the eastern shore of the lake. The lake is fed by the waters of Owens River, which in its northern sources brings waters from the crest of the Sierra range near San Joaquin Pass. Practically all its tributaries are from the crest region of the Sierra, fed almost wholly by snows that accumulate east of the divide. The pure waters of the upper river are captured south of Big Pine, about 40 miles north of Owens Lake, and conveyed by

Photo by Adolph Knopf, U. S. Geol. Survey

FIG. 56. East fault scarp of Inyo Range facing Saline Valley.

aqueduct to the city of Los Angeles. The lake, having no outlet, its waters become very saline by evaporation. Owens River is a turbulent stream in its upper course. It crosses a large lava plateau, into which it has eroded a canyon 800 feet deep before it emerges upon the flat plain of Owens Valley proper. The elevation of the valley floor where the river emerges from the canyon cut in the lava plain, is a little more than 4,000 feet above sea level. The valley in its upper courses is about 8,000 feet above sea. The flat even floor of the Valley below the lava plateau descends at a rate of about 7 feet to the mile, to 3,600 feet where the river enters Owens Lake. The northern part of the Valley, between Big Pine Creek and Bishop Creek, and north to big bend of Owens River, is so flat and even that the streams pool their way across through ponds and marshes. The flat even floor of the Valley varies in width from 2 to 8 miles. The mountain walls on either side of the Valley rise to great heights. The Sierra range in the vicinity of Mount Whitney is 8,000 feet above the valley floor, and the Inyo range is nearly as high.

A Faulted Mountain Valley

It is hardly necessary to state that the Valley, with its flat, level, uniform floor and steep precipitous walls, is not a valley of erosion, but is a *structural* valley. The walls on either side are the faces of great fault blocks. To the eye they appear to rise almost vertically from the valley floor to the high crests of the mountain ranges on either side. The level floor of the valley extends from the great lava plain on the north a distance of nearly 80 miles southward, with steep fault escarpments on either side. It is thought that the basin in which Owens Lake lies is due to sinking of a fault block, thus causing the basin. Owens River flows through the valley from the great lava plateau to the north not as a drainage stream but pools its way down the flat plain simply because water runs down hill.

To the east of the Inyo range is Saline Valley, an arid basin having a salt sink at its lowest point. Its floor is 2,500 feet lower than that of Owens Valley west of the range. There is no drainage connection between Saline Valley and Owens Valley. East of Saline Valley is the Panamint range, which forms the west wall of the north end of Death Valley. South and east of the Panamint range is the Amargosa range. East of the Amargosa range, rising in Nevada, is the Amargosa River, which flows south 25 miles, then turns west and north around the Funeral Mountains in San Bernardino County, and then flows north and west and disappears in the sink of Death Valley. (See Chap. X.) To the south and east of Owens Lake is the

Coso range, separated from the Inyo range by a high valley. To the south of Owens Lake is Rose Valley, separated from Owens Valley and Owens Lake by an alluvial divide 3,760 feet above sea level, or 160 feet above Owens Lake.

Rocks Faulted and Capped by Lava

The Inyo range (including the White Mountains) is a faulted block, a "horst." (See p. 155, Chap. XIII.) The stratified sedimentary rocks of which the range is made up include those of all ages from pre-Cambrian to Triassic, except

Photo by Adolph Knopf, U. S. Geol. Survey

FIG. 57. Sierra escarpment, south of Owens Lake.

Silurian. The rocks are very much broken by faulting. They are upturned, folded, bent, and broken. The southern part of the range east of Owens Lake is capped by a vast lava flow. These lava beds lie horizontally over the eroded ends of Carboniferous and Triassic rocks that were upheaved into vertical position before the lavas were poured forth. The lava beds are broken into segments by faults by which the range has been much rent, and the lava segments cap blocks that have been thrown downward along the fault slips, so that the lava beds appear as terraces high on the mountain range.

Batholith Intruded under Sedimentary Rocks

It has been stated that the sedimentary rocks that occur in the Inyo range include most of the formations from pre-Cambrian to Triassic. The formations are separated by unconformities, showing that the region was not continuously sea bottom, but was at intervals elevated and became dry land. During the next great era, the Mesozoic, probably in late Jurassic time (the next period following Triassic) a tremendous revolution occurred during which disturbance the Inyo range acquired much of its complex internal structure. The rocks were faulted and folded, and this was followed by an up-welling from the interior of the earth of a vast mass of molten rock forming a batholith. During this revolution the Inyo range acquired the major portion of its complex internal structure. It acquired its present topographic form, however, by profound faulting that occurred probably about the end of Tertiary time. The intruded mass of molten rock forced upward the originally horizontal sedimentary rocks. The great batholith did not reach the surface but lifted the superjacent rocks as a great roof. The revolution was of mighty power. The sedimentary rocks were not only uplifted but were crumpled, folded and contorted. Rocks that had been originally horizontal came to rest in vertical position, folded, bent, and variously deformed. Lavas were poured out. It has been stated before that a series of basaltic lava sheets rest horizontally on vertically upturned strata and form the plateau summit of the southern portion of the range. The molten rocks that were welled up from the interior of the earth, and which formed the great batholith, cooled slowly under the great mass of roof rocks, and crystallized into the granitic rocks (quartz monzonite and allied rocks) which, uncovered by erosion, now make up a large part of the range.

Further Uplift, Faulting and Erosion

At a later time, probably during the Quaternary period, another upheaval occurred by which the Inyo range was brought to its present height. Erosion in the long lapse of time since has caused the removal from great areas of the overlying roof rocks that were uplifted by the great batholith. Thus the granitic crystalline rocks of the great batholith are exposed now at the surface. Metamorphism by the great heat and pressure of the intruded molten rocks transformed the sedimentary rocks, as sandstone to quartzite, shale to slate, and limestone to marble.

The eastern and western walls of the Inyo range are very steep and rugged, fault planes or zones of faulting marking both slopes. The western wall of Owens Valley is the great fault scarp of the Sierra range, higher and more rugged than the east wall, that of the Inyo range. The great scarp of the Sierra rises from 3,600 feet in the vicinity of Lake Owens to 14,500 feet in Mount Whitney. The average height of the Inyo range is about 10,000 feet. The fault walls or scarps on both sides of the valley are deeply scarred by erosion, and alluvial deposits of vast extent border the sides of the valley against the bases of the two ranges. Those on the west side of the valley are more extensive, forming a nearly continuous plateau abutting the foot of the scarp. On the east or Inyo side of the valley the alluvial cones or outwash from the mountain gullies extend far up the ravines, spreading out below as great alluvial fans or aprons, but not forming a continuous plateau as on the west or Sierra side. The precipitation is less on the Inyo range than on the Sierra, owing to the fact of the greater height of the Sierra and the robbing of the clouds of their moisture as they are carried by the winds eastward from the Pacific Ocean.

Tributaries from West Form Piedmont Plateau of Alluvium

Most of the tributaries of Owens River come from the crest of the Sierra on the west. These are turbulent streams in their upper courses, being fed by the snows and glaciers of the range crest. The great piedmont plateau of alluvial wash that lies all along the foot of the Sierra escarpment is crossed by the many streams, and these have cut deep gullies. The alluvial plateau extends up the face of the fault scarp to an altitude of approximately 8,000 feet above sea level, or more than 4,000 feet above the flat plain of the valley bottom. Comparatively few streams, and most of these short, descend the western slope of the Inyo range. Some have cut deep canyons, and their walls are rocky and rugged. Alluvial fans reach far up from their mouths.

Canyon of East Sierra Slope Flanked by Moraines

The largest stream entering Owens River from the west is Bishop Creek, far north in the valley. A few hours by automobile up this valley offers a most thrilling experience. The valley has been eroded through a great granite plateau. Down this valley a tongue of ice pushed its way during the earlier of two glacial epochs, and moraines of the earlier and more extensive glacier tongue flank the valley sides. Through the valley after the ice had disappeared ran the creek which has cut a deep canyon. A later invasion of ice, from a glacier of the later ice epoch, deposited moraines over the old moraines. The later moraines may be distinguished from the older by their greater freshness and less weathered character. Far up the stream, among the peaks of the high Sierra, many lakes occupy basins at altitudes of 11,000, 12,000 and even more than 13,000 feet, a typical alpine region. A trip by auto, if time will permit, will well repay the effort. It will not be possible to reach the high altitude lakes by auto, but the road leads far enough to afford abundant reward for the journey.

It is interesting to note that at the head of North Fork of Bishop Creek is Piute Pass, through which a trail crosses over to the westward-flowing waters of the San Joaquin. This gap or notch in the main divide of the Sierra range was cut by ice of two cirques, one on either side of the divide. The ice of each cirque basin cut back until the wall separating the two cirques was completely obliterated.

The canyons in the eastern slope of the Sierra Nevada have been heavily glaciated. Glaciers in time past have moved down the gullies from the crest of the range, and tremendous moraines now flank the sides of valleys that come into Owens Valley from the west. Far up the steep slope, along the high crest of the range, glaciers form today in cirques among the high peaks. These are tiny miniatures of the glaciers that existed here during the glacial period. Two epochs of glaciation are recognized as having occurred on the Sierra Nevada escarpment during the Quaternary period, the two epochs being separated by a long interval of time. The earlier glaciation was the more extensive and endured for a much longer time. Moraines of the earlier glaciation reach down the valleys to altitudes of 6,000 to 6,500 feet, or half way from the crest of the range to the present floor of Owens Valley. Many glaciers, however, did not reach the mouths of their canyons, and in consequence many canyons show profound contrasts between their upper portions and their unglaciated lower portions. The lower stretches of the great canyons are deep clefts that are no wider at their bottoms than the streams by which they have been eroded, whereas the glaciated upper portions are wide-floored and generally characteristically U-shaped.

Marked Difference in Age of Moraines

The difference in age of the early and later moraines is shown by the degree of weathering and breaking down of the rock fragments that the moraines contain, and by the extent to which streams have cut gullies and canyons in the morainal debris. Boulders of the later moraines are fresh and comparatively little weathered. Granite boulders of the older moraines have become so decomposed, so disintegrated by weathering, that they crumble and fall to pieces with a blow of the hammer. Boulders of the same original character in the later moraines are still fresh and hard, and when broken show the crystal minerals of which they are composed just as they occur in the ledges of undisturbed granite in the mountain sides.

Cinder Cones and Basaltic Lava Flows Mark Valley Floor

On the flat level plain of Owens Valley a few isolated groups of hills rise above the general level, but they are dwarfed by the great bordering mountain ranges. These are, from south to north, the Alabama Hills, northwest of Lone Pine; Poverty Hills, between Independence and Big Pine; and the Tungsten Hills, west of Bishop. A volcanic field lies southwest of Big Pine, and its finely preserved cinder cones and lava flows are notable features of Owens Valley, and a marked feature of the east flank of the Sierra Nevada between Independence and Big Pine. The highest of the extinct volcanoes is Crater Mountain, which rises 2,000 feet above the valley floor. (El. 6,123 feet.) It is composed largely of black basalt lava flows capped by a cinder cone with a crater in its top about 100 feet deep. The cinder cones of this field are fine examples of their type. Some are symmetrical conical heaps of scoria and lapilli. In others the craters have been broken by the escape of molten lava. It is interesting to note that some of the cinder cones are situated upon fault lines, and that motion has recurred along some of these fault lines as recently as 1872. The most perfect and symmetrical of the cinder cones is Red Mountain. It rises 600 feet above the alluvial slope upon which it stands. An extensive flow of basalt issued from its vent, but the crater rim extends unbroken over the head of the lava flow. The cone is built mainly of fragments, commonly 6 inches in diameter, of cellular lava, red in color. Spirally twisted volcanic bombs occur, as do also other bombs as much as 4 feet in size. A plateau of basaltic lava and cinders stands out on the plain of Owens Valley north of Independence, below the mouth of Sawmill Canyon. Lava flowed down Sawmill Canyon in the interval between the two ice epochs. Among all the profound canyons incised in the great escarpment of the Sierra Nevada none shows in more impressive fashion the striking contrast between its glaciated and unglaciated portions, the upper canyon U-shaped and that below deeply incised as a V-shaped gorge.

Valuable Ores in Inyo and Sierra Ranges

The mineral resources of the region occur chiefly in the Inyo Range, and most abundantly in the southern part, coinciding with the occurrence of the intrusive granite. The principal mineral resources are silver, lead, zinc, tungsten, gold, copper, and marble, and sodium carbonate, which is derived from Owens Lake. In the Sierra Nevada the principal ore body is that of the Bishop Creek gold mine, on the middle fork of Bishop Creek. The gold occurs in a quartzite band which forms part of a downward projecting mass of the sedimentary roof rocks which overlie the granitic masses of the range. Later large deposits of tungsten ore have been discovered west of Bishop, in the zone of metamorphic rocks where the intruded granite is in contact with the sedimentary roof rocks.

The premier producing mine in the Inyo Mountains is the Cerro Gordo. It has yielded more silver-bearing lead ore than any other mine in California. The mine is at the foot of the scarp forming the western face of Cerro Gordo Peak. A broad band of white marble is surmounted by dark-gray limestone which forms the summit of Cerro Gordo Peak. The white marble is the principal repository of the ore. It is a white marble, essentially a pure calcite rock, of Carboniferous age.

The zinc, lead, silver, and copper deposits as a rule are in limestone, but the gold deposits seem closely linked to the granite, occurring chiefly in the marginal zone of the granite masses or in the immediately adjacent country rock. The primary ores are probably genetically related to the granite intrusions.

Source of Ores Deep-Seated in the Earth

The source of the minerals gold, silver, lead, tungsten, copper, and zinc is deep-seated. The primary ores are thought to be genetically related to the granitic intrusions common in the Inyo and Sierra ranges. The metals occur in veins, or associated with intruded granitic rocks. The ultimate source is the interior of the earth, and little is known of the character of the deep interior from which the vast extrusions of molten rocks have come. The gold of the Bishop Creek mine occurs in a great quartz band or vein in sedimentary rocks that formed part of the rock roof under and into which the great granitic batholith was intruded. The gold deposits of the Inyo range are mainly small, narrow quartz veins that occur either in the borders of the granite intrusions or in the surrounding country rock at no great distance from the granite. The lead ore of the Cerro Gordo mine occurs in masses in a zone of marble, the marble having been dissolved out and lead deposited in its place. The primary ore is galena (sulphide of lead). With it is associated the sulphides of silver, copper, zinc, and iron. Zinc ore, in the form of carbonate of zinc, replaces limestone (marble) in the Cerro Gordo mine.

Originally as all the zinc came from the depths of the earth it came in contact with sulphuric acid and became zinc sulphide. By processes too complex to be discussed here the sulphide was oxidized to zinc carbonate. All the metals are deep-seated in their origin. Under the complex conditions resulting from the up-welling of vast bodies of molten rock, and the slow cooling of these extruded rocks, from the processes of metamorphism, and the circulation of waters through the rocks, together with the heat generated in the crust of the earth by mountain-making movements and earth-warpings, the mineral-bearing veins have been developed, and ore bodies segregated. Chemical changes in the rocks have resulted from the complex physical conditions which have prevailed within the earth. When more is known about the character of the interior of the earth, and the physics of the earth's crust is better understood, it will be possible to more clearly interpret the facts of earth.

Chapter XVI

YOSEMITE NATIONAL PARK

Incomparable Yosemite! No words are adequate. To attempt to write a description of the Yosemite Valley is to attempt to talk about the untalkaboutable! There is no such thing as exaggerating in trying to express the grandeur and magnificence of this vast chasm carved in the hard granite rocks. Superlative adjectives become empty and fall flat in attempted description.

Grandeur and Sublimity are Measured by the Vision of the Beholder

True it is that the stupendousness, the sublime grandeur, the vastness of what the beholder looks upon, is circumscribed by the mental horizon of the observer. Someone has wisely said that he who does not see beyond the rocks does not see the rocks. He who sees only granite walls and a deep gash cut in the rocks by erosion of streams of water and the plucking of glacier ice, with water descending the walls in cascades in response to the law of falling bodies, does not see Yosemite. He sees only granite and the work of erosion. A man said to have been an Irishman (I cannot vouch for his nationality) was standing in view of the great brink of Niagara Falls when a stranger who stood viewing in awe the great cataract remarked upon the overwhelming grandeur of the scene. The man said, as he stood looking at the tremendous cataract, "Well, I do not see what is to prevent the water from going over!"

The gorge or valley that is called Yosemite is indeed a gash cut in the rocks by running water and moving glacier ice, and there is nothing to prevent the water of tributary streams that come to the edge of the chasm from falling down to the floor of the Valley and finally joining with the modest Merced River which courses its way through the Valley, much in the fashion that the Tuolumne, San Joaquin, Kings, Kern and other rivers flow through gorges likewise cut in the hard rocks by water and ice. But the soul that is not stirred and filled somewhat with awe and wonder who stands on the gravel filled plain at the foot of El Capitan or the Cathedral Rocks and gazes upward with his head set backward at an angle of 90 degrees, or who stands on any vantage point, as Glacier Point, and looks out upon Half Dome and Basket Dome and North Dome, and reflects on the valley that separates Half Dome from North Dome and Basket Dome, one who thus gazes and really sees what he looks at, will feel to cry out Incomparable Yosemite, and will despair of words to express the emotions that arise in his soul, and in the souls of those who see beyond the rocks.

The Yosemite Region Geologically Old

The history of the Yosemite region goes far back as time is measured in years. Geologically the region is young. In an earlier chapter the uplifting and tilting of the great Sierra block was described. The uplifting of the eastern side of this great block and the westward slope of the tilted block toward the Pacific Ocean caused the streams that flowed westward to move with increased velocities, and hence to erode their valleys more vigorously. Practically all the great streams that flow westward from the Sierra crest toward the Great Valley flow today through deep gorges. South of the Merced the San Joaquin, Kings, Kaweah, and Kern, and to the north the Tuolumne and others, have cut deeply into the great granitic batholith that was upwelled under the Cretaceous and Tertiary (and older) formations. Running water, particularly when loaded with sand and gravel derived from the land surfaces adjacent, erodes the hardest rocks. Thus streams have cut deep channels as they coursed down the inclined slope of the great Sierra uplifted and tilted block. Thus nature set about the task

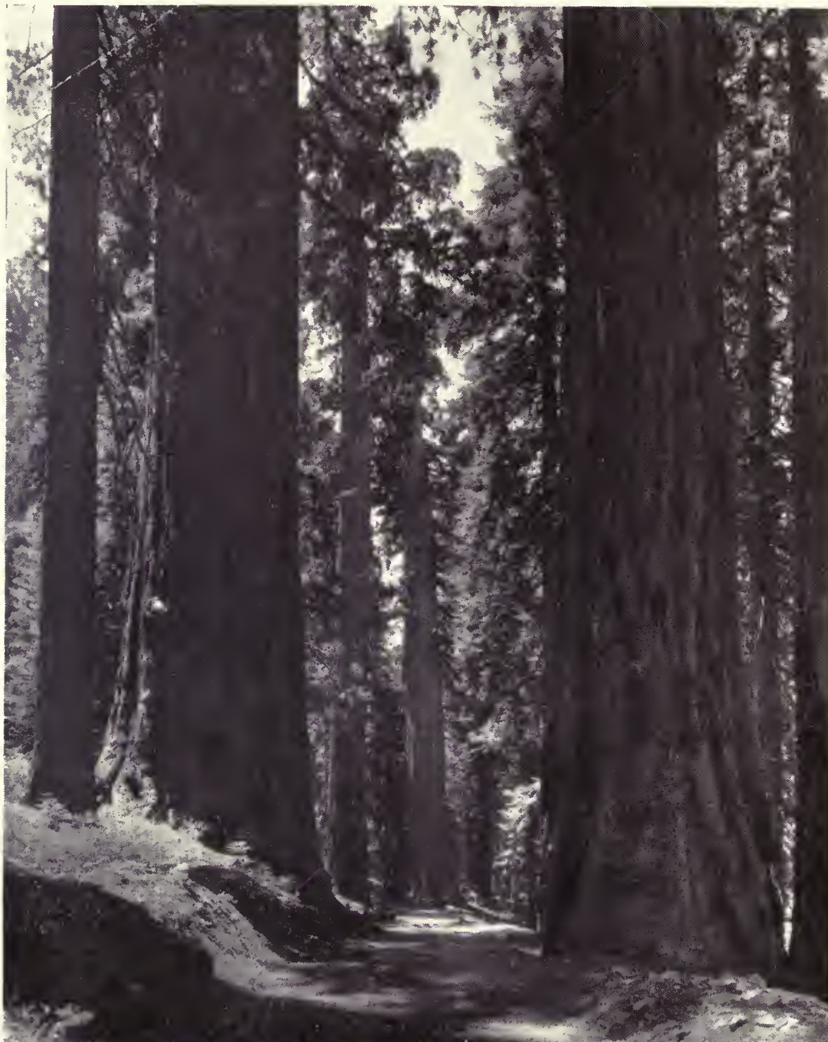


Photo by Californians, Inc.

FIG. 58. Mariposa Grove of Big Trees (*Sequoia gigantea*), Yosemite National Park. In constructing the Wawona road a tunnel was cut through a tree, in center of picture, which permits autos to pass through.

of reducing back toward sea level the lands that had been elevated to the height of a great mountain range by upheaval. In the long time since the beginning of the great upheaval rock formations miles in thickness have been eroded and carried away by streams from over the whole area of the Sierra Nevada Range. Much of this material now rests in the Great Valley of central California. Some of it indeed has been carried out through the Golden Gate and deposited on the bottom of the Pacific Ocean.

Gorges Cut by Running Water and Moving Ice

The uplifting of the great mountain range caused the more rapid movement of the waters of streams down the western slope, and added greatly to their eroding power and their ability to carry away rock waste. But further than this, the high elevated regions came to have a colder climate, and thus resulted in the development of an added agency of erosion, glacial ice. Snows gathered on the high mountain lands of the Sierra, and being compressed into hard ice moved by the pressure of the weight of its own mass down the western slope. Valleys which had been cut into the hard rocks became the paths down which the ice from the high mountain crests moved.

Ice, like running water, is a powerful agent of erosion. How much of the great work of excavating the vast gorges—the many yosemites—of the great Sierra slope has been due to the eroding action of running water and how much to the eroding power of ice, moving, as it is known to have done, in vast viscous-acting streams, has been a question among geologists. Indeed there have been marked differences in judgment of geologists as to the causes that have produced the great canyons. Without troubling ourselves about the differing opinions that have been expressed about the causes of these great chasms, we may content ourselves with the conclusion now generally accepted by geologists that both running water and slowly moving glacier ice have been the factors that have determined these great canyons.

Three Stages of Glaciation

The details of the glacial history of the Yosemite region would make a somewhat complicated and long story. It may serve our purpose to state briefly that at least two definite and distinct invasions of glacier ice have occurred in the Yosemite region. Indeed there is evidence of three glacial epochs or invasions of ice, separated by long interglacial intervals. Whether there have been more than three glacial invasions is still open to question. That two, and probably three, epochs of glaciation have occurred on the Sierra Range is beyond question, and some observations have been made that indicate more than three. It is not known whether the glacial epochs in the Sierra region occurred simultaneously with the several epochs of glaciation on the continent of North America. There were five glacial epochs on the continent separated by long inter-glacial intervals during what is known as the Glacial Period of the Quaternary Era, but correlation of these epochs with Sierran glaciation has not been worked out.

The cause or causes of the intervals between glacial epochs is not known. That the intervals between glacial epochs were long is evident from what can be seen in the field. What may have been the causes of greater warmth, or what may have caused periods of greater or less precipitation, is not known. The epochs of ice invasion, and the intervening periods when the ice was not present, are facts established by observation of conditions that now exist. There were two, or three, epochs of ice invasion, and corresponding interglacial epochs. The facts are established, but our knowledge of the causes is largely lacking.

That ice moved; that it acted with tremendous power; that it disrupted rocks and carried them long distances; there can be no question. That rock fragments were torn from parent ledges and transported long distances is shown by the study of the rocks themselves. Moraines tell their own story. The ultimate causes of many natural phenomena are as yet unknown.

The stages in the glacial history of the Sierra region are marked by the results of the action of the ice itself. Deposits made by the ice, moraines consisting of earth materials carried by the ice and thrown down when it melted, tell unmistakably of the movements of the ice and the work done by it in its slow

Photo by F. E. Matthes, U. S. Geol. Survey

Fig. 59. Crest of moraine of Wisconsin stage.

but relentless progress. Terminal moraines, the dumping-grounds where rock fragments of all sizes—boulders, gravel, sand, and clay—are mixed in confused order, mark the ends or limits beyond which the ice did not go. These are the places where melting from the sun's heat balanced the onward movement of the ice mass. The character of the work done by the moving ice is shown in marks it left in its path. Fragments of rock carried by the ice, plucked from rock floors and walls, were rounded and ground to powder. These, held in the viselike grasp of the ice, cut grooves and scratches on rock floors over which they passed. The glacial scratches, called striae, thus made, tell the direction of ice movement. The finely powdered rock dust served as a polishing agent, and expanses of highly polished rock surfaces show unmistakably the work done by the ice in abrading hard surfaces. Such polished and striated surfaces high on rock walls and on the tops of high promontories give indisputable evidence of the depth of the ice mass. Erratic boulders perched high above the valley bottom, or strewn in moraines, or as isolated fragments, show by their character (texture and composition) the parent ledges or sources from which they came, and the direction of the movement of the ice.

Sierran Glaciation Independent of Continental Glaciation

The formation of glaciers in the High Sierras was independent of the formation of the Continental Ice-Caps in the Hudson Bay and Labrador regions. Snowfall in the High Sierras is very great at this day, the moisture-laden winds from the Pacific Ocean, rising above the Coast Ranges and moving landward, lose their moisture in the cold air of the high crests of the Sierras, and the Great American Desert of the Basin region to the east results. In Quaternary geologic time, when continental glaciation occurred, continental conditions may have been such that the precipitation was greater than at present. At any rate snowfall was great enough in Quaternary time so that glaciers formed along the Sierra crest. Snow gathered among the high peaks in protected basins and on the shaded sides of mountain crests. More snow fell during the winters than melted during summers. Thus bodies of snow gradually changing to névé and ice came to lie in great masses. Basins or slopes so situated as to become gathering places for snow-ice are called cirques. Such gathering-grounds for snow, the headquarters so to speak of glaciers, were, and are, common in the high Sierra region. From these cirques came the smaller glaciers which coalesced with others and formed the great trunk glaciers which bore down the Sierra slope, following naturally the lines of least resistance and descending the chasms which had already been formed by the streams.

Snow-ice formed a mantle along the crest of the High Sierra from Mount Lyell to Mount Whitney, a distance of fully 100 miles, and having a width of 20 to 30 miles. Only the major peaks and crests stood out above the ice flood like dark rocky islands above a dazzling sea of ice. It covered all those parts of the High Sierra which are drained by the San Joaquin, Kings, Kaweah, and Kern rivers. At first only drifts and fields of compacted snow survived from year to year. By degrees these perpetual bodies of snow-ice or névé attained sufficient depth so that under the influence of gravity they acquired a slow motion forward, and pushed in tongue-like ice streams or glaciers down valleys that had been cut by streams. Each ice-stream tended to follow a pre-glacial stream channel. Where such pre-glacial valleys united the glaciers merged together forming wider and deeper ice-streams. Down the Sierra slope these ice-streams coalesced to form trunk glaciers that moved down the main Sierra canyons. Thus at length every valley in the High Sierra came to hold an ice-stream. During the time when glaciation was at its height the snows were so abundant that the trunk glaciers, though thousands of feet in thickness, could not carry away the snow-ice from the gathering grounds of the High Sierra as fast as it accumulated. Branch glaciers overflowed and submerged the low divides between them so as to form broad fields of snow-ice scores of miles in extent.

Extent of Glacier Ice

Thus a vast field of snow-ice came to cover the upland of the Yosemite region. The ice mantle extended for many miles down the western slope from the high Sierra crest, but did not reach to the foot of the range slope due to melting at the lower altitudes. Trunk glaciers ploughed down the deep canyons beyond the lowest limits of the general ice field. In the region of Yosemite Park the ice field extended down the slope to present altitudes of a little less than 5,000 feet. The trunk glaciers extended to lower levels but did not reach to the foot of the Sierra slope.

The Tuolumne glacier attained a length of 60 miles, and extended a dozen miles beyond the margin of the general ice field. It terminated, however, 30 miles above the foot of the range slope. The Yosemite glacier reached a length of 37 miles, and extended 7 miles beyond the margin of the ice mantle. Its lower end was in the Merced canyon below El Portal, about 50 miles from the foot of the range. The San Joaquin glacier was more than 50 miles in length, but it pushed only a few miles beyond the margin of the ice mantle and ceased 45 miles above the mouth of the canyon through which it flowed. Kings glacier was 44 miles in length (along the middle branch) and came to an end 37 miles above the base of the range.

The ice movement of the trunk glaciers farther down the Sierra slope than the general ice mantle was natural. The canyons offered easier highways for the passage of the ice. The canyons were wide and deep. The depth of the ice in the great canyons was 3,000 to 4,000 feet. Movement or flow of the ice in canyons was less hindered by friction than when spread out over broad rock surfaces. The movement of the ice was more rapid, probably several feet in a day. The high canyon walls protected the ice from the melting effects of the sun. Thus the trunk glaciers offered easier escape for the great body of ice which pushed down from the uplands.

Work Done by Moving Ice

The work done by the ice in giving the Yosemite landscape its present form was unmistakably very great. That glacial ice has been an important agent in giving the Yosemite region its present character there can hardly be serious question. The canyons have been deepened and broadened. The valleys, V-shaped as cut by streams, have been generally rendered U-shaped by the plucking and wearing of the ice on the bottoms and walls of the canyons. Rock fragments were plucked from walls and floors, carried along by the moving ice, and when the ice melted the rock debris carried along was thrown down.

The most important deposits, and probably the most significant of all the effects of the ice, are the moraines—heaps and

Photo by F. E. Matthes, U. S. Geol. Survey

FIG. 60. Old moraine, near Wawona Road south of Turtleback Dome.

ridges of boulders, gravel, sand, and clay—thrown down by the melting ice. The most reliable record of glacial activity, on the whole, is that embodied in the deposits of rock waste left behind by the glaciers. These, wherever well preserved, accurately define the limits reached by the ancient glaciers. Terminal moraines mark the ultimate limits reached by the ice. Lateral moraines mark the limits of trunk glaciers and tongues of ice on the sides of valleys down which the ice moved. Medial moraines mark the joining or coalescing of glaciers which converged from adjacent valleys. The materials of which moraines are composed—especially boulders and rock fragments of all sizes—show by their nature where the materials came from, and hence give much assistance in determining the direction of ice movement. Every glacier carries large quantities of rock waste, ranging from huge boulders down to the finest mud. Of this material part has fallen upon its surface from the frost-riven canyon walls; part has been torn from the floor and sides of the canyon by the glacier itself. As the ice melts in summer some of the rock waste is released and dropped at the sides and front of the glacier. If the edge of the ice remains stationary, that is, if melting just about keeps pace with the forward movement of the ice, the rock waste accumulates in the form of more or less sharp-crested ridges, or moraines. The height to which moraines may be piled depends upon the amount of material carried by the ice and the length of time that the *edge* of the glacier remains "stationary." In the Sierra Nevada mountains moraines generally range from 10 to 30 feet in height, but few reaching 60 feet. When a glacier melts back the moraine loop formed during its "stationary" period is left standing as a sort of monument that bears witness to the former proportions of the ice mass.

Moraines in Yosemite Valley

In the lower half of the Yosemite Valley six frontal or terminal moraines may be counted within the distance of 1 mile. The one farthest down the valley is immediately above the Bridalveil Meadow. The fifth and sixth moraines together form a nearly straight dam across the valley just below the El Capitan Meadow. A small gap cut by Merced River interrupts the continuity of this dam and is now spanned by the El Capitan Bridge. A remnant of the fourth moraine stands out boldly from the northwest base of the Cathedral Rocks in the form of a stony scantily timbered ridge about 30 feet high. The second and third moraines have been largely demolished and washed away, yet remnants may be identified by their constituent materials exposed in the sections at the banks of the river.

The materials of which these moraines are built are of special interest. Most conspicuous are large smoothly rounded boulders, but mixed with these are cobbles, pebbles, angular fragments of rock of all sizes, and much sand and mud. Many rounded boulders and cobbles are highly polished and in places scratched and scored, like many rock floors in the High Sierra. This shows that they have been brought down by a glacier, that they have been ice-worn. The polish could only have been imparted by long-continued abrasion with the impalpably fine rock floor which is produced by the grinding action of glaciers. Among the boulders and cobbles there are some that represent rock types not known to occur in the Yosemite region, though they do occur in the mountains and rock floors of the highlands above the valley. The occurrence of these foreign materials, rounded and polished boulders and irregular fragments, with sand and mud, in a confused mixture with rocks from near-by formations, suggests the work of ice.

The moraine just above the Bridalveil Meadow marks the farthest limit reached by the Yosemite Glacier during the last stage of glaciation, the Wisconsin—what may be called the latest chapter in glacial history. During the earlier stages of glaciation the ice extended many miles farther down the valley—as far as El Portal, to be referred to later. Above the El Capitan Bridge no further moraines are to be found in the Yosemite Valley for a distance of about 5 miles. There, near the head wall that marks the upper end of the valley, occurs the largest and most conspicuous moraine of all, a hummocky ridge 50 to 60 feet high and half a mile long. That this ridge is a moraine of glacial deposit is shown by the fact that rounded and polished boulders of rock fragments such as occur in the High Sierra region far above the valley have been taken from a cut in the road which crosses the ridge.

Moraines of Little Yosemite Valley

In the Little Yosemite Valley moraines of the Merced Glacier are much more plentiful than in the main Yosemite Valley. No less than 30 distinct lateral moraines occur one above another in a generally parallel series on the north side of the valley in the broad embayment southeast of Half Dome. Terminal or frontal moraines curve across the entire valley above

Photo by F. E. Matthes, U. S. Geol. Survey

FIG. 61. Lateral moraine on south side of Little Yosemite Valley. The figure of the horse at the right indicates the size of the moraine.

Liberty Cap. Many large blocks of granite occur in these moraines, blocks 5 or 6 feet in diameter being common, and some as much as 10 to 15 feet in length. These granite blocks are fresh-looking and unweathered. They ring when struck by a hammer, and appear to be composed of sound hard granite. When it is considered that these blocks have been exposed to the weather for not less than 10,000 years the fact becomes significant.

The glacial features that have been considered in the foregoing pages relate to the latest epoch of glaciation in the Yosemite region, the Wisconsin. This was the lesser of two, possibly three, glacial invasions that have ploughed down the Yosemite Valley. Evidences of an earlier and more extensive glaciation occur on the higher slopes of the valley and adjacent mountains. The later Yosemite Glacier extended down the Yosemite Valley as far as the Bridalveil Meadow. The earlier Yosemite Glacier ploughed down the valley of the Merced River as far as the vicinity of El Portal, and it is spoken of as the El Portal stage of glaciation. Scattered boulders that are foreign to the Yosemite region and that have come from the crest of the Sierra Range occur above the moraines that lie along the sides of the Little Yosemite Valley. These boulders are all rust stained and weathered to a depth ranging from an eighth of an inch to half an inch. Many of them are so "rotten" that they fall apart at a moderate blow of the hammer. Study of these rocks and their occurrence high above the moraines that have been noted leads to the conclusion that ice of a glacier at a comparatively early date reached a level much higher than that of the prominent moraines of the valley below. The highest of these old weathered moraines in which the boulders referred to occur is more than 1,000 feet above the level of the highest of the younger moraines which lie along the sides of the Little Yosemite Valley.

Depth of Ice of Earlier Glaciation

The Cathedral Rocks bear on their summits and slopes deposits of glacial boulders that give some idea of the depth attained by the earlier Yosemite Glacier. So imposing are the Cathedral Rocks when viewed from the floor of the Yosemite Valley that it is difficult to imagine them as once having been covered by the ice, yet the testimony of the boulders leaves no doubt that they were. Even the highest of these boulders do not mark the highest level reached by the ice flood. On the brush-covered summits south of the Cathedral Rocks remnants of moraines occur at altitudes ranging 200 feet higher. The earlier Yosemite Glacier passed over the summit of the Cathedral Rocks with a depth of not less than 300 feet.

Moraines of the earlier glaciation in the lower part of the Merced Valley are of particular interest. The highest moraine on the south side of the valley is crossed by the Pohono Trail at an altitude of 2,400 feet above the floor of the valley. The second highest moraine is so well preserved for a stretch of a quarter of a mile that it constitutes one of the notable landmarks of glacial origin in the lower Yosemite region. On the slopes west of Cascade Creek moraines of the earlier Yosemite Glacier are well preserved, the highest extending almost unbroken for a distance of 2½ miles. A series of moraines, some of which are more massive than any other moraines in the Yosemite region, occur on the northwest border of Big Meadow Flat.

The farthest point reached by the earlier Yosemite Glacier, in the vicinity of El Portal, is not marked by any terminal moraine. The height at which the last patches of morainal material lie above the floor of the canyon—between 1,200 and 1,300 feet—show that the ice extended some distance, perhaps a mile, below El Portal (west). Along the lower Merced Canyon, below El Portal, occur masses of boulders and coarse gravel on both sides of the canyon that evidently are remnants of the outwash from the glacier. This outwash material is conspicuous in many cuts along the automobile highway, and also in some places along the railroad. It shows that a "valley train" of glacial wash extended down the canyon a distance of about 30 miles.

Boulders Indicate Existence of an Earlier Glacier

In several localities in the Yosemite region glacier-borne boulders occur singly, in groups, or in rows, without any accompanying fine debris. Most of them lie in places where it seems likely from the character of the topography and from the courses pursued by the ancient glaciers that heavy continuous moraines once existed. The majority of the boulders are composed of extremely durable types of rocks which weather and disintegrate more slowly than most of the rocks in the moraines of the Yosemite region. It is thought that these boulders are the last remnants of moraines of a very early glaciation ante-

Photo by F. C. Calkins, U. S. Geol. Survey

FIG. 62. Glacial boulder at base of Sentinel Dome, on Glacier Point. The boulder is located near the trail leading to Sentinel Dome. This with other boulders marks the highest level reached by the ice of the (earliest) Glacier Point stage, 3,600 feet above the floor of the gorge below.

dating the El Portal stage. A number of the boulders in question lie on the broad divide east of Mount Starr King, between 200 and 400 feet above the highest moraines of the El Portal stage. The fact that only a few sparse boulders now remain would seem to show that a long period has elapsed since the ice deposited what is thought was probably a continuous and considerable moraine. It seems reasonable to infer that these boulders belong to a stage of glaciation earlier than the El Portal.

Other erratic boulders belonging in all probability to the same early glaciation lie near the east base of Sentinel Dome. Some of them, conspicuous for their large size, are close to the trail that leads to the Dome. They are strung out at intervals of 100 feet or more in an irregular line that curves from the Dome southeastward to the north end of Illilouett Ridge. These boulders are isolated, and are surrounded by finer glacial debris, whereas the steep slope below is heavily cloaked with

Photo by F. C. Calkins, U. S. Geol. Survey

FIG. 63. Sentinel Dome. Massive granite rock, rounded by exfoliation (casting off of successive shells by weathering). The small speck at the top is the Jeffrey Pine, twisted and bent by the wind shown in figure 64.

such material of the El Portal stage. It can hardly be otherwise therefore than that the boulders are the last vestige of a once continous moraine that was deposited by the ice during a stage much earlier than the El Portal. This very early stage of glaciation is referred to as the Glacier Point stage.

Glacial Deposits Near Glacier Point

Of interest to the tourist, as to the student of geology, are the glacial deposits near Glacier Point, for they answer the question whether that high promontory was ever overtopped by the ice. The point of the promontory is bare, but on the slope immediately below the Glacier Point Hotel, and in the hollow to the west, and, what is more significant, on the wooded slope above, glacial material is abundant. The glacial origin of this material is definitely proved by the presence in it of great numbers of rounded boulders and cobbles and angular frag-

FIG. 64. Storm-scarred Jeffrey Pine standing on the top of Sentinel Dome. It appears as a small speck at the apex of the Dome in figure 63.

ments, all deeply weathered, of granite of which Half Dome and the heights of the Little Yosemite Valley are composed, also boulders of a coarse-grained and highly distinctive granite from Mount Clark, 8 miles east of Glacier Point. It is evident that these highly distinctive materials were carried to Glacier Point on the southern margin of the ice stream. On the slope above Glacier Point morainal deposits are found up to an altitude of 7,700 feet, or 500 feet above the point on the promontory.

Higher still, however, on the bare rock slope at the immediate base of Sentinel Dome, scattered boulders indicate that at a very early stage in the history of the region the ice may have reached an altitude of 7,900 feet, or fully 700 feet above Glacier Point, and nearly 4,000 feet above the Valley floor.

It is apparent that ice has played an important part in giving the Yosemite Valley its present form. Other canyons—other yosemites—were cut in the hard rocks of the great Sierra range, and in these canyons ice has left its mark. All the canyons were first formed by running water, and all were scoured and changed by moving ice. No other of the great canyons that mark the western slope of the Sierra Nevada compare in grandeur of scenery with the Yosemite Valley. Why, it is natural to ask, the outstanding features of the Yosemite Valley?

Causes of the Great Gorge of the Yosemite

The key to the understanding of this remarkable gorge lies in the character of the rocks in which the gorge was cut. To understand why the part of the valley of the Merced that is known as the Yosemite Valley is there, in other words the reason why such a valley exists, it is needful to look at the rock formations in which and through which the great chasm has been cut. This involves consideration of the character and something of the history of the rocks of the region.

The Merced River starts from among the high peaks and crags of the High Sierra, and flows in a southwesterly course down the western slope of the Sierra Nevada, and joins the San Joaquin on the bottom of the Great Valley of California. It is what geologists term a "superimposed" river, its course being determined sometime during the hundred million years during which the ancient "roof" that covered the great Sierra batholith was being removed by erosion and weathering.

It will be recalled from a previous chapter (Chapter XIV) that a vast batholith or lake of molten rock was upwelled from the depths of the earth, uplifting the sedimentary formations that had been deposited long ages ago but not reaching the surface. The molten rocks surged up under the confining roof of slate, quartzite, marble, and volcanic rocks, whose buckled and folded beds formed the ancestral Sierra ridges of Cretaceous time. The granitic rocks that are now exposed to view over large areas are now at the surface due to the fact that in the course of periods probably aggregating 100,000,000 years the roof rocks were removed by the slow wearing action of streams and other eroding agents.

The flow of the Merced was accelerated by the uplifting and tilting of the great Sierra block. Its course was determined by the slope and its channel established in the comparatively soft rocks of the sedimentary formations that formerly lay over the great batholith. As the softer sedimentary formations were removed the river became entrenched in its course. It cut down into the hard granitic rocks of the batholith, and having become entrenched it was not able to leave its established channel and so has continued to move across obstructions of hard granitic rocks encountered as it deepened its channel into the batholith.

Complex Character of Rocks Explains Cutting of Gorge

The reason for the remarkable canyon cut by the Merced River lies in the complex character of the rocks encountered in its course. At first glance the walls and domes of the Yosemite region appear to be formed of one and the same kind of rock. In reality there are present in the Yosemite region about a dozen distinct types of rock, all granitic in character and ranging in color from nearly black to nearly white. Technically the species of rock range from nearly black horneblende gabbro through successively lighter-colored diorite, granodiorite, quartz monzonite, and biotite granite to nearly white alaskite. All exhibit a strong family resemblance, yet show by their differences that they were upwelled in the great batholith at different times. In the Yosemite Valley as in few places in the world can be seen in cross section so remarkable a complex of intrusive igneous rocks. They show the astonishing details of a portion of the earth's crust that once lay miles below the surface, beneath the roots of a former mountain system, and that was disturbed by repeated upwellings of molten rock.

The batholith of the Sierra Nevada is made up of a number of distinct bodies of igneous rock, each differing somewhat from its neighbors in mineral composition and representing a separate upflow of molten material. Many of these igneous bodies are of great extent, their areas at the surface being measured in hundreds of square miles. The uplands flanking the Yosemite Valley are made up almost wholly of such large intrusive bodies. The Valley itself, however, crosses an area where many small intrusive bodies and narrow projections from the larger ones intersect each other in an intricate manner. It is to the great diversity in character and the complexity of the rock formations that make up the walls and floor of what is called the Yosemite Valley that the unique character of the Valley is due.

The Yosemite upland north and northeast of the head of the Yosemite Valley is in the main massive (mostly unjointed) granitic rock—the eroded surface of the Sierra batholith. The Merced River, as has been stated, starts from near Mount Lyell, amongst the crests and peaks of the High Sierra. Over the hard massive granite passes the river, with comparatively slight erosion. Massive granite, that is, not broken by joints or cracks, erodes very slowly. In these places where the rock is broken by joints or cracks erosion goes on much more rapidly. Blocks and slabs are loosened by frost and other weathering agencies, and moving ice is far more effective in quarrying and eroding in jointed rocks.

Yosemite Chasm Eroded in Jointed Granitic Rocks

The course of the Merced River, like the other streams of the Sierra slope which descend through great gorges, flows down the slope essentially in disregard of rock structures. (It is a "superimposed" river.) At the head of what is known as the Yosemite Valley the river enters upon a zone of rocks of great complexity, all granites to be sure, but varying in texture and composition, and variously, and in places very closely, jointed. To this change in the character of the rocks is due this most remarkable canyon.

Photo by F. C. Calkins, U. S. Geol. Survey

Fig. 65. Crumpled and contorted chert. Above the mouth of Ned Gulch, lower Merced River.

The Yosemite Valley extends down the course of the Merced a distance of 7 miles. The head of the valley is marked by a wall of hard granitic rock (Half Dome quartz monzonite) 1,000 feet in height. The lower end of the valley terminates in a rising sloping wall of hard massive granite (El Capitan). The river leaves the valley through a narrow canyon cut in this hard rock known as the Merced Gorge. The gorge, which is U-shaped and ice-polished, continues through The Gateway (which marks the transition to another type of rock, granodiorite), a distance of 8 miles, to the vicinity of El Portal.

Beyond El Portal the ice of the Yosemite Glacier (of the earlier or El Portal stage) did not go. Beyond El Portal the gorge loses its U-shape and in cross section becomes V-shaped. Below El Portal, through the belt of metamorphosed sedimentary rocks (remnant of the ancient roof which lay over the great batholith) the river has cut a deep gorge the walls of which rise abruptly and steeply on either side.

A dozen kinds or types of rocks occur in a belt a few miles in width where crossed by the Merced River. Here in brief is the key to the Yosemite Valley, one of the most unique and stupendously overwhelming in grandeur, in the world. The valley is 3,000 to 4,000 feet deep, and the enclosing walls rise from a flat nearly level floor in what appear to the observer to be perpendicular precipices. About 5½ miles down the valley from the headwall the valley is narrowed, dividing the great chasm into two parts known as the upper and lower chambers. On the north side of the valley, and forming one of the shoulders of the narrows, stands El Capitan, a vast monolith of hard massive granite, its wall facing the valley being almost vertical, and rising above the valley floor 3,000 feet. On the south side of the valley and opposite to El Capitan the Cathedral Rocks project into the valley boldly more than a mile, forming the south shoulder of the portal. The rocks are very hard and massive (that is, unjointed) and, like El Capitan, stood fast against the ice of the glaciers. These two promontories form the portal between the upper and lower chambers.

Above the Cathedral Rocks (east) is a wide embayment or broadening of the valley. Here the rocks are no longer massive granite (unjointed) but a complex mass of intruded igneous rocks (technically diorite and gabbro) which are largely and intensely jointed, and therefore affected by erosion and readily quarriable by glacier ice. The valley wall is deeply dissected by ramifying gulches. Craggy slivered spires of more resistant intruded granite stand out in intricately and irregularly sculptured forms. The twin shafts of the Cathedral

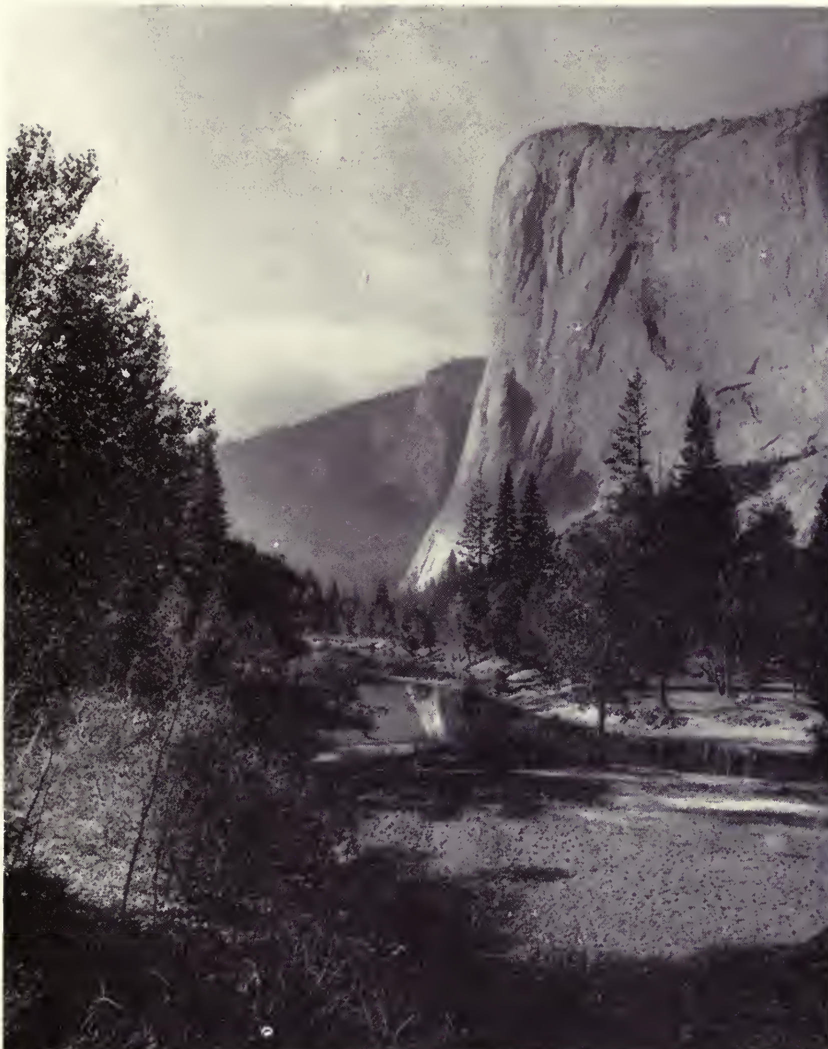


Photo by J. K. Hillers, U. S. Geol. Survey

FIG. 66. El Capitan. Massive granite, a 3,000-foot cliff, highest in the Yosemite Valley, and one of the highest in the world. This is a remarkable example of unjointed granite. (Compare figure 67.)

Spires are made of resistant massive granite. The intrusions of (Bridalveil) granite are large and irregular in shape, and because the rock is resistant to weathering it forms the summits of pinnacles and crags.

Massive Granite Forms Lower Limit of Gorge

In the lower chamber, that is, below the portal, the jointed character of the rocks enabled the ice of the glaciers to quarry and remove the rocks, and thus there came to be the lower chamber. The rocks forming the north and south walls of the lower chamber are diversified in character. Large bodies of diorite and gabbro are systematically jointed and fractured and

Photo by G. K. Gilbert, U. S. Geol. Survey

FIG. 67. Well-jointed granite in the High Sierra.

hence readily quarried and eroded. West of the jointed and fractured gabbro and diorite of the lower chamber the rocks consist of massive granite (El Capitan). This rock is but sparsely jointed and not readily quarriable. Here is the western limit of the jointed quarriable rock, and here the Yosemite Valley ends. The rock continues down the course of the Merced as far as The Gateway, and this explains the narrowness of the gorge.

An Impressive View from Glacier Point

The lower end of the valley is of interest because a considerable part of the mass of the Yosemite Glacier had to move up-

Photo by F. E. Matthes, U. S. Geol. Survey

Fig. 68. Glacial floor and side of Merced Canyon. The rocks have been smoothed and polished by glacier ice. The row of stones in the foreground marks the trail across the smooth rock floor.

ward over the hard (El Capitan) granite to get out of the valley. The central portion of the glacier passed through the Merced Gorge, but the ice outside of this rode up and over the rock slope. Debris carried by the ice, and markings left on the rock surface by the moving ice, show that the ice pushed up the dome-shaped granite slope as much as 1,000 feet. That the ice rode over the hard sparsely jointed rock with only slight plucking and quarrying is shown by the smoothly curving shield-like hump of Turtleback Dome. The direction of movement of the ice over the hard granite rock is clearly shown by striae and other glacial markings on the rock slope.

Most strangely modeled is the valley head of Yosemite Gorge. It is squared off at right angles to the sides by a high straight wall of rock a mile in length. At the north end of this wall is the broad U-shaped mouth of Tenaya Canyon. At the south end opens the narrow tortuous gorge through which the Merced River descends from the Little Yosemite. The head of the valley is thus marked, but for the two openings mentioned, by continuous massive cliffs. The cliffs rise almost sheer from the valley floor.

The most remarkable rock forms cluster about the head of the Yosemite Valley. Most impressive of all for height and verticality is the famous cliff at Glacier Point. It is a straight wall a quarter of a mile long and 1,000 feet high. It is really vertical. It is this absolute verticality of the rock face that permits the "fire fall" which customarily is produced every night during the tourist season by pushing the glowing embers of a bonfire from the edge of the platform above, to descend through space untrammeled, deploying gradually like a waterfall of the Yosemite type. At the extreme top of the precipice, which is 3,200 feet above the valley floor, there projects a large rough slab, the famous "overhanging rock of Glacier Point."

Standing on Glacier Point the view is one to be remembered. The panorama is probably unique in all the world. Directly opposite are the Royal Arches, a series of natural arches carved in the hard granite. Near by is the Washington Column, a colossal pillar standing upright to a height of 1,700 feet. Surmounting these is North Dome, a smoothly rounded helmet-shaped mass of bare granite that rises to a height of 3,530 feet above the valley. To the northeast is Basket Dome. Most conspicuous of all is Half Dome. To the right (east) are two huge bosses of rock, Mount Broderick and Liberty Cap, standing in the mouth of the Little Yosemite. These are typical "roches moutonnées," knobs rounded and polished by the ice, but too hard and resistant to be wiped away. Dome-shaped

Photo by A. C. Pillsbury. Courtesy U. S. Geol. Survey

FIG. 69. Tenaya Canyon, from Glacier Point. A U-shaped glacial canyon. At the right is Half Dome, Basket Dome at the left. In the far distance is Mount Hoffman, white with snow. Dark in center is Mount Watkins. Below at the mouth of the canyon is Mirror Lake.

masses of bare granite abound in the upper Yosemite region. Most readily accessible to the sightseer is Sentinel Dome, which stands on the upland southwest of Glacier Point. Several of the domes were never overtopped by the ice of the glacial epoch. Sentinel Dome stood above the highest level of glaciation. The crown of Half Dome rose like a rocky island 500 feet above the surface of the glaciers which coalesced about it.

Half Dome Formed by Exfoliation of Granite

The most imposing and most strangely shaped dome, and one that will be certain to catch the eye and engross the attention of the observer standing on Glacier Point, is Half Dome, which stands at the head of the Yosemite Valley on the divide between Tenaya Canyon and the Little Yosemite. Rounded on the south side and cut off sheer on the north side, it has the appearance of a great dome that has been split in two and whose other half has been destroyed. Measured parallel to its sheer front it is nearly a mile long. The total height of the dome above Tenaya Canyon is 4,770 feet. Viewed from Glacier Point the tourist is almost bound to ask what has become of the other half of Half Dome. Briefly answered it was never there. Had there been another half of the dome consisting of a gigantic monolith it would be still in existence to-day, for neither the Tenaya Glacier nor the agents of erosion that shaped the preglacial valley of Tenaya Creek could have demolished it. It is generally recognized by geologists that the domes, which form so conspicuous a feature of the Yosemite region, owe their rounded forms to the exfoliation of massive granite, that is, the casting off of successive curving shells or scales from their exposed surfaces. The cause of exfoliation is not fully understood. That the shells burst loose from the core of a dome because of expansive stresses in the granite is clear from the facts of observation, but how the stresses originate is not fully known. In brief the probable cause is thought to be relief from pressure experienced by the granite as the overlying masses of rock are removed by erosion. The form of Half Dome, as indeed of the many domes for which the Yosemite region is famous, is due to the process of exfoliation. The curving back of the dome is evidently a product of long-continued exfoliation. Shells have been formed on it and have been dropped from it in succession for millions of years. The straight sheer front of Half Dome is by comparison a rather new feature, yet it too has suffered from exfoliation. Its general trend and its angle of declivity (about 82°) were determined by a zone of nearly vertical joints extending in a northeasterly direction. This sheeted structure terminated in the shoulder at the northeast end of the cliff face. Doubtless the thin sheets were readily plucked away by the Tenaya Glacier, which during the earlier stages of glaciation reached within 500 feet of the top of the dome. Then, the body of the monolith being exposed, it began to exfoliate in plane sheets parallel to the zone of joints. Perhaps the Tenaya Glacier plucked away some of these newly formed sheets, but it seems more probable that the exfoliation took place largely during the interval following the El Portal glaciation. The ice of the Wisconsin stage did not reach the base of the cliff. This interpretation of the evolution of Half Dome, if it is correct, leaves no room for any assumed demolition of one-half of the dome.

More Than Rocks and Running Water

If the reader has had the patience to peruse the preceding pages of this chapter it is hoped he is able to "see beyond the rocks," to see in Yosemite more than rocks and the effects of running water and the eroding power of ice. To the mind of the author the Yosemite Valley offers the most stupendous spectacle of Nature's handiwork he has ever beheld. Probably nowhere in the world is there so remarkable a panorama of nature's processes displayed in an equal area. Stand upon Glacier Point and look away over Half Dome and off to Clouds' Rest, over exfoliated domes and ice-smoothed hummocks, and behold the effects of running water and moving ice, combined with weathering of frost and heat on hard rocks; walk on the gravel-filled floor of the valley and marvel at the towering walls of massive granite; gaze at the rugged gulches that tell of upheaved igneous rocks broken by deep-seated forces into jointed blocks that made possible the amazing spires and the inaccessible crags; look up at the waterfalls, regarded by many, and

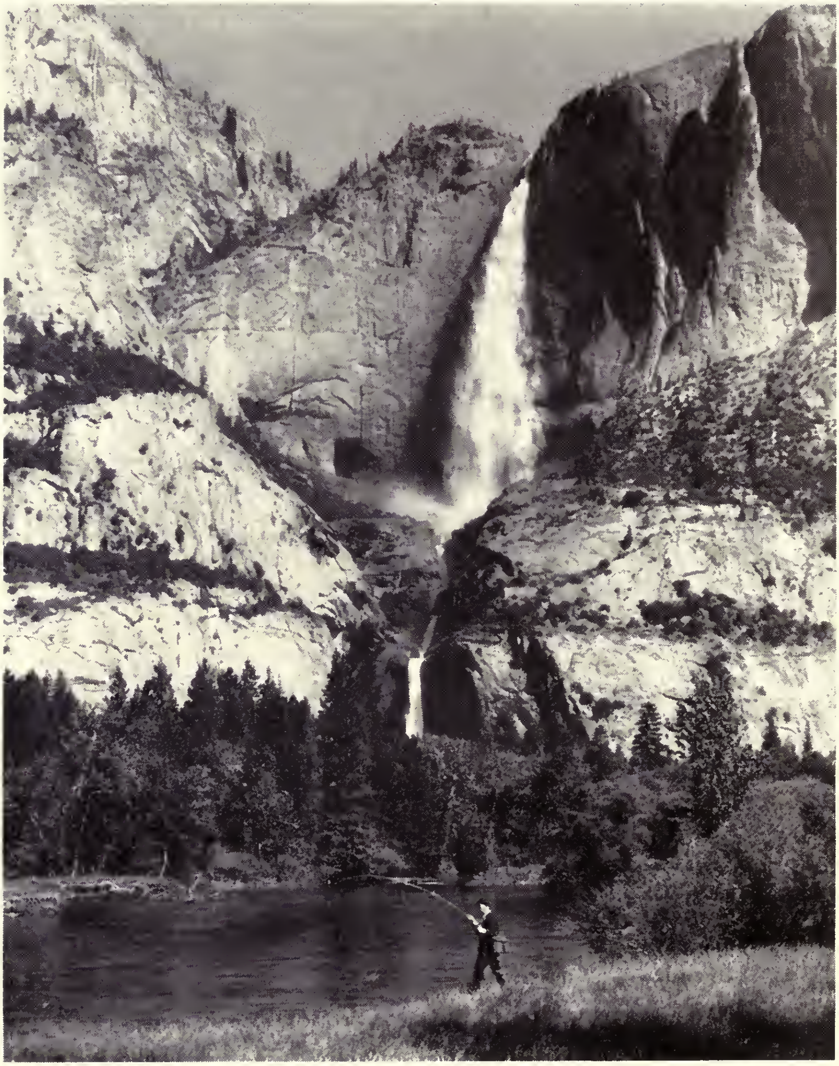


Photo by Californians, Inc.

FIG. 70. Yosemite Falls, Highest Waterfall in America. The upper fall, 1,430 feet, is probably the highest leaping waterfall in the world, The lower fall, 320 feet, is twice as high as Niagara Falls. The total height of the two and the intermediate cascade is 2,565 feet.

probably rightly so, as the most outstanding and wonderful features of the park—upper Yosemite Falls, 9 times the height of Niagara, descending from the lip of a hanging valley down a sheer straight cliff 1,430 feet, so far as now known the highest free-leaping waterfall in existence; then read again the first words of the chapter, "Incomparable Yosemite," and if this, as the final conclusion, does not harmonize with the reader's thought then the fault is in what has been said, or in what has not been said, and not in what Nature has done.

Chapter XVII

MOUNTAINS OF THE SOUTH

The Mountains of California Most Complicated in Structure

Southern California is marked by many mountain ranges. Probably it would not be far from the truth to say that the most complicated mountain structures in any part of North America, or indeed of the world, occur in California. The central part of the southern one-third of the State is a sort of focus of mountain ranges, a point from which many ranges radiate. The Tehachapi Range is generally regarded as marking the southern end of the Sierra Nevada Range. From the Tehachapi Range the system of Coast Ranges extends west and north. South of the Tehachapi Range is a broken mountainous region, to the east of which is the Mojave Desert, also broken by many irregularly distributed mountain ranges. In a general way transverse to the State lie the San Gabriel and San Bernardino ranges, the former extending west from Cajon Pass to the Santa Clara River; the latter extending east and south from Cajon Pass, and separating the Mojave and Colorado deserts. The Santa Monica Range lies south of and generally parallel with the San Gabriel Range, northwest of Los Angeles. A vast area lying between the Los Angeles Basin and the San Diego Coastal Plain on the west, and the great basin of the Colorado Desert, including the Imperial Valley, on the east, is a broken mountainous plateau, the continuation of the Peninsular Range, which forms the axis of the peninsula of Lower California, and extends 100 miles into California, including the Santa Ana Mountains on the west and the San Jacinto Range on the east. Connecting the ranges of the Peninsular system with the transverse ranges of the San Bernardino, the San Gabriel, and the

Santa Monica ranges are subordinate ridges or groups of hills, as the Repetto and Puente Hills, Montebello Mountain, the Newport-Inglewood fold, the San Juan Hills, the San Jose Hills, the Jurupa Mountains, the Bunker Hill Dike, Box Springs Mountains, and the Badlands of San Timoteo Canyon.

The cores of all the mountain ranges are granitic in character, igneous rocks and metamorphosed sedimentary formations, the latter originally sandstones, shales, and limestones, metamorphosed out of all semblance to their former characters to quartzites, slates, schists, and marbles. The entire region is cut and broken by faults. Igneous and metamorphic rocks make up the greater part of the formations exposed at the surface. All geologic sedimentary formations later than Jurassic occur in larger or smaller areas, showing that portions at least of the region were covered by the sea during the later geologic ages. On the western slope of the Santa Ana Range an almost complete series of geologic formations occurs, representing the periods from early Cretaceous to Quaternary (and Recent) time.

Even a brief consideration of these mountain ranges, their history and the processes by which they have come to their present forms, would make a large volume. Only an outline of the history and the agencies that have been involved will be here undertaken. It will be convenient to begin with a consideration of the Peninsular Range, taking up in brief outline the Santa Ana, the San Jacinto, the Santa Rosa, the San Bernardino, the San Gabriel, and the Santa Monica ranges, and touching a few of the intervening regions which are closely related to the adjacent mountains.

The Peninsular Range a Great Elevated Plateau

The Peninsular Range of Southern California is essentially a great uplifted plateau, cut off from the great Colorado Desert valley on the east by a fault zone, uplifted more toward the east and tilted toward the west and south. The body of the great plateau mass is made up of plutonic rocks, probably of late Jurassic age. A vast mass of intrusive rocks was forced up as a batholith underneath a roof of sedimentary rocks of probably Triassic age. These intrusive rocks cut into pieces the once widespread sedimentary formations. Only remnants of the sedimentary roof rocks remain, and these appear as metamorphic schists in scattered areas. Volcanic lavas lie along the western flank of the range, notably in Otay, Jamul, and San Miguel mountains. Bordering the range on the west, and forming the coastal belt, are upper Cretaceous and Tertiary strata, capped by a series of Quaternary marine terraces. Strata of Tertiary age occur in the foothills of the Desert region just east of the main range.

Viewed in a broad way the whole mountainous region may be looked upon as a vast much eroded Quaternary fault block, with a steep eastern scarp and a general downward tilt to the west and southwest. This plateau or highland region, 30 to 50 miles wide, is dissected by many streams. Numerous gorges and canyons, from 500 to 1,500 feet deep, have been cut into the plateau. The plateau is cut and broken by many faults, and some of the more important streams follow fault zones as lines of weakness in the rocks. The plateau surface generally increases in altitude from 1,500 feet or more in its western portion to over 4,000 feet in McCain's Plateau and more than 6,000 feet in the Laguna Mountains in the eastern portion of the highland. The increase in altitude eastward is not uniform, as the region has been broken by faulting into many large and small blocks, most of which stand out in the form of more or less well defined secondary plateaus, while others, relatively less uplifted and usually smaller, mark sites of valleys or basins. Various small and large parts of the great broken-up plateau surface, which represent a former old age erosional surface, are but little affected by stream dissection. Examples are south of Alpine; south and southwest of Gautay Mountain; west of

Buckman Springs; and the larger area of McCain's Plateau, lying between La Posta and Jacumba valleys. These and other elevated old age surfaces are largely mantled with deep residual soil and rotten rock. Certain of the minor blocks rose a good deal less than the immediately adjacent ones, and they appear like relatively sunken fault blocks. Good examples are Viejas, Cottonwood, Morena, and Potrera valleys, the valley just east of Jamul Mountain, and the valleys just northwest of Tecate Mountain.

The Plateau Made up of Fault Blocks

The fault blocks, which constitute the highland or plateau region, are generally stepped-down from the east at successively lower levels toward the west and southwest. The triangular, quadrangular, and pentagonal shapes of the mountain masses and associated valleys strongly indicate that they are fault blocks rather than results of stream erosion. Tracts that are comparatively flat, some of them surrounded by steep mountain walls, cover many square miles within the highland area. The floors of these valleys are comparatively smooth and slope gently toward the streams to which they are tributary, in distinct contrast to their rugged surroundings. Each basin is crossed by one or more streams, but there is nothing to indicate that the basins were formed by erosion of the streams. The highland basins are grouped into three belts trending parallel with the axis of the main range. The correspondence in the elevations of the basins in each of the three belts, and the fact that the belts are successively higher from the coastal region eastward, indicate that the high flat areas so widely distributed throughout the region are remnants of an extensive rolling plain that sloped gently toward the west in an earlier geologic time, and the highland basins are down-faulted segments of the ancient plain. The nearly flat summit areas of the plateaus that intervene between the highland basins and valleys are interpreted as old-age surfaces recently elevated by faulting. Previous to the uplifting of the land the region was a peneplain—that is, a region reduced by stream erosion until it had comparatively little relief. As the land was raised the streams were rejuvenated and cut their valleys to their present depths. During the time of the uplifting of the land faulting of the rocks occurred, and this has contributed materially toward the development of the present topography of the highland area.

The Eastern Front of the Plateau a Steep Eroded Fault Scarp

The eastern front of the highland area or plateau, facing the desert, is generally a high, steep, eroded fault scarp representing a southeasterly extension of the Elsinore fault. The descent from Monument Peak or Vallecito View (altitude 6,000 feet) on the Laguna Mountains to the floor of the valley at the foot of the scarp is approximately 4,500 feet in four or five miles. Farther south, from the top of Jacumba Mountain to the floor of the desert is a descent of 3,000 feet in five or six miles. Farther north, and east of the Elsinore fault zone, is a series of northwest-southeast mountain ridges which are plainly fault-block mountains associated with intermontane valleys representing sharply defined sunken fault blocks. The Santa Rosa Mountains form the greatest ridge, which is a distinctly tilted fault block with a long, straight, steep scarp thousands of feet high forming the southwest face and a slope from 7 to 10 miles wide descending northeastward from an altitude of 6,000 to 8,000 feet to sea level. The Santa Rosa Mountain block is regarded as a typical high and large tilted and eroded fault block.

View from Cuyama Peak

From the summit of Cuyama Peak (6,515 feet) a panoramic survey of California's Peninsular Range is most impressive, and to be long remembered. In 1870 this vivid word-picture was expressed by W. A. Goodyear, who made a survey of the region for the State Bureau of Mines: "Reaching toward the south the view extends far into the Republic of Mexico, and to the north as far as San Jacinto Peak and Mount San Bernardino; to the west the broad expanse of the Pacific Ocean; on the east the Cahuilla Valley and the Colorado Desert. Looking down from this elevated standpoint over the surrounding region the whole country from just back of San Diego easterly to the western edge of the desert is like an angry ocean of knobby peaks more or less isolated, with short ridges running in every direction and inclosing between and amongst them numerous small and irregular valleys. As a general rule the higher peaks and ridges rise from 1,000 to 2,500 feet above the little canyons and valleys around their immediate bases. But in going easterly from the coast each successive little valley is higher than the one immediately preceding it, and the dominant peaks and ridges are gradually higher and higher above the sea until the irregular line of the main summit is reached, when the mountains break off suddenly and fall within a very few miles from 4,000 to 5,000 feet, with an abrupt and precipitous front toward the east, to the western edge of the desert."

More than 50 years ago Professor Waldemar Lindgren emphasized the existence of a great escarpment along the eastern side of the Peninsular Range. Coming to the eastern side of the mountains from the west he said: "The spectator suddenly and unexpectedly finds a view extended before him which in grandeur and sublimity is surpassed by but few places on the continent. He stands at the edge of a gigantic escarpment descending about 3,000 feet in 5 miles; naked granite cliffs, separated by steep ravines, and a few canyons cut more deeply into the rock, form the face of the escarpment; and at its base the Colorado Desert spreads out, a dazzling white plain."

The Great Mountain Ranges of the South

The Peninsular Range extends 100 miles into California from Mexico. At the north it is represented by the San Jacinto Mountains on the east and the Santa Ana Mountains on the west. The transverse ranges, San Gabriel and San Bernardino, lie in a generally east-west direction and form a sort of division line between the north and the south. South of the San Gabriel Range is the Los Angeles Basin. The San Gorgonio Pass is a sunken valley lying immediately south of the San Bernardino mountain range. The San Andreas fault extends through the San Gorgonio Pass, marking the south wall of the

Photo by W. S. W. Kew, U. S. Geol. Survey

FIG. 71. Little Tujunga Canyon, Los Angeles County. Eroded slope of San Gabriel Mountains.

San Bernardino Range and passes northwestward through Cajon Pass to San Francisco and beyond. The Peninsular Range is represented in its northern portion by the San Jacinto Range, extending north-northeast and cut off by the San Andreas fault, and the Santa Ana Range, extending in a northwest direction 25 miles from the Pacific Ocean and terminating in the Puente Hills in the Los Angeles Basin. Between the San Jacinto and Santa Ana ranges the surface is broken by plateaus, the highest of which rise above 2,500 feet, with broad valleys intervening with elevations as low as 1,200 feet. The Peninsular Plateau slopes in a general way toward the north to about 900 feet in the vicinity of Riverside.

The San Gabriel and San Bernardino ranges together form an east-west transverse range dividing Southern California into north and south. These are the highest mountain ranges in southern California. The San Gabriel Range extends from the Santa Clara River on the west 50 miles to Cajon Pass on the east. The San Bernardino Range extends east and south 80 miles to the Cottonwood Range, and separates the Colorado Desert on the south from the Mojave Desert on the north. The San Gabriel Range is the higher of the two. It has been suggested by an eminent geologist that the two ranges may have been originally continuous; the break at the Cajon Pass, through which passes the San Andreas fault, marking a torsion stress in the crust of the earth by which the mountain range was broken in two. The character of the rocks suggests that earth stresses caused a movement of the rocks by which the two ranges were rent apart a distance of 15 to 25 miles.*

The San Gabriel Range

The San Gabriel Range is an uplifted block 50 miles in length east and west, and 25 miles across. It is bounded by faults or fault zones on three sides, the Sierra Madre on the south, the San Andreas on the northeast, and the Soledad on the northwest. The block covers an area of 1,200 square miles. Uplifted thousands of feet, it stands out boldly above the surrounding country. It is what is technically called a horst—a block of the earth's crust cut off at its sides by faults and uplifted as a huge wedge or block. The great block is clearly a horst, though its mass is broken into many minor blocks by faults which crisscross the range. The surface is exceedingly rugged, being cut by streams into canyons and V-shaped gorges to depths of a few hundred to several thousand feet. Altitudes in the western part of the block rise to 4,000 to 7,000

* William J. Miller, Univ. of Calif. (See Appendix.)

feet, and in the eastern from 6,000 to 10,500 feet. The original faulting by which the great block was outlined dates back probably to early Tertiary time, or possibly earlier. That the region has long been subject to erosion is shown by the deeply dissected character of the surface. The upheaval which brought the range to essentially its present altitude occurred, however, in later (Quaternary) time. The great horst block is itself broken into many smaller blocks by faults. These minor faulted blocks were uplifted to different heights, and thus the surface of the range is broken into higher and lower peaks and ridges. Located in the heart of Los Angeles County, 15 to 25 miles from the population center of the city of Los Angeles, the region is an almost inaccessible wilderness, for the most part untouched by the foot of man. The southern part of the region is more accessible.*

Rocks of the San Gabriel Range

The rocks of the San Gabriel Range are exceedingly complex. In a general way the range is a great block of pre-Cretaceous metamorphic and igneous rocks thousands of feet high, bounded on all sides by Tertiary and Quaternary deposits. All the rocks making up the San Gabriel Range proper are crystalline. The oldest rocks are schists, crystalline limestones, and quartzites, probably pre-Cambrian in age, originally shales, limestones, and sandstones. The old sedimentary rocks have been invaded by igneous intrusions of diorite, granite, quartz syenite, granodiorite, and other molten intrusives. These upwellings of molten rock have occurred at repeated intervals, and the rocks now exposed at the surface are broken and intermixed in great confusion, so that over large areas the rocks make up a complex of igneous and metamorphic sedimentary and metamorphosed igneous rocks of a very complicated nature. Large areas of mixed rocks consist of schist cut and injected by granite or other intrusive. Dikes cut sharply all

* William J. Miller, *op. cit.*

types of the great series of metamorphic and igneous rocks. Tertiary lavas occur along important fault zones. The ancient sedimentary formations which were intruded, cut, and injected by igneous molten rocks from the depths of the earth have been largely removed by erosion. Only remnants of them remain in the form of metamorphic quartzites, schists, and marbles (crystalline limestone).

The San Gabriel Range is divided into north and south parallel ridges or ranges by a valley that extends east and west almost through the range. The East and West forks of the San Gabriel River meet near the center of the range, and from here the main river flows south and across the alluvial San Gabriel Valley, which lies at the base of and parallel with the range. (The alluvial San Gabriel Valley is not the valley of San Gabriel River.) East from the head of the East Fork of San Gabriel River the middle fork of Lytle Creek occupies the valley leading eastward nearly to Cajon Pass. West from the West Fork Tujunga Canyon opens west and south to La Canada Valley, which is the western continuation of the alluvial San Gabriel Valley. The range or ridge lying south of the east-west valley is the Sierra Madre Range. The main range lies to the north and is generally higher than the Sierra Madre. The Sierra Madre has its culminating point in Cucamonga Peak, 8,911 feet. The highest point in the north range is San Antonio Peak (Old Baldy), 10,080 feet. South of the alluvial San Gabriel Valley and La Canada Valley are the Verdugo Mountains and the San Rafael Hills. These are cut off from the San Gabriel Range by the fault which extends along the foot of the main range.

The San Bernardino Mountain Range

The San Bernardino Mountain range is a faulted block extending 80 miles in a generally easterly direction from Cajon Pass. The width of the range in its western portion, where both the height and the width are greatest, is about 30 miles.

The range has been raised between faults on the north and south sides. To the north is the Mojave Desert. On the south the range is bounded by the western portion of the Colorado Desert, the San Gorgonio Pass, and the San Bernardino Valley. The range as a whole is a vast uplifted block. It is, however, broken by many faults, so that the range may be said to be made up of a considerable number of "horst" blocks. San Gorgonio Pass is a sunken valley, technically called a "graben," between the San Bernardino and San Jacinto mountains.

The general "floor" of the top of the San Bernardino Range is in marked contrast to that of the San Gabriel Range, which lies immediately to the west of Cajon Pass. The San Bernardino upland surface is marked by broad comparatively level plains with many old rounded hills, whereas the San Gabriel upland is all cut by deep gorges and canyons which are separated by sharp knife-edge ridges with no flat tops or plateaus. Throughout the western end of the San Bernardino Range there is a strikingly level sky-line at an elevation of 5,000 feet or more. There are many broad meadows, with lakes and playas, separated by smooth ridges. The central part of the range, a few miles to the east, has a general elevation of 7,000 feet, and the surface outline is that of a subdued worn-down old-age region, a rolling plain with rounded hills and broad meadows.

Standing high above the general plain are two outstanding peaks, San Gorgonio, 11,485 feet, and San Bernardino, 10,500 feet. A long even summit ridge extends from San Bernardino Mountain to San Gorgonio Mountain. From these two prominent peaks the highest ridge of the range extends westward to Cajon Pass. The summit of San Gorgonio Mountain is generally flat except for knobs of granite, boulders carved by wind-driven sand into fantastic shapes, and pinnacles of granite boulders resembling crude monuments made by placing one stone above another. San Bernardino Mountain culminates in a serrate ridge, but half a mile to the east this changes to a narrow flat summit, and half a mile farther this broadens to a considerable area. East and west of The Pipes are flat-topped summits, also flat-topped ridges occur on both sides of Antelope Creek. All these flat surfaces are at about the same level as the summit ridge between the high peaks San Gorgonio and San Bernardino. The fact that these flat areas extend across eroded surfaces of gneisses, schists and basalts as well as granite suggests that these are remnants of an old peneplain, or worn-down landscape. This ancient land surface existed before the San Bernardino Range was uplifted. The difference in elevation between these remnants of an old land surface and the broad valley floors and meadows indicate the amount of the uplift. The summit ridge between San Bernardino and San Gorgonio mountains rises 4,000 to 4,800 feet above Big Meadows and the floor of Bear Valley. This then represents the amount of uplift that occurred during the time that this vast erosion was going on.*

An Ancient Worndown Land Surface

About eight miles north of the high ridge between San Gorgonio and San Bernardino mountains is an ancient land surface (peneplain) having broad valleys and meadows, and hills with rounded profiles. The general elevation is around 7,000 feet above sea level. The most important valley is Bear Valley, extending 12 miles in an east-west direction. Bear Lake, five or six miles in length, lies in the lower part of the basin and Baldwin Lake in the upper part of the basin. The basin is drained by Bear Creek to Santa Ana River through a precipitous gorge. The region of Bear Valley and Holcomb Valley to the north is in a stage of topographic "old age." Streams of low gradient flow sluggishly through the meadows, but plunge down steep canyons in their lower courses as they descend from the uplifted land.

North of Bear Valley about seven miles the surface breaks off by a precipitous declivity to the Mojave Desert. East and

* F. E. Vaughan, Univ. of Calif. (See Appendix.)

south of Bear Valley the mountains are rugged, and are traversed by steep crooked canyons. On the south flank of the range the extremely rugged topography such as occurs south of San Gorgonio Mountain gives way to low foothills, which are cut by many streams that lead southward to San Gorgonio Pass.

Drainage from the western part of the San Bernardino Range is southwesterly by the Santa Ana River to the Pacific Ocean. Streams east of Banning and south of Morongo Valley flow into the Salton Sink or disappear in the desert before reaching it. Those north of Morongo Valley and Bear Creek flow out upon the Mojave Desert and sink into the sands or are evaporated.

Alluvial Fans on North and South Slopes of San Bernardino Mountains

Extensive alluvial fans are built along both the northern and the southern flanks of the main mountain range. Those on the south flank spread out across San Gorgonio Pass. One at the mouth of Mission Creek is well developed and shows the character of such stream deposits. Near the mouth of the canyon the material making up the fan is mainly a mass of boulders. To the southeast, toward Palm Springs, the material is finer, but even here are large boulders brought down during cloudbursts. The stream is constantly changing from one radiating channel to another across the fan. At the mouth of Millard Canyon the fan is a mass of slightly rounded boulders. At Cabezon, farther down the fan, the alluvium is finer and the land is planted in orchards. At Banning the upper part of the fan contains many boulders brought down by floods of San Gorgonio River, whereas south of the town the soil is fine-grained and fairly heavy.

Similar deposits made by streams during earlier stages in the uplifting of the mountains occur in many places, on the flanks of the main mountain range, and also along streams that flowed from higher lands and discharged their load of boulders, gravel and sand at their mouths or on flat meadows or in basins. These older fan deposits are technically called "fanglomerates." They do not differ essentially from the alluvial fans that are being deposited at the present time only as they may have been deposited under different climatic conditions. Some fanglomerate deposits contain boulders of great size, carried from adjacent heights by torrential streams such as occur from cloudbursts. Fanglomerate deposits are widespread over the San Bernardino Range. They form an important feature of the landscape, as they were formed during the time when the range was being uplifted, and they are in many cases dissected by streams which cross them due to the uplifting of the land. Along the south front of the range recent movement has raised the old fanglomerate floor more than 500 feet above San Gorgonio Pass. San Gorgonio River, Millard Canyon, Potrero Creek, and Whitewater River have cut down through the fanglomerate to the level of the Pass.

Rocks of the San Bernardino Range
Very Old

The rocks that make up the formations of the San Bernardino Range are, generally speaking, very old. Over much of the mountain area the rocks now exposed at the surface are granitic in character—igneous intruded granite and metamorphic schists. These cover a large area south from San Bernardino Mountain and from San Gorgonio Pass north and east. North of San Gorgonio Mountain are considerable areas of quartzite and limestone. The sedimentary formations are very old, and have been much intruded by granite. Granites are the most widespread rocks of the region. Nowhere are there any considerable areas entirely free from intruded granites. Along the south flank of the San Bernardino Mountains there are sandstones, shales, and fanglomerates of Tertiary and Quaternary age. Remnants of basalt (lava) flows also occur here. Areas of basalt are widely distributed. They are remnants of lava flows which are thought to have extended over a large part of the region previous to the uplift of the mountain range. Erosion has dissected the basalt beds so that they occur now only in patches.

Glaciation has played a part in fashioning the surface in the highest parts of the range. At first thought it may seem surprising that glaciation should occur in this southern latitude. However, San Gorgonio Mountain and the ridge extending westward show unmistakable evidence of the effects of glacial ice. In Quaternary time (the era in which the Glacial Period occurred) the climate may have been colder than at present. The fact is, however, that today a little snow lingers on the higher slopes throughout the year.

Evidences of Glaciation on Ridge West of San Gorgonio Mountain

On the north side of the high ridge that extends westward from San Gorgonio Mountain between Santa Ana River and Mill Creek well defined glacial cirques and moraines occur, giving certain evidence of glacial ice action. There is a typical glacial cirque on the northeast side of San Gorgonio Mountain. Less than a quarter of a mile below a well developed moraine lies across the uppermost part of the north fork of Whitewater River. On the northwest side of San Gorgonio Mountain a large moraine lies across the east branch of the south fork of Santa Ana River. A most ideal example of a glacial moraine is at the head of Hathaway Creek, northwest of San Gorgonio Mountain. A long narrow tongue of ice reached down the valley a mile and left a nearly perfect moraine. Five semicircular terminal moraines cross the canyon. The middle one is formed of immense blocks of rock, which when viewed from below its curving front forms a wall nearly 100 feet high. Conditions in the region indicate that glaciation was of considerable duration.

The Glacial Period in geologic history is a part of the Quaternary Era, which is the era just preceding the Recent, in which we live. The history of the San Bernardino Range dates back to pre-Cambrian time, which marks the earliest stages of the history of the earth. The Cambrian formation marks the beginning of geologic history, as revealed in the sedimentary rocks in which fossil remains of living things furnish the key to the successive stages of progress. In pre-Cambrian time, that is, some time during the indefinitely long time before the oldest fossil-bearing sedimentary rocks were deposited, molten rock was forced up from the depths of the earth under the region where the San Bernardino Mountains now are. These once molten rocks uncovered by erosion now appear as crystalline granitic rocks.

History of San Bernardino Range Is Long

The details of the geologic story are long. The region of the San Bernardino Mountains has long been land, and it has at times been covered by the sea. This means that the region has been elevated, and has in turn subsided or been depressed or sunken. That it has been rent by earthquakes and the rocks broken is shown by the faults or breaks in the crust of the earth, such as the San Andreas fault.

That the region was below sea level is shown by the formations of sandstone, shale, and limestone that are now part of the rocks of the range. These sediments have been intruded, crushed, and folded by later intrusion of molten rock from below. Heat and pressure from the molten materials changed (metamorphosed) the rocks with which they came in contact. Sandstones became quartzites, limestones became marble, shales and other rocks became schists. Thus the rocks that are now seen in the San Bernardino Mountains are very complex.

In comparatively late geologic time (technically late Tertiary) the region was uplifted, and this means that erosion of streams was accelerated, and as the movement upward continued fanglomerate deposits were laid down in basins and at the mouths of streams. The whole region was reduced to a surface of low relief, and basalt flowed out over the level surface.

Finally, in Quaternary time the country was subjected to earth stresses to which the rocks yielded by faulting, and a great block began to rise which ultimately became the San Bernardino Mountains. The San Bernardino Mountain range owes its existence as such to a great system of Quaternary faults. The mountain range has been raised between faults on the north and south sides. The range is being eroded rapidly by deep-cutting canyons and gorges. The region has been made "young" by reason of being uplifted. Such a mountain-building upheaval is generally accompanied by faulting. The general uplift of the region, and the faulting as well, which has given rise to the mountains, is recent, and indeed may be still going on.

The San Jacinto Mountains a Stupendous Range

The San Jacinto Mountains constitute one of the most stupendous mountain ranges in Southern California. The dominating feature of the range is San Jacinto Peak, 10,805 feet above sea level. The peak is an outstanding monument that compels the attention of the passer-by by its towering majesty. Seven miles to the east is far-famed Palm Springs, 500 feet above sea level, and a little beyond is the Salton Sea, the surface of which is 280 feet below sea level. While the observer will probably not look away over the landscape from the top, he may gaze upward from a wide radius and imagine himself looking over the Colorado Desert; off to the southwest to the Santa Ana Mountains; northwest to and beyond Riverside 25 miles away; and north to the great heights of the San Bernardino Mountains beyond the San Gorgonio Pass.

The peaks and higher slopes are rugged in the extreme. On the north slope Snow Creek, which descends to the San Gorgonio Pass, falls 4,000 feet in one mile of its course. On the northeast side of the mountains the slope falls 2,500 feet in as many feet of horizontal distance. Torrential streams descending from the high peaks have notched deep narrow canyons in the mountain sides, and these have precipitous walls and are separated by narrow ridges giving to the mountain side an exceedingly rugged slope. The southwest side of the mountains

Photo by W. S. W. Kew, U. S. Geol. Survey

FIG. 72. Massive Conglomerate, Sandstone and Shale, in Escondido Canyon, Los Angeles County. Picturesque outcrops north of Soledad Canyon.

is less precipitous. It is outlined by the zone of faulting of the San Jacinto fault, which is considered to be a branch of the San Andreas fault which passes through San Gorgonio Pass on the north, the two meeting in Cajon Pass 30 miles to the northwest.

The San Jacinto Range a Vast Uplifted and Tilted Block

The San Jacinto Range is a triangular block having a northwest southeast trend. It is bounded on the three sides by fault zones, the San Jacinto on the southwest side 35 miles in length; the San Andreas on the north, 25 miles, along which lies the

Gorgonio Pass; and the Palm Springs fault on the east, 25 miles. The range is a vast uplifted block, tilted or rotated toward the northwest on an axis crosswise of the length of the range. The core of the mountain mass is granitic rock in the form of a batholith, which was forced upward underneath and into very ancient sedimentary formations of sandstone, shale, and limestone, which are thought to be of Palaeozoic age or older. These sediments are thought to have accumulated when the region was a depressed area to a thickness of 10,000 feet or more. These sediments were intruded by an igneous magma of molten rock, and they now form several thousand feet of metamorphosed gneisses and schists. This is thought to have been near the close of Jurassic time. The main body of the magma of molten rock cooled slowly, resulting in the granitic batholith which is now the core of the range. Erosion during a long period has removed a great part of the overlying roof of sedimentary metamorphosed rocks. The igneous material making up the body of the San Jacinto Mountains is granite, and this is the most widespread rock now exposed in the range. It is best observed near Tahquitz Peak, where a large area is exposed. About 200 square miles of such rock is exposed in the higher mountains and an equal amount in the Sage Hills Upland to the southwest. Irregular areas of metamorphic rock, sometimes in comparatively small patches, occur throughout the mountains, remnants of the ancient sedimentary roof rocks not yet removed by erosion. To the north the granite passes beneath the alluvium of San Gorgonio Pass.*

Faulting and Upheaval of Geologically Recent Occurrence

Throughout a long time following the intrusion of the molten magma, during which time erosion of the uplifted sedimentary rocks was going on, so far as is known probably in early Tertiary time, faulting occurred which later resulted in

* D. M. Fraser. (See Appendix.)

the uplifting of the San Jacinto mountain block. It has been stated that the San Jacinto Mountain range is a great triangular uplifted block, bounded on three sides by faults. Just when faulting and the uplifting of the block began is not definitely known but is thought to have been probably in early Tertiary time. The uplifting of the great block was not by a sudden convulsion. Indeed there is reason to think that the uplifting of the mountain mass may be still in progress, evidence of which is seen in earthquakes of recent occurrence, which are known to have been caused by earth movements along the San Jacinto fault. At any rate it is known from indisputable geologic evidence that the disturbance by which the mountains were uplifted to their present height was in very recent geologic time. The earthquake which affected San Jacinto and Hemet was apparently caused by earth movement along the San Jacinto fault. Displacement of the earth by faulting has caused the San Jacinto Valley to stand at a lower level than the very recent Pleistocene beds in the Badlands near by. During late Tertiary and Quaternary time vertical movement amounting to thousands of feet displacement have taken place along the San Andreas and San Jacinto fault zones.

Stages of Uplift Marked by Benches of Erosion

A series of benches has been cut at various levels in this great block of granitic and metamorphic material. These it is thought may be related to successive stages of uplift of the mountain mass. Their correspondence in time has not been definitely established, but since other mountains, as San Gabriel, San Bernardino, and Santa Ana are known to have been uplifted at successive intervals since late Tertiary time down to their final uplifting to their present heights in very recent geologic time, probably Pleistocene (Quaternary), it seems not unreasonable to think that these benches are due to successive uplifts of the mountain block, each uplift being preceded by the development of an erosion level.

The most conspicuous bench of the San Jacinto Mountains is found on the southwestern slope. It extends the entire length of the mountain face, and lies about a mile below the high-peaks level. It is thought that this bench has resulted from the relative uplift of the San Jacinto Mountains in relation to the San Jacinto Valley block to the southwest, and that it was originally cut by stream erosion or planation at an elevation near that of the alluvial plain of the San Jacinto Valley below; in other words that the two surfaces were originally at about the same level.

Near the top of the great mountain pyramid there is a plain surface at an elevation of about 10,500 feet. Tahquitz Valley is a gently sloping plain which has an average elevation of about 7,500 feet. It is known that the great mountain pyramid is bounded on three sides by faults. The most logical explanation of these benches therefore seems to be successive uplifts of the mountain block and that each of these benches represents a period of erosion.

The Core of the Range an Intruded Batholith of Granite

Thus the San Jacinto Mountains are seen to constitute an immense uplifted block, cut off on three sides by great fault zones, the core of the range being an intruded batholith of granite, a vast series of ancient sedimentary rocks originally forming a roof over the intruded granite and now largely removed by erosion during the long lapse of time since the original uplift, probably in Jurassic time. The slopes of the mountains are exceedingly steep and rugged, particularly the northern and eastern sides, carved by torrential streams which tear with great force down the slopes during times of precipitation in winter and spring. The towering heights of San Jacinto Peak and San Gorgonio Peak, monarchs of their respective ranges, stand as sentinels on either side of the great San Gorgonio Pass, the first discovered pass across the mountains between the east and the west. Whether the two mountain ranges, San Jacinto and San Bernardino, were originally one mountain range formed by the intrusion of a granitic molten magma and the uplifting of the intruded formations we do not know. Both ranges have a core of intruded granite. They are now separated by the great San Gorgonio Pass, a sunken valley floor, with the San Andreas fault forming a break in the crust of the earth by which California has been rent in twain, and along which earth movements of tremendous geologic significance have occurred, and may still occur.

North and West of Los Angeles Is the Santa Monica Range

North and west of Los Angeles the Santa Monica Range lies parallel with the Pacific Coast, which runs nearly due west. In the distance to the east may be seen in the blue haze the outline of the San Gabriel Range. At the western end of the San Gabriel Range is Newhall Pass, and west of this is the Santa Susanna Range. This last in turn joins the Santa Monica Range still farther west, and northward extends the Coast Ranges. North of the Santa Monica Range lies the San Fernando Valley, a mountain basin having its outlet at Burbank, where the Los Angeles River creeps through the mountains on its way to the coast. Thus the Santa Monica Range is part of the complicated system of mountain ranges which gives to Southern California its remarkable topography.

The Santa Monica Range is an arched ridge, technically called an anticline, its axis parallel with the ocean coast. The drainage of the southern slope is to the Pacific; that of the northern to the San Fernando Valley. The slope on the north as compared to that to the south is narrow. Streams flowing toward the San Fernando Valley are generally not more than one mile in length, whereas those draining to the ocean are as much as seven miles in length. The fall to the San Fernando Valley is much less than that to the Pacific. The streams have pushed their heads backward up each side of the ridge, but because those leading to the ocean have a greater fall their heads have pushed back more rapidly than those of the north slope. As a result the axis of the ridge or anticline is considerably south of the dividing line between the north and south streams. The ridges between the streams are all of nearly the same height.

The Range an Arched Ridge of Former Sea Sediments

What is now the Santa Monica Range of mountains was at one time a flat plain. This plain had been for a long time sea bottom, and on it were deposited sediments which became solidified as shale. Later, due to uplift of the region these sediments became dry land. They are now the slates and schists which are among the oldest rocks of the range. They are thought to be of Triassic age, but no fossils have been found in them and hence the age cannot be exactly determined.

A Batholith of Molten Rock Forced under a Roof of Sea Sediments

At a later time, thought to be Jurassic (the next great geologic period later than Triassic), a vast upwelling of molten rock (technically called "magma") occurred. The great molten mass was intruded under and into the shale formation as a great batholith. The shale, several thousand feet in thickness, which had been deposited on the old sea bottom and elevated to become dry land, was uplifted, forming a roof or covering over the intruded mass of molten rock. Heat and pressure of the intruding magma transformed the shales by metamorphism to slates and schists. The liquid molten rock that was forced up under and into the shale formation slowly cooled during the lapse of time following the intrusion, and the minerals composing the magma crystallized and thus came to be the hard Hollywood granite, which now forms the core of the Santa Monica Range.

Uplifted Sediments Worn Down, Submerged, and Again Uplifted

After the instrusion of the molten rock the region was uplifted and remained land during long geologic epochs. Whenever any region is above sea level the rocks at the surface, however hard, are attacked by the weathering and eroding agencies of heat and frost, wind and rain. The hardest rocks give way, and slowly but ceaselessly the land surface is reduced back toward sea level. The sediments which had been deposited on the bottom of the Triassic sea and later intruded by molten rock, uplifted, bulged upward into a vast anticlinal fold, now stood as a land surface for long ages while streams eroded and the lowering of the uplifted land went on. This continued for so long that the once elevated land was worn down to a low plain not much above sea level.

Another epoch in the geologic history of the region was ushered in. The land which had been reduced to a low essentially flat plain sank so that it was covered by the sea. Gravels and sands were deposited on the bottom of a shallow sea. These deposits are now represented in the Topanga formation, which is widespread in the Santa Monica Range, having a thickness of approximately 5,000 feet. Basaltic lavas were poured out upon the sea bottom or were forced into the consolidated rocks. The disturbance involved in the volcanic activity resulted in the outpouring of vast beds of lava, and upheaval occurred such that the rocks were crumpled, folded, and faulted, and the whole region involving the present mountain range was raised in a dome-like ridge or arch (anticline) along the line of the Santa Monica Range of today.

The uplifting of this long dome or arch was followed by the withdrawal of the sea, and the great arch became dry land. The work of stream erosion started all over again. This all involved a long time as measured in years, but it must be remembered that time is long in geologic history, and is marked off in epochs or periods rather than in years. So let the imagination picture erosion of the land as going on till the uplifted region was again reduced to a low flat plain with streams meandering widely over the worn-down surface.

Submergence and Uplift Repeated, and Final Uplift of Present Range

Again the sea covered the land as a new geologic epoch was ushered in. When an eroded land surface is covered by the sea and deposits are thrown down upon the more or less broken

Photo by W. C. Mendenhall, U. S. Geol. Survey

FIG. 73. Coastal Bluffs, Santa Monica. View west from near mouth of Santa Monica Canyon.

former land surface the new formation deposited by the later sea does not "fit" upon the old eroded surface, and the result is an "unconformity." It thus comes about that the Modelo formation, which rests upon the earlier formed Topanga formation, is separated from the latter by the broken line of the old land surface. The Modelo formation is made up of the remains of great numbers of minute organisms known as diatoms, which swarmed in the sea; of volcanic ash thrown out from vents in the surrounding land; and silt or very fine mud swept into the sea by streams. The deposit thus made upon the sea bottom became the silicious or diatomaceous shale of the Modelo formation.

During a later epoch, after the Modelo shale had been deposited, the great anticlinal fold or arch again was raised, and the whole series of formations comprising the Santa Monica Range was arched upward. The whole region henceforth remained land, and erosion went on until from the crest and flanks of the great arch much of the Modelo formation was removed. The region continued to be worn down by streams and weathering until the land became reduced to the stage of a peneplain—that is, worn down nearly to base-level or landscape *old age.*

Finally in late Quaternary time (Pleistocene), the last geologic epoch preceding the present or Recent, the arch was uplifted to essentially its present height. Since the final upheaval of the range streams have cut deep canyons and the present topography has been developed.

Coastal Plain Affected by Changes in Adjacent Land

The Coastal Plain is not a part of the mountain range, but the movements which have given form to the mountain range have affected the coastal plain. Streams leading to the ocean from the mountains have been affected by the uplifting of the land. Changes in the elevation of the mountains have given rise to the formation of terraces in the valleys of streams. Hence the mountains may be said to be the controlling influence that determined the plain.

Santa Barbara Islands Projecting Peaks of Santa Monica Range.

It should be stated further that the Santa Monica Mountain range does not end where it is cut off by the sea at the west. The Santa Barbara Islands are really mountain peaks which rise above the surface of the sea. The intervening lands have been submerged beneath the waters of the Santa Barbara Channel. The projecting mountain tops, which appear as islands, are thought to be the tops of uplifted faulted blocks, and the parts of the range that are submerged may represent down-faulted blocks. The Santa Monica Range, particularly in its western portion, is broken by many faults. The submerged coastal shelf has at a former time been dry land above the waves. Just how much of the submerged land has been depressed by downward faulting is not known.

Core of Santa Ana Mountains a Granitic Batholith

The Santa Ana Mountain range belongs to the Peninsular System. The range is about 40 miles long, lying 25 miles inland from the Pacific Ocean. The core of the range is granitic rock, which was intruded as a batholith under and into the rocks of Triassic age, probably in Jurassic time. The range has played hide and seek, so to speak, with the ocean during all the epochs and periods of geologic time since early in the Mesozoic Era. What occurred before that time we do not know. The oldest sedimentary formation in the range is Triassic, as shown by fossils that have been found in the rocks.

Sea Sediments Flank Santa Ana Range

During the almost inconceivably long time since the Triassic (see table, p. 59) throughout the periods and epochs of Cretaceous and Tertiary time upheavals and down-sinkings of the land have been going on. This is shown by the successive formations of stratified marine sediments that have been deposited and are now exposed in rock outcroppings on the slopes of the range in eroded canyons and gullies. We speak of upheavals and down-sinkings of the land, as we cannot conceive of the sea rising over the land only as the land sinks below sea level. That the sea has covered the land that is now the Santa Ana Range at different times, and several times, is shown by the fact that marine sedimentary formations now occur on the flanks and top of the range. Fossils in the different formations prove unmistakably the age to which the rocks belong. An almost complete succession of geologic formations representing the periods from Triassic to late Tertiary time is revealed in the western flanks of the range.

The range was originally uplifted in (probably) Jurassic time by upwelling from below of molten rock after the Triassic rocks were laid down. The range has been raised and depressed several times since. A great fault in the crust of the earth marks the eastern foot of the range. The mountain block was uplifted more on the east and was tilted toward the west. The deep-lying granite has been brought up, and uncovered by erosion, so that it is exposed at the surface on the flanks and top of the range. The eastern slope of the range is therefore steep and precipitous whereas the western side slopes more gently toward the coastal plain. One mile south of Corona a winding highway leads across the northern end of the range. Following this highway through Mine Canyon and Black Star Canyon a cross-section of the formations making up the mountain may be seen. In Mine Canyon the bed-rock is metamorphosed Triassic slate. At the crest of the mountains a conglomerate and sandstone formation of Cretaceous age (Chico) overlies the Triassic slates. The Chico formation is not metamorphosed, which means that the intrusion of the granite and the metamorphism of the slates occurred in the great mountain-building upheaval before the Chico formation was deposited. This means further that the uplifted mountain range was lowered nearly to or below sea level during the time when the conglomerate sandstone formation was being laid down. The road across the mountains passes through the Chico formation to the contact between these Cretaceous rocks and the overlying Tertiary (Martinez) formation. On this northern portion of the range several marine formations representing successive Tertiary epochs occur. These do not lie regularly one above another in order of age or time of deposition, but with intervening gaps or skips (unconformities), showing that the sea withdrew and re-advanced over different parts during the successive epochs of Tertiary time.

Upheaval at Close of Tertiary Period

The end of Tertiary and the beginning of Quaternary time was marked by very profound disturbances affecting a large area. During late stages of Tertiary time a great region of southern California had been depressed and covered by the sea. An upheaval of tremendous proportions followed, and the formations that had been laid down during the successive epochs since Cretaceous time were not only uplifted but were bent, folded, and crumpled by earth contortions due to stresses in the crust of the earth. Sediments which had been deposited in horizontal layers were wrinkled, warped, and upturned so that they now appear, where exposed in canyons or other outcroppings, tilted at various angles and even in vertical position. Slipping movement along old fault lines, and the forming of new faults contributed to the mountain-building activities. The Santa Ana Mountains were uplifted to approximately their present height at about this time.

This great disturbance which marked the close of Tertiary time and the beginning of Quaternary was followed in early Quaternary time by a widespread subsidence of the land. Quaternary sediments were carried to the sea, or deposited in valleys before reaching the sea. Deposits that now make up large areas of the Coastal Plain were laid down during this time. Later in Quaternary time upheaval brought these deposits high above sea level. Terraces of great extent that now make up parts of the Coastal Plain are these deposits which were thrown down in horizontal layers over the bent, broken, crumpled and deformed rocks and eroded edges of the Cretaceous and Tertiary formations. In many valleys these have been cut in recent time by streams, so that broad terraces now stand along the sides of valleys, remnants of the former plain of deposit.

East Face of Range Marked by Fault

The east slope of the Santa Ana Mountain range is definitely and abruptly cut off at its base by the fault which marks the east side of the uplifted block. This is the Elsinore fault, a continuation southward of the Whittier fault. It may be traced southward a distance of 50 miles. Elsinore Lake lies in a depressed valley or basin caused by the sinking of a fault block east of the line of the Elsinore fault. Sierra Peak, near the north end of the range, is more than 3,000 feet in altitude. The altitude of the crest of the range increases southward, and culminates in Santiago Peak, which is 5,680 feet in height. Much of the higher part of the range is so rugged as to be reached with difficulty, even on foot, and many slopes are practically impassable.

Up the steep escarpment from north of Lake Elsinore a highway has been constructed across the range. Along this highway the granite rock that forms the core of the mountains is exposed, and also the metamorphic rocks that were intruded by the molten magma. The granite and the metamorphosed rocks have been broken into blocks which show crushing and polishing (slickensiding) due to the fault movement. Near the top of the mountain a striking feature is that of giant blocks of granite in the form of huge boulders which have been formed by erosion and chemical action. These immense granite blocks, rounded by wind and weather, project above the surface as boulders. These form an outstanding feature of this mountain region and are well worth the climb over this mountain highway to see.

The highway continues to the west through the gently rolling country with its many scattered boulders of granite projecting through the meager coating of residual soil, and passes downward into San Juan Canyon. Contact between the granite and the metamorphic slates will be observed. At San Juan Hot Springs a series of hot springs come up along fissures close to the line of contact between the granite and the Triassic slates. Continuing down San Juan Canyon Cretaceous and Tertiary formations are crossed, and broad terraces which show evidence of many successive uplifts.

Region Broken by Many Faults

At the south end of the Santa Ana Mountains Temecula River crosses the south end of the range where the mountains give way to the San Juan Capistrano basin, 40 miles south from the Narrows at the north end of the range. No other stream crosses the uplifted range throughout the 40 miles of its length till the Santa Ana River is reached. The mountain range is cut across by the Santa Ana River in the Narrows, a canyon which divides the main range from the Puente Hills and San Jose Hills to the north, these hills being regarded as the continuation of the Santa Ana Range. From the axis of the Santa Ana Range, high above the Coastal Plain, the slope toward the west is gentle. Toward the east from the crest of the range the slope is very abrupt to the Elsinore Valley, the descent to which is down the fault scarp along which the range was uplifted. The high crest of the range has been much rasped and eroded by wind and weather, and the ancient intruded magma, long since cooled and crystallized to hard granite, is exposed at the surface. The eastern steep fault-wall is very rugged. Whether movement along the fault-plane is still going on we do not positively know. That movement has occurred in time geologically recent is known. Whether the mountain crest is still being uplifted we do not know. The mountain range is young as a geologic feature of the landscape. Faults along which no movement has occurred within historic time such as to cause earthquakes are spoken of as "dead" faults. Movements on the San Andreas, San Jacinto, Elsinore, and Inglewood faults have occurred within recent historical time. The Elsinore fault, which extends along the northeast base of the Santa Ana Mountains, was one of the controlling factors in the origin of the mountain range. The Elsinore fault splits into the Whittier and Chino faults a few miles southeast of Corona. The Whittier fault crosses the Santa Ana Canyon about midway of the canyon, and the Chino fault is less than a mile east of the upper end of the canyon. Evidence of the uplifting of the land near these faults is seen in terrace gravels along the canyon high above the level of the stream, remnants of an old floodplain of the river that has been uplifted (but not crumpled or folded). That these gravel terraces were elevated in comparatively recent time is shown by the occurrence of known Quaternary (San Pedro) beds in undisturbed layers west and north of Horseshoe Bend near the west end of the canyon. There is no evidence of recent disturbance in these deposits. Whether the faults are permanently "dead" or not we do not know. Whether there was any uplifting of the mountains during the earthquakes that occurred in recent time we do not know. The deposits mentioned show no disturbance, which is negative evidence that the mountains have not been uplifted since the deposits were laid down. The Perris Plain and adjacent regions were, however, "shaken." The uplifting of a range of mountains, such as the Santa Ana Mountains, implies that there has been movement in the crust of the earth of considerable magnitude along the Elsinore, Whittier, and Chino faults in time past. Whether the time is entirely *past* or not we do not know.

Mountains of Southern California Part of Great System

Thus it will be seen from this hasty glance at the mountains that Southern California is marked by mountain ranges of great extent. From the boundary of Mexico, where the International Boundary line crosses the great Peninsular Range, mountain ranges form a somewhat broken line along the Pacific Coast throughout the length of the State. Northward from the ranges of southern California the Coast Ranges are continuous, though somewhat brokenly, to the Siskiyou Mountains of northern California and Oregon, thence as the Coast Range Olympics of western Washington, and the Coast Range (Island Ranges) of western British Columbia, to the great mountains of Alaska. Whether or not the igneous granitic rocks that so extensively underlie and form the bed-rock or cores of the ranges represent one great earth upheaval that embraced the entire western side of the continent may only with some hesitation be asserted. But that a great earth convulsion, or series of convulsions, occurred—so far as is known probably in Jurassic time—seems established. That tremendous disturbances have occurred that have resulted in the fracturing of the crust of the earth and the uplifting of mighty mountain ranges by the intrusion of molten rock as vast batholiths, now cooled to crystalline granite, there can be no question. What we do not know about the geologic activities involved in the history of the earth during the ages would make a vast library as compared with the little volume of what we know. Diligence in the study of the earth and inquiry into earth processes will add to our knowledge. California is a State of exceedingly complex geology. If any region of the United States has a more complicated geologic history the writer does not know of it. Because the geology of California is complicated it is interesting. But it is interesting more because of the bearing that the great geologic events have upon human activities and the progress of civilization upon the earth. The industries of Agriculture, Forestry, Petroleum, and Mining of California are determined by geology. The great harbors of the coast owe their existence to geologic structure. The fact that the geology of California is complicated determines the wide diversity of activities that characterize the State.

Chapter XVIII

THE VALLEY OF THE SOUTH

The Great Valley of the South a Structural Basin

Lying south of the San Bernardino and San Gabriel ranges, embracing the rolling plain between the San Jacinto and Santa Ana mountains, is a vast structural basin called the Valley of the South. It is cut off abruptly at the north by the fault walls of the San Bernardino and San Gabriel ranges, and is sharply delimited on the east by the San Jacinto fault and on the west by the Elsinore fault, which forms the eastern wall of the Santa Ana Mountains. Transversely across the northern side of the great basin lies the sunken San Bernardino Valley, which includes the deeply depressed San Bernardino Basin, the Riverside basin, and the Chino and Cucamonga plains. To the west the alluvial San Gabriel Valley extends to the Los Angeles Basin and the Santa Ana coastal plain, beyond the low Puente, Merced, and Repetto hills. The San Jose Hills, regarded as the northern continuation of the Santa Ana Mountains, project into the valley northeast of Pomona, about 25 miles from the Pacific coast. Southward from the San Bernardino Valley and Riverside an undulating plain extends to Lake Elsinore and the towns of San Jacinto and Hemet, and includes the broad Perris plain. This is an old worn-down plain, interrupted by ridges and knobs of granite, "stumps" of granitic and schistose rocks, remnants (monadnocks) of an "old" landscape. The whole region from the northern end of the San Jacinto mountains westward to the Puente and San Jose Hills was at one time not very far back in geologic history an undulating worn-down plain (a peneplain). The granitic knobs and ridges are the stumps of mountains, remnants of the old landscape. The "floor" of the present valley, that is, the bed-rock below the filling of alluvium and the crumpled and folded clays and sandstones, is hundreds of feet below the present surface, estimated to be as much as 3,000 feet in some of the lower places.

A Worn-down Plain of Erosion

Back in Pliocene time (late Tertiary)—about six or seven million years ago—southern California was considerably nearer

FIG. 74. Cloister wing, Mission Inn, Riverside.

sea level than now. The mountain ranges, San Bernardino, San Gabriel, San Jacinto, and Santa Ana, with the San Bernardino Valley and Perris Plain between them, and differing greatly in elevation, once formed a continuous surface. It may seem strange to think of the top of the San Bernardino Mountains as part of a plain that once extended to Lake Elsinore and the broad plain about Perris. The San Bernardino Mountains were uplifted north of the San Andreas fault, but south of the fault where the San Bernardino Valley is now, the surface was depressed below sea level.

Crumpled Clays and Sandstones Underlie the Present Valley Alluvium

Somewhat later in Tertiary time, after the fracturing of the earth along the San Andreas fault and the subsiding of the San Bernardino Basin, a great area to the south was a lowland region but little above sea level. The broad valleys were occupied by lakes, of brackish or fresh waters. The great mountain ranges that now surround the area had not been uplifted more than slightly as compared to their present height. During a long time sediments were carried from the adjacent higher lands (which were later to be uplifted to become the present mountains) and deposited to great thickness over the lowland. These were the fine-grained sediments which are now the clays and sandstones that form the crumpled, bent, and wrinkled beds that lie buried beneath the "valley fill" which makes up the present land surface south of the San Bernardino Valley, as about Riverside. The sediments were made up of the rock waste of the granitic rocks which form the cores of the present mountain ranges, and wash from the hills and peaks which dotted the ancient worn-down plain. Water occupied the lowest valleys and spread widely over the land. Within it islands of granitic and schistose rocks rose, as the Box Springs and Lake View Mountains now rise above the Perris and San Jacinto plains, and as the Jurupa, Slover, Rubidoux and other granitic and schistose mountains and hills farther north rise above the surrounding plain.

Fossil Remains of Extinct Animals Found

An interesting assemblage of animals roamed these plains in Pliocene times, animals that have long since ceased and disappeared from the earth. Grazing over the open stretches were droves of small light-limbed horses (Pliohippus), several species of camels, large and small antelopes, herds of deer, pigs, and four-tusked elephants. Also in the forests lived sabre-toothed cats, ground-sloths, wolves, and bears of greater size than any known today, exceeding in size the Alaskan Kodiak bear, the largest bear of modern times. These animals are all gone. They are known only from fossil remains preserved in the sedimentary rocks. Very interesting fossil remains of animals now extinct have been obtained by the University of California from the Pliocene (late Tertiary) formations, called the Mt. Eden beds, that flank the San Jacinto Mountains at their northwest end. These deposits extend from the head of San Gorgonio Pass to the eastern end of the San Bernardino Valley. These beds are made up of sandstones and shales, with coarse conglomerate deposits. San Timoteo Canyon, heading near Beaumont at the west end of San Gorgonio Pass, cuts through this series of loosely consolidated beds, and due to the high gradient of the stream caused by the San Jacinto Mountain uplift, the canyon has been deeply eroded, and side streams entering the main gorge have dissected the surface to a typical badlands topography.

About six miles south and east of the Mt. Eden beds, where fossil remains of extinct vertebrate animals were found, and east and southeast of San Jacinto and Hemet, occur what are known as the Bautista beds (early Quaternary—Pleistocene). The materials of the Bautista deposit are markedly different from those of the San Timoteo beds. Finely stratified sands and clays, with entire absence of the cobbles and conglomerates of the San Timoteo badlands, make up a conspicuous part of the beds. It is in these clays and fine sands that the best of the Bautista fossil material has been secured. The Bautista deposits, it is considered, offer a rich field for the collection of fossils.

When the disturbances occurred by which the San Bernardino Mountains were raised north of the San Andreas fault, and the San Bernardino Basin had been depressed below sea level, folding and crumpling of the rocks occurred. The softer clays and sands south of the San Bernardino Valley yielded to earth compression and were folded and crumpled. The Perris plain was uplifted somewhat, but more in the southern part. The faulted block comprising the Perris plain was rotated toward the north, that is, it was elevated in its southern portion and tipped down at the north. The granite which forms the floor of the Perris plain being more rigid resisted folding and moved as a block.

Fold in Rocks Forms Dam Across Valley

A wrinkle or fold that has great significance in the San Bernardino Valley extends from the San Jacinto Mountains northwestward along the line of the Badlands between the San Timoteo Canyon and the San Jacinto Valley. The rocks that

Photo by W. C. Mendenhall, U. S. Geol. Survey

Fig. 75. Bunker Hill Dike. Not a dike but a fold. Near San Bernardino.

were folded into this arch are soft shales, sandstones, and gravelly alluvium, much like that deposited by rivers today in the San Bernardino Valley. This is known as the Bunker Hill Dike (though it is not in any proper sense a dike). This clay and gravel ridge forms an effectual dam across the valley behind which waters percolating through the stream wash accumulated in the upper basin are held until they rise as springs and flow over the dam to sink again in the gravel and sands below. This furnishes the key to the cienaga which is known as the San Bernardino Basin.

The series of crustal movements which caused the folding and crumpling of the clays and sands resulted also in the further uplifting of the San Bernardino Mountains so that they stood well above the adjacent valleys, but not to their present height by many hundreds of feet. Mountain streams became active. They cut deep canyons, and the products of erosion were carried to the lowlands as they are today. The stream wash was widely distributed over the lowlands south of the mountains. Boulder beds, sand and gravel beds, and clays were laid down in alternating layers in alluvial fans until many hundreds of feet of "valley fill" were laid down.

San Fernando Formation Marks Close of Tertiary Time

The Fernando epoch is generally regarded as marking the close of the Tertiary Era. This was a time of great and widespread disturbance. The period of deformation is definitely fixed by the fact that Fernando and all older formations are folded, bent, and crumpled, whereas the younger Quaternary formations remain practically undisturbed, and rest horizontally upon the eroded and truncated edges of the older formations. As a result of the folding of the rocks the Fernando strata are mostly tilted at considerable angles from their original horizontal position. Dips of 75 to 85 degrees are common, and in places the strata stand in a vertical position.

The Fernando formation consists of sandstones, shales, and clays, with some coarser conglomerate. East of Olinda a section 5,000 to 6,000 feet in thickness is exposed, sandstone and sandy clay, with conglomerate. Farther east, as about Riverside, the formation contains comparatively little sand, and forms a generally impervious clayey substratum below the overlying Quaternary riverwash or "valley fill." Farther east beds of sandstone, shale, and clay have been uplifted and form the Redlands Heights and Smiley Heights mesas. Southward the Perris Plain is but thinly veneered with Fernando clays and sands, and weathered knobs of the granite bed-rock project as rugged wind-eroded boulders and crags.

San Bernardino Range Uplifted

Finally, as a climax of the great disturbances which have so markedly determined the present character of the landscape, movement again occurred along the many faults along which disturbance had occurred during the preceding periods. The San Bernardino Mountains were at this time raised to their present height. The earlier deposited alluvial wash was uplifted into the sloping mesas of Smiley Heights and Redlands Heights, and the coarse boulder beds south of San Timoteo Canyon were uplifted so that they now dip markedly toward the north. The San Bernardino Valley subsided still lower than before. Stream activity was renewed and deep canyons were cut. Fans were built at the mouths of streams. The great alluvial mantle, spoken of as "valley fill," which makes up the present surface of the San Bernardino Valley, was deposited, and forms the broad expanses of fertile lands for which the great Valley of Southern California is noted.

The Fernando epoch is regarded as marking the end of Tertiary and the beginning of Quaternary time. The Fernando epoch was marked by disturbances, with great crumpling and folding of the rocks, and vast crushing along the lines of faults. The deposits made by streams since the close of the Fernando epoch are in horizontal position as deposited, or in gently sloping layers where thrown down by streams in alluvial cones or fans. The Quaternary deposits, which are widespread throughout the valley from the Badlands on the east westward to the narrowing of the valley northwest of Pomona, and beyond in the San Gabriel Valley to and including the depressed faulted valley of La Canada, constitute the later alluvium or "valley fill," as distinguished from the "older alluvium" represented by the clays, shales, and sands of the earlier Fernando epoch.

The Great Valley a Faulted Sunken Basin

South of the foot of the great escarpment that forms the south wall of the San Bernardino and San Gabriel ranges lies The Great Valley of southern California. Its depressed faulted bottom is deep below the present surface, and the nature of the bed-rock floor is not known, as it has not been reached by the deepest wells. It is probably 1,000 feet or more below the present surface of the alluvial valley fill. East of the Bunker Hill Dike, east of the washes of Lytle Creek and El Cajon Canyon, the valley is known by the name of the mountain range that overhangs, San Bernardino. To the west the valley is known as the San Gabriel Valley. It lies on the depressed floor below the wall of the uplifted San Gabriel Mountain range. The San Gabriel Valley extends westward as the La Canada Valley, the bottom of which is a depressed fault block which cuts off the San Rafael Hills and Verdugo Mountains from the San Gabriel Range.

Throughout its whole length this sunken valley floor is buried beneath the porous sediments which have been carried down from the high mountains through canyons that have been cut by torrential streams which descend the steep faulted scarps of the mountain ranges. At the mouth of each canyon the stream builds a cone or alluvial fan from the detritus eroded from the rocks of the high land. The cones or fans are built up of layer upon layer of rock fragments of all conceivable sizes from boulders weighing many tons to the finest sand, silt, and clay. Naturally the coarser materials and heavy blocks of rock are thrown down in the mouth of the canyon at the apex of the cone or apron. Succeeding storms may and do result in unusually powerful torrents of water, and these may and do pick up and move further down the slope of the cone or fan very large boulders as well as gravel and sand. Thus the cones tend to flatten out apron-like farther from the mouths of the canyons. When it is considered that the carrying power of a stream increases as the sixth power of its velocity it will be readily seen how boulders of tremendous size may be moved by running water. Doubling the velocity means increasing the carrying power 64 times. The velocity of a mountain stream may be easily imagined to be three times as great following a storm as during ordinary time. This would mean increasing the carrying power more than 240 times. If a stream having a velocity sufficient to move a rock weighing one pound were doubled twice, that is, its velocity increased four times (which could easily be imagined in mountain torrents) it would be able to move a boulder weighing more than two tons.

Alluvial Fans or "Washes" Formed in Valley

During the long time since the mountains were uplifted streams have been cutting canyons and building cones or fans at their mouths on the floor of the great depressed valley. Fans formed by the great series of mountain streams have spread and merged together so that a continuous floor of porous valley fill or alluvium now extends from the east end of San Bernardino Valley to the valley of La Canada between the Verdugo Mountains and the San Gabriel Range, and westward to the San Fernando Valley (another faulted basin).

The San Gabriel River descends from the mountains through a deep canyon and crosses the San Gabriel Valley. It has not merely built a cone or fan of boulders, gravel, sand, and clay but it has spread a vast field of sand and gravel far to the southward, known as the San Gabriel Wash. In a similar manner San Dimas Creek debouches at the mouth of its canyon upon the San Gabriel Valley at its narrowest point north of the San Jose Hills, and has spread a vast fan or "wash" south and west to Vineland, and its waters in flood seasons cross the porous plain to join the waters of the San Gabriel River by which it finds passage to the sea. Streams of other canyons, as San Antonio, Cucamonga, Deer, Day, and San Sevaine have in like fashion built up cones at their mouths which have been broadened out as fans till they have coalesced and form a continuous alluvial plain, and this remarkable plain, extending from La Canada on the west to El Cajon Canyon on the east is known as the San Gabriel Valley. This alluvial valley floor extends eastward from the Lytle Creek and El Cajon washes to the great Santa Ana and Mill Creek washes at the east end of the San Bernardino Valley.

The San Bernardino Basin

The eastern end of the San Bernardino Valley is called the Basin. The north wall of the Basin is formed by the San Andreas fault. The Perris faulted block was tilted downward at its northern end. The axis of the Basin is the line of meeting of the slope from the fault with the northward dipping slope of the granitic Perris Plain. Along this axis passes the Santa Ana River.

The depth of the Basin to the underlying granite bed-rock is not known. The Basin has been depressed below sea level and filled with detritus borne by the Santa Ana River, Mill Creek, and San Timoteo Creek, and other smaller streams. Wells sunk to a depth of 1,000 feet have not reached the bottom, but the floor of the Basin is doubtless granitic rock such as forms the floor of the Perris Plain to the south. The coarse detritus that has been borne from the mountains by torrential streams furnishes a vast storage reservoir for water. The Bunker Hill Dike acting as dam holds back the water that penetrates the alluvial washes or fans of the debouching streams. The Basin thus becomes filled with water, and under pressure of the head due to the higher level of the washes this rises as springs, and flows over the Bunker Hill Dike. Such a basin, in a semi-arid region, filled with porous detritus and saturated with water, was called by the early Spanish settlers a "cienaga," a name which has persisted to our time.

The Santa Ana an "Antecedent" River

The Santa Ana River originates far in the San Bernardino Mountains. It is a torrential stream even in its upper reaches during the seasons of heavy precipitation, and it has cut a deep canyon in hard rocks. The stream makes a tremendous fall to the plain of the San Bernardino Basin where its waters spread over a broad alluvial fan or apron. This is the Upper Santa Ana Wash, a rough expanse of boulders, gravel, sand and silt over which flood waters surge with great force. In a similar manner the waters of Lytle Creek, El Cajon Canyon, Mill Creek, and San Timoteo Canyon enter upon the Basin plain over alluvial fans or washes, and join with the waters of the Santa Ana above the Bunker Hill Dike. Below the "dike" and before the river enters the great canyon that has been cut through the north end of the Santa Ana Mountains it is joined by the waters of Temescal Canyon from the south, and Chino Creek and numerous smaller streams from the north. Below the dike the river winds among granitic hills near Riverside, and 25 miles below enters the Narrows at Rinçon, where begins the canyon through which the river flows for 15 miles, when it debouches upon the Downey Plain before crossing the Santa Ana Coastal Plain to the ocean.

Below the Bunker Hill Dike the waters during much of the year sink into the porous gravels and the river's bed becomes a dry streak of gravel and sand. In flood seasons it is a wild and destructive raging torrent. In times past it has meandered over a wide terrane. Terrace benches and eroded channels on the plain of the Cucamonga Valley give evidence that the river was there during a time of earlier meandering. The middle basin is interrupted by protrusions of granite bed-rock. The granite floor extends along the southern part of the basin from Colton to Corona. Since Fernando time, when the older alluvial deposits were crumpled and folded, the river has cut its channel through granitic areas and follows the lowest parts to its entrance into the canyon below. It is thought that at an earlier time the river flowed north of the Jurupa Mountains. During more recent time the river has shifted its course to the south of these mountains.

Below Rinçon steep rugged hills of hard rock form the walls of the canyon. The river maintained its course across the rising mountain ridge, cutting down its channel as the mountains were uplifted. Terraces as much as 200 feet above the present river bear testimony to the uplifting of the land and the persistent cutting of the river to maintain its grade in its progress toward the sea. The Santa Ana River is an "antecedent" river. The river became established before (antecedent to) the present conditions, and it follows now the path that it followed before the uplifting of the land. It is "antecedent" in that it keeps its way to the sea despite obstructions raised in its path. It was there before the land forms were developed and it has maintained its course in spite of them. It was there before and is still there, part of the year a "lost" river pursuing its way below its own bed, and at flood times a roaring, rampant destructive giant resistlessly sweeping toward the sea.

How Old Are the Hills?

"As old as the hills" is a familiar expression. How old are the hills? Movements along fault lines have brought old deep-lying formations high above "young" formations. The Santa Ana Mountains were uplifted to their present height only recently geologically. The San Bernardino Mountains were elevated to their present height probably within the era in which we live—the Quaternary. (They may be still rising.) Are these mountains then old or are they young? Over in the Temescal Valley east of the Santa Ana Mountains movement along fault lines in comparatively recent time cut off drainage and caused a lake to form. In this lake sediments washed from

FIG. 76. St. Catherine's Well. Mission Inn, Riverside.

the adjacent higher lands were deposited. These fine sediments are the clays that are now the source of the material from which the terra cotta works at Alberhill have been developed. The clays have been eroded into hills. Are these hills old or young?

Mount Rubidoux stands up near Riverside as a bold rugged granite monument. It is apparently a part of the granite bedrock that underlies the San Bernardino Valley and the hill-dotted plain to the south (Perris Plain). Are Mount Rubidoux and other granite monadnocks that stand above the intervening valleys old or are they young? West of Riverside, near Corona, a very old granitic rock, technically known as granodiorite, is quarried from an old worn-down mountain. The granite was a molten magma in (probably) Jurassic time; a molten liquid mass that was forced up as a batholith under the rocks that originally existed here. The overlying roof rocks have been removed by erosion during long ages, and the mountain stump which is now being quarried, and other granitic peaks and ridges, are remnants of the once molten mass that long ago cooled and crystallized under the overlying roof of ancient sedimentary rocks. Are these crags and peaks then old or young? They are remnants that are left after a long time of erosion. As they stand they represent a late chapter in the long story of uplift and erosion. As crags, peaks and ridges they are young. As rocks they are very old.

A few miles west of Riverside (at Crestmore) are some hills in which limestones occur—highly metamorphosed by heat and chemical activity related to the molten magma that has been spoken of. The base of the hills—the bed-rock underneath—is the rock technically called granodiorite, which is the "granite" underlying the mountains. The limestone is metamorphosed to a highly crystalline marble. No fossil remains have been discovered, and the age of the limestone is therefore not known. If fossil remains were once there, entombed in the sediments, they have been utterly destroyed as to their original forms by the extreme metamorphism. One hill is called Sky

Blue Hill because a distinctively blue crystalline limestone occurs in it. In the other, called Chino Hill, the limestone is a pure white marble. Limestone occurs as one of the sedimentary formations in the San Bernardino Mountains. The San Bernardino Mountains have been far uplifted above the Riverside plain and all the San Bernardino Valley. Limestone occurs in Sky Blue and Chino Hills. Is is reported to occur also in other hills a few miles west, and probably in Slover Mountain near Colton. Are these limestone deposits—now metamorphosed out of all resemblance to their former character—remnants of a widespread formation that formerly existed over the whole valley, a part of the ancient roof rocks that were uplifted by the intrusion of the molten granite magma, and now remain as the caps of worn-down mountains and hills? It would seem so.

Are the Limestone Hills Young or Old?

Are these limestone-capped hills then old or young? At their bases is the very old granitic rock. But the peaks, like Mount Rubidoux, have just been formed—by erosion. They are in process of "forming" now, that is, they are being worn down all the time. They are being "made" into peaks by wind and weather at this very time, every day. Are the hills then old, or are they young—just being formed?

The blue crystalline limestone, blue calcite, that occurs in Sky Blue Hill, is a somewhat rare mineral. It occurs elsewhere in California. (It has been reported from mountains in the Mojave Desert.) The cause of the blue color is not known. There are also pale pink and green limestones in the Sky Blue Hill. The mineral occurs as crystals of calcite (calcium carbonate) in seams, bands, and patches mixed with other metamorphic minerals. The Sky Blue Hill limestone capping was subjected to later metamorphic action by intrusion of highly heated igneous rock and the action of mineralized solutions.

The beautiful blue calcite crystals occurring in the Sky Blue Hill were formed out of mineralized solutions. The two hills, Sky Blue and Chino, differ greatly in the effects of metamorphism. The limestone of Chino Hill was converted into a white marble and is little mixed with other minerals. It was not invaded by the later invasion of igneous rock, as was that of Sky Blue Hill, where the blue calcite is mixed with various metamorphic minerals.

The occurrence of the great number of minerals in the highly metamorphosed limestone of these hills is a subject of interest (more than 50 minerals have been described from this locality). Our purpose is study of the geology of the formations and not the minerals as such. The metamorphism of the limestone rock was a geological event. It occurred long ago from the great heat and pressure of the intruded molten rock. The minerals were formed in the process of metamorphism by combination of the chemical elements that were in the geologic formations.

The limestone rock in the hills is an old formation. It was formed on a sea bottom long long ago. When the hot liquid magma was intruded into it and the minerals crystallized, that also was long ago (Jurassic time). But the "hills" were not there then. The land had not at that time been eroded as now. The limestone extended in great beds far over the region. The limestone was part of a great formation that extended over many miles. Erosion during long ages carried away the limestone. Streams flowed between hills, and the hills that we now see are a little of the land that was not carried away. The limestone rock is old, but the hills are young. They were formed recently—geologically yesterday and today.

The mind can hardly grasp the great length of time. The broad plain, of which these hills formed a part, was eroded into hills and valleys. The hills were slowly worn down and carried away. The hills that we see today are what is left. They are remnants of the ancient plain. They were being worn away every year before the quarries were opened. They would soon (geologically) have been entirely worn away. No, the *hills* are not everlasting! The rocks are *old*. The hills, as hills, are young features of the landscape. They are not the "eternal hills" of folklore imagination. Mountains are an evanescent feature of the landscape. Hills are ephemeral. They tarry but a day geologically in the great process of the evolution of land forms. "As it was in the Beginning; is now; and ever shall be" was not written of the mountains and hills geologically. When the Prophet sang this choral chant he was evidently not thinking of the geologic history of the earth.

Chapter XIX

RANCHO LA BREA AND THE LOS ANGELES BASIN

The Los Angeles Basin is an unique part of the State of California. It embraces an area of about 1,000 square miles. The Basin is bounded on the northwest, north, and northeast by the Santa Monica Range, the Verdugo Mountains and the San Rafael Hills; on the southeast by the Repetto Hills; and on the south and west by the Pacific Ocean.

The mountains served as a source of detritus that was carried by streams to the margin of the continent. What is called the basin has been a basin for a long time. This "time" is represented by two great periods, the Miocene and Pliocene, and indeed by a third period, the Quaternary or Pleistocene, which immediately precedes modern or Recent time. Erosion of the upheaved masses furnished the sediments that make up the formations by which the basin has been filled. These sediments, originally laid down in essentially horizontal layers, have been disturbed by deep-seated forces by which they have been much folded and faulted.

The present surface formations, of Pleistocene age, consist of gravel, sand and clay, gravel being the most predominant. Deep below the present surface are strata of gravel, sand and shale, of Miocene and Pliocene age, having a total thickness of 11,000 feet, or more than two miles. This astounding thickness of sedimentary deposits represents the "wash" from the mountain highlands which border the basin on the north and northeast, borne into the shallow sea, the bottom of which slowly sank as the sediments accumulated. That this has been a sinking coast during most of the long ages of Miocene, Pliocene, and Pleistocene time is attested by the great thickness and character of the formations revealed in deep borings.

The Los Angeles Oil Fields

The Los Angeles oil fields lie within the basin in which the Miocene and Pliocene sands were deposited. The occurrence of petroleum in the porous sands is due to complicated processes of distillation of oil, probably from the innumerable bodies of minute organisms that make up the diatomaceous shales that occur in the formations, and the complex geological changes by which the formations have been upheaved, bent, and fractured by the not well-understood forces deep in the earth by which the rocks have been changed.

Southern California has been much rent and broken by faults. The character of the Los Angeles Basin has been much changed by faulting of the rocks. Faults, or breaks in the rocks, caused by stresses in the crust of the earth have made it possible for oil, distilled by heat and pressure from organic remains in the rocks, to be drained from where it was formed, and to accumulate in porous sand formations.

Complex Structure of the Los Angeles Basin

The structure of the basin, which at first seems simple, is in reality somewhat complex. As has been stated, mountains lie to the north and east. The Verdugo Mountains, San Rafael Hills, the Repetto Hills, and the Puente Hills, represent an axis connection between the Santa Monica Mountains to the northwest and the Santa Ana Mountains to the southeast. These mountains or ranges of hills that intervene between the two principal ranges mentioned are upheaved masses, blocks of the earth's crust, bounded by faults or breaks in the rocks. Erosion of the upheaved masses contributed to the sediments that make up the formations by which the basin has been filled. These sediments, originally laid down in essentially horizontal layers, have been disturbed by deep-seated forces, probably the same forces that resulted in the upheaval of the mountains.

The Los Angeles Basin is bordered on the north, northeast, and east by ranges of mountains and hills, elevated and intricately folded and faulted, composed of rocks ranging in age from Triassic to Pliocene. These adjoining upland areas received most of their present elevation as a result of crustal movement during the Quaternary period. The surface formations of the Los Angeles Basin are of Quaternary age, in part land laid deposits (terrestrial) and in part marine, laid down as sediments when a shallow sea covered the land.

Deformation, that is, upheaval, warping and breaking of the rocks of the earth's crust, occurred in Quaternary time, and as a result most of the anticlines and faults in the rocks of the basin, as exposed at the surface, are elongated low hills of late Pleistocene rocks. In many places these are marked by prominent scarps or cliffs of more or less ragged rock. The Baldwin Hills (Inglewood), Dominquez Hill, and Signal Hill (Long Beach) are examples of such anticlinal hills.

The dominating landscape feature of the northern Los Angeles Basin is the Elysian Park hills. This region is structurally an anticline. It is an elongated dome the rocks of which on the southwest dip gently to the southwest under the Los Angeles basin, but slope abruptly to the Los Angeles River on the northeast.

Folds and Faults in the Rocks

Running in a generally northwest direction across the basin are folds or arches of the rocks. Two major lines of anticlinal folding in the Los Angeles Basin are known as the Newport-Inglewood-Beverly Hills uplift and the Coyote uplift. The former is generally considered to have resulted from movement along a deep-seated fault extending from Newport Beach northwestward across the basin to Beverly Hills and the Santa Monica Mountains. These major lines and adjoining ones of lesser magnitude contain 17 oil fields, most of which are on more or less perfectly formed anticlinal folds (H. W. Hoots).

The basinward dipping rocks along the northern and northeastern borders of the Los Angeles Basin are commonly separated from the adjoining upland areas by high-angle faults or fault zones. Such fault zones pass along the southern base of the Santa Monica Mountains, through Hollywood and Los Angeles, and along the southern border of the Puente Hills. The fault which marks the southern boundary of the Puente Hills, it may be remarked in passing, extends southeast forming the east boundary of the Santa Ana Mountains, and is known as the Whittier fault. Oil has been trapped within and just south of these fault zones in Pliocene and Miocene rocks that have been bent into minor folds since they were laid down. Surface seepages of oil along fault zones and along outcrops of sand-rock early attracted the attention of prospectors and resulted in the production of oil as early as 1880 (H. W. Hoots).

The Los Angeles oil fields lie in a zone extending in a generally east-west direction immediately north of the business center of the city. The axis of the Los Angeles anticline extends from west of Los Angeles River west of Sunset Boulevard and northwest of the Sisters' Hospital almost in a straight line to a point in Benton street 200 feet south of First. Near this point the axis of the anticline bends and passes to the northwest toward Colegrove. The zone of faulting and fracturing in which the productive oil wells occur lies to the south of the axis of the anticline in a generally east-west direction. The anticlinal axis is an expression of a deep-seated fold in the rocks, which dates back to Miocene time and the disturbances which marked that period in southern California. The fault zone in which the oil fields occur dates from Pleistocene time when the Miocene and Pliocene sandstones and shales were faulted and shattered.

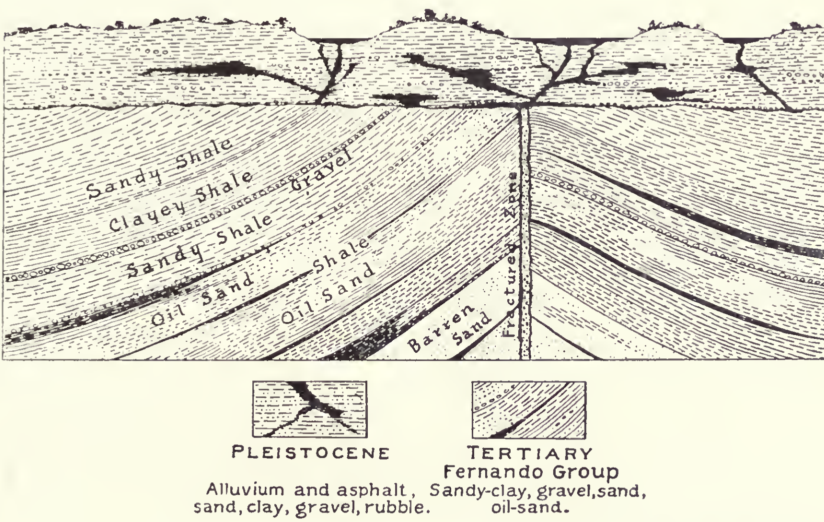
Oil Fields Determined by Structural Features

The oil fields occur in a zone of faulting which lies a few miles north of Los Angeles. What is called the eastern field extends from the vicinity of the Catholic Cemetery at Buena Vista and Sutherland streets westward to the Sisters' Hospital. Lying west of the Sisters' Hospital and extending westward to a line running north through West Lake is the central field. Extending north and west from the region about the Baptist College to the south of Colegrove is the western field. To the southwest is the Salt Lake field, in which the tar pits of Rancho La Brea are located.

The structural features of the region about Los Angeles, which determine the location of the oil fields, represent two systems of disturbances. The older, of Miocene age, consists primarily of folds, with many minor faults. The younger, in which faults predominate, is of Pleistocene age. The structure of the Los Angeles Basin as it pertains to petroleum is related to the later system of fractures. These trend diagonally northwest and southeast across the basin. The larger oil pools are associated with anticlinal structures along fractures or fault lines. The oil pools occur upon short anticlinal folds which join the main fold or fault at angles in stair-like fashion (what geologists call *en echelon*). The anticlinal structures along these fractures (both the main faults or folds and the shorter branches) are apparently a result of predominantly horizontal movements in the rocks which probably occurred at the same time with the general mountain-building disturbances which occurred in southern California in late Pliocene and Pleistocene time. According to Eaton* the predominantly horizontal folds and faults in the deep-lying rocks are probably the result of crustal movements deep in the earth which have resulted in a relative movement or shifting of the rocks of the basin from southeast to northwest along the coast and from northwest to southeast upon the landward side; in other words, deep-seated forces in the earth have caused a twisting or whirling or rotating of the rocks of the basin, as though the rocks of the basin

* J. E. Eaton, "Geology of the Los Angeles Basin," A.A.P.G. Bull. 10.

had been turned as on a pivot clock-wise from left to right. The deep-lying folds or dome-like structures which have been the sources of the productive wells are generally represented by surface elevation. These elevations range from the elongated hills of Dominquez and Long Beach to the low swells of Richfield and Huntington Beach. The surface domes closely follow the sub-surface structure.



Courtesy Los Angeles Museum Publications

FIG. 77. Cross section showing geologic structure of formations at Rancho La Brea during period of miring of Pleistocene animals and plants. From section in Salt Lake oil field, after Arnold (U. S. Geol. Survey). (After Stock: Los Angeles Museum Publications, No. 1).

Oil Accumulated through Joint Cracks

The accumulation of oil in pools and in porous sand rocks has probably been facilitated by the fracture or cracking of the rock strata into joints. All the rocks in the Los Angeles district are intersected by numerous joint cracks. In many places a slight displacement by slipping has occurred. These tiny cracks in the rocks are thought to have played an important part in the accumulation of oil. The joints or cracks seem to have made possible the movement of oil from whatever its original source upward into the porous sandstone. Had it not been for the joint cracks it would seem to have been impossible for oil to pass through the impervious beds and so become concentrated in pools in the higher porous sandstone formations.

Location of Rancho La Brea

About seven miles west of the business center of Los Angeles, in what is known as the Salt Lake oil field, on Wilshire Boulevard west of La Brea Road, are located the far-famed tar pits or asphaltum lakes of Rancho La Brea. These are pools or seepages of petroleum tar or pitch-like oil oozed from depths in the rocks probably by gas pressure. The pits or oil pools are distributed over an area embracing 32 acres, and known as Hancock Park, from the donors who gave the grounds to Los Angeles County.

These pools are noted for the great number of relics of animals and plants that have been recovered by excavation from the deposits of asphaltum. Between 400 and 500 kinds of animal remains (species, genera and families), and many fragments of trees, and seeds and leaves of plants, have been recovered, many of them representing species that no longer live upon the earth.

The pools have existed during and since Pleistocene time. Animals that lived in the long past were entrapped in the sticky mire of the pools, and skulls and bones, hard parts of many species, have been recovered, and are now preserved in the Los Angeles Museum, the Museum of the University of California, and in other institutions.

Asphalt Beds Formed in Oil Pools

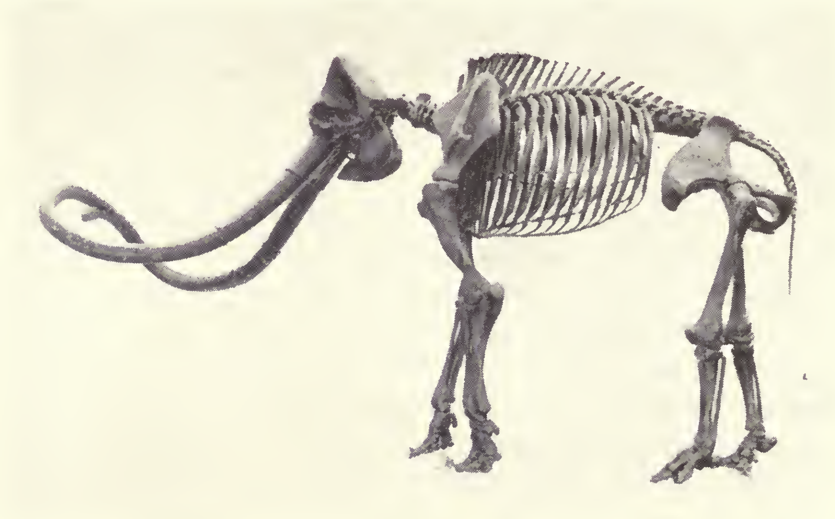
Pools of oil, into which dust and other debris have been borne by the winds, formed during Pleistocene time, the geologic age preceding Recent or modern time, have developed into beds of asphaltum, thousands of tons of which have been removed for commercial uses. A tooth was discovered in the year 1875, and this led to exploration and search for other remains. Beds of skulls, teeth, and bones were exhumed, preserved by the asphaltum in which they had been buried. Trunks of trees, many fragments of wood, and even leaves and seeds of plants have been so perfectly preserved that the minute tissues could be studied.

Animals Trapped in Tar

It is noteworthy that so many species of carnivorous animals have been recovered, which suggests that predaceous animals were attracted to these pools in search of prey that had been entrapped and mired in the pools. Specimens of skulls and other bones of large cats, bears, wolves, and other flesh-eating animals that are now extinct have been recovered, and from these it has been possible to restore the complete skeletons of these animals. Remains also of huge mastodons, mammoths, elephants, camels, and deer have been recovered, showing that these animals, many of which no longer roam the earth, lived in Pleistocene time on what is now the plain of the basin of Los Angeles. Restored skeletons of some of these animals are shown in accompanying figures.

Let the imagination dwell upon the menagerie of wild animals that once roamed the Los Angeles plain. The 3-ring circus, with trained elephants, camels, trained tigers, zebras, and monkeys, with the adjoining caravan of jungle beasts, seems insignificant by comparison!

The climate may not have been much different from now. Perhaps there was somewhat more rainfall. Anyway vegetation evidently abounded upon which such monstrous beasts as the mastodon, mammoth, elephant and camel subsisted. Whether there was unusual food about the oil pools is not known, but apparently plant-eating animals frequented the pools—and unfortunately for them it seems—for they became mired in the pools where they became (supposedly) easy prey to hungry carnivorous beasts, such as the great cats (lions) and huge short-faced bears, wolves, and other savage flesh-eating animals.



Courtesy Los Angeles Museum

FIG. 78. Restored skeleton of Imperial Mammoth (*Archidiskodon imperator,* Leidy). From tar pits of Rancho La Brea.

The great abundance of skeleton remains of carnivorous animals seems to indicate that these animals hovered around the pools ready to pounce upon even the large mammals and other animals that became mired and therefore helpless. Beds of skeletal remains of both carnivorous and herbivorous animals have been discovered in some pits that seem to indicate that carnivorous animals hovered in numbers around the pools for the purpose of preying upon any animals that became entangled in the morass.

The animal and plant remains are not petrified, but have been preserved sealed in the asphaltum. The tissues of tree trunks are impregnated with tar, and leaves and seeds are also thus preserved. It has been possible to extract the tar so that the plant tissues can be perfectly restored, and the species of plants thus determined. Plants and trees of species now living, and of species that are no longer living upon the earth have been recovered.

Rancho La Brea Donated to the Public

It is well that Rancho La Brea has been donated to public use. The oil pools furnish a notable example of the preservation of species of plants and animals of a period of geologic time (Pleistocene). It is unique in the world as a locality of its kind. At no other single place in the world has so great a number of fossil relics been recovered. The Park, embracing 32 acres, is preserved and protected as Nature left it. In the Los Angeles Museum, and in other museums, are housed the restored skeletons and many relics. As further explorations are made the collection of pre-historic fossils it is expected will be added to, and our knowledge of the life of the past thereby increased.

The peculiar character of the material in which the fossil remains have been entombed at Rancho La Brea, a heavy oil, a soft tar, or granulated asphaltum, have probably contributed largely to the preservation of the animal and plant remains. The great accumulation of fossil remains is remarkable. Skulls and fragments of skeletons of mammals and birds, and indeed of reptiles and insects, as also frequently of trees, seeds, and leaves, have frequently been found in thickly matted accumulations. Dr. John C. Merriam states that in a mass of less than four cubic yards there were counted more than 50 heads of the dire wolf, 30 skulls of the sabre-tooth cat, and many remains of bison, horse, sloth, coyote, and birds, and even of reptiles, amphibia, and insects.

Many Predatory Animals Trapped

A census of mammals from the Rancho La Brea indicates that 90% belong to the group of predatory animals. A similar preponderance of predatory birds of prey is shown among the avian population. Among the mammals those that were entrapped in the greatest numbers were the sabre-tooth cat and dire wolf, both of which are represented in the deposits by many skulls and parts of skeletons.

The cat family, as represented in the asphalt deposits of Rancho La Brea, includes both the sabre-tooth (Smilodon) and the true cats (Felicidae, genus Felix). The sabre-tooth cat ranks next to the dire wolf in the number of individuals found in the tar pools. The last of this group of sabre-tooth cats occurs in the Pleistocene. They are now entirely extinct.

The great lion-like cat (*Felix atrox*) was the most remarkable member of the group of true cats. Male individuals of this great cat were nearly one-fourth larger than any of the large living cats (lion, tiger, leopard, etc.) of Eurasia. This great lion was the most formidable predaceous mammal present in the Rancho La Brea assemblage, being rivaled only by the powerful short-faced bears.

Of a total of between 4,000 and 5,000 Pleistocene mammalian relics in the Los Angeles Museum 90% are carnivores. Of the 90%, 57% are of the dog family (Canidae), closely followed by the cats (Felidae) with 40%. Each of these groups greatly exceeds the bears, badgers, skunks and weasels.

Among the bears the short-faced bear (Tremarctotherium) was more abundant than the black-grizzly type. These were of large size, resembling the brown and kodiak bears of the Alaska coast. The short-faced bear was the largest flesh-eating mammal that occurs in the Rancho La Brea deposits. The species is now extinct, for which the civilized world of today need have no regrets! The short-faced bears (Tremarctotheres) enjoyed an extensive distribution over the North American continent in Pleistocene time. With the disappearance of the short-faced bears the black and grizzly bears established themselves as the prevailing representatives of the bear family in California. The grizzlies have since become extinct in this region.

Many Herbivorous Animals Trapped

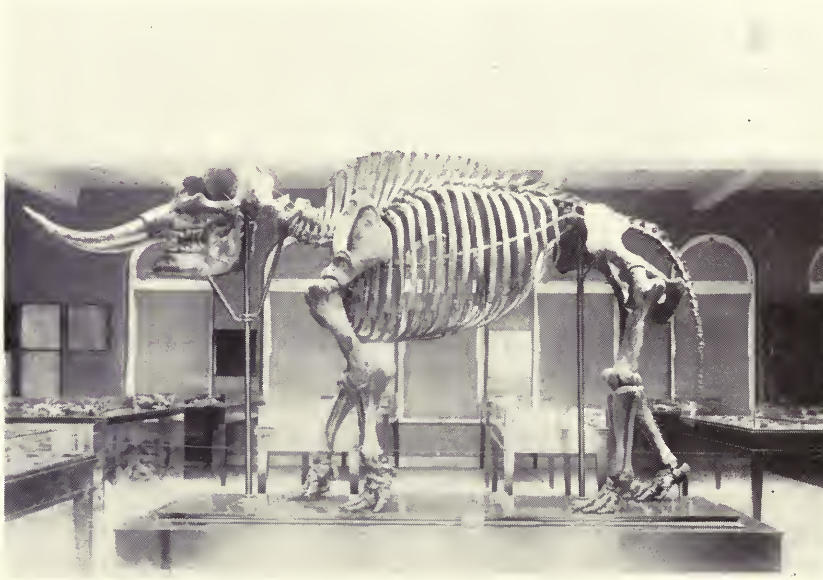
Among the herbivores (plant-feeders), remains of which have been exhumed at Rancho La Brea, the largest family is that of the bison (Bovidae). Then follow in turn the horses (Equidae), edentate ground sloths (Mylodontidae), the camels (Camelidae), the antelopes (Antilocapridae), the huge Megatherium ground sloth, the elephants, the mastodons and the deer, and finally the peccaries and the tapirs. Many animals belonging to the families mentioned are now extinct, but many living species are included in the preserved fauna.

Bison or buffalo were apparently more numerous than the horses in the vicinity of Rancho La Brea during Pleistocene time. The total number of these animals from the asphalt deposits exceeds that of all other even-toed hoofed animals. These ancient bison were larger than the living North American buffalo, the mounted skeleton having a height of more than six feet. Some individuals are thought to have been even taller.

That bands of horses existed in the vicinity of the asphalt deposits during Pleistocene time is attested by the numerous remains of these animals found at Rancho La Brea. This species, now extinct, resembles the modern horse, but differs in many particulars, noticeably in the hoofs which are distinctly smaller and more slender than in the larger types of existing horses.

Several distinct types of camels are known from the Pleistocene of North America, but the camels of Rancho La Brea all belong to a single species. The fossil materials recovered have made it possible to more completely restore this species than any other camel type from the Pleistocene. The restored skeleton has a height of more than seven feet as measured from the highest point of the back.

Remains of elephants and mastodons occur at Rancho La Brea, but not frequently. The elephants and mammoths recovered from the asphalt were distinctly larger than the mastodon, and exceeded in size elephants that are living today. Some of these animals had a height of more than 13 feet as measured at the shoulders. The American mastodon during Pleistocene time is known to have ranged widely over the United States. Fragmentary remains of mastodons have been found at a number of localities in California.



Courtesy Los Angeles Museum

FIG. 79. Restored skeleton of American Mastodon (*Mammut americanum*, Kerr). From tar pits of Rancho La Brea.

Many Remains of Birds Recovered

The geographic distribution of extinct species of birds is not as well defined or as well known as that of extinct mammals. The remains of birds from the asphalt at Rancho La Brea form a varied and interesting assemblage, more interesting perhaps than even that of the extinct mammals. Approximately 75 different types have been recognized. Within the group occur forms now entirely extinct and principally known from this locality. The unusual conditions that made possible the preservation of so complete a record of the mammalian life of the region may be regarded as equally favorable to the preservation of the remains of birds. Live bait furnished by mammals and other creatures entrapped in the tar doubtless served to attract the predatory and scavenger types of birds to the locality. Remains of raptors (eagles) and certain species of owls, crows, ravens, and magpies, occur in great numbers. Thus the same inducement—viz., the quest for food—that led beasts of prey to harbor about the tar pits to feed upon entrapped animals attracted the scavenger birds in the same way, and this explains in some measure the presence in the region of the asphalt deposits of great numbers of wolves and cats, and in turn their entrapment and preservation in the asphalt.*

* Approximately 100 papers relating to the fossils excavated at Rancho La Brea are listed in the bibliography of Los Angeles Museum Publication No. 1, by Chester Stock, which publication has been freely drawn upon in the preparation of these pages.

Chapter XX

PETROLEUM OR ROCK OIL

Petroleum (from two Greek words, *petros* meaning rock, and *oleum* meaning oil) is *rock oil.* Rock oil is one of the minerals of the earth. It occurs in California in great quantities. The geology of oil has become a science in itself. Petroleum geologists are specialists in oil, just as mineralogists are specialists in minerals; paleontologists are specialists in fossil remains of living things, remains of which are entombed in the rocks; soil specialists who study the soils formed from the rocks; and stratigraphers who study the character of rock formataions laid down in once horizontal beds on sea bottoms. To every man according to his several ability.

The Origin and Nature of Oil

Rock oil is derived in some way from the rocks. Where it comes from, that is, how it was formed in the earth, is not certainly known. It is one of the minerals of the earth. It has been thought by some that it has been formed by some chemical process in the rock formations of the earth. It is composed of carbon and hydrogen. The greater part of all plants is some combination of these same chemical elements, with oxygen. Sugar, starch and wood are carbon, hydrogen and oxygen. The tissues of animals are also carbon, hydrogen and oxygen, with nitrogen.

Natural gas, petroleum, bitumen, and asphaltum are all essentially compounds of carbon and hydrogen, or mixtures of such compounds. They are known as hydrocarbons. Consisting essentially of carbon and hydrogen, they contain also many impurities, as sulphur compounds, nitrogenous substances, and other impurities. The simplest hydrocarbon is marsh gas, having the chemical symbol CH_4. All the hydrocarbons fall into a number of regular series. Each member of the series differs from the preceding member by the addition of CH_2. The petroleum hydrocarbons begin with CH_4, marsh gas or methane, and range as high as the compound $C_{35}H_{72}$, technically known as Pentatriacontane (a name which you do not need to try to remember!). It is interesting to note in passing that carbon and hydrogen combine chemically directly when an electric arc is formed between carbon terminals in an atmosphere of hydrogen.

It has been thought that oil—rock oil or petroleum—has been distilled in some way from plant and animal tissues. Plants and animals have lived upon the earth—on land or in the seas—since very early in geologic time, but no one has yet explained how the oil originated as oil. It has long been known that the destructive distillation of organic matter, animal or vegetable, under conditions which preclude the free access of air, will produce hydrocarbons. Probably no subject in geochemistry has been more discussed than that of the origin of petroleum. Its nature is known. It is a compound of carbon and hydrogen. It is lighter than water, hence is crowded out by water because of the greater pressure of water. Under conditions such as have existed and still exist in the rocks it collects in pools or lakes deep in the ground. It may and does fill the interstices in porous rocks. It may and does "drain" from one rock horizon to another through a fracture or "fault" in the rocks. It may be and is forced by the pressure of heavier water from the rocks where it may have been formed to gather in a cavity, or in another porous formation higher up. If a hole is drilled from the surface and taps the pool or lake where the oil has accumulated then a productive well results. Geologists have come to regard some formations as oil producing formations, as "oil sands." Such a "sand" may be located but may not yield any oil when reached by the drill. The oil may have "drained away" to some other location. Many rocks are not oil bearing, and are known to be barren. Granite, quartzite, many sandstones, and limestones, in California are barren of oil.

Where does the oil come from? If we knew the origin of oil it would help in locating pools or sources from which oil might be obtained. This is one of the problems of the petroleum geologist. The nitrogenous element of California petroleum furnishes perhaps the strongest evidence that the proteids (from animal tissues) contribute a share to the make-up of petroleum, and show that these particular oils are of animal origin. Eminent geologists have regarded liquid petroleum as a natural

Photo by W. S. W. Kew, U. S. Geol. Survey
FIG. 80. Simi Oil Field, Ventura County.

distillate from carbonaceous deposits, which latter were laid down at depths below the horizons where the oil is now found. The heat generated during metamorphism is supposed to be the dynamic agent in this process, although many productive regions show no evidence that any violent metamorphism ever occurred. In most cases geologists have subscribed to the theory of the organic origin of petroleum, but their reasons for so doing are generally the absence of igneous activity, and the great mass of sediments containing organic remains in the oil fields. The organic origin of petroleum seems to be best supported by the geologic relations of the hydrocarbons, which are found in large quantities only in rocks of sedimentary character. Any organic substance which becomes enclosed within the sediments may be a source of petroleum. There is no evidence to show that any important oil field derived its hydrocarbons from inorganic sources (F. W. Clarke).

Microscopic Animals and Plants
Possible Sources

It is well to remember the enormous accumulation of "oozes," the radiolarian and globigerina oozes, on the bottom of the sea. The organic matter thus indicated is abundant enough, if it decayed under proper conditions, to form more hydrocarbons than the known deposits of petroleum now contain. Animal matter in some cases, vegetable matter in others, or both together, are supposed to be the source of supply. Some oils are supposed to be of mixed origin, and it is thought by some geologists that the mixed class is the most common. The idea has also been held that Pennsylvania oils have been derived from marine vegetation, while California oils were attributed to animal remains. Wherever sediments are laid down enclosing animal or vegetable matter there bitumens may be produced. Sea weeds, mollusks, crustaceans, fishes, and microscopic organisms may contribute material. In some cases plants may predominate; in others animals, and the character of the hydrocarbons is likely to change accordingly just as petroleum varies in different fields. Such differences are most easily explained on the supposition that different materials have yielded the different products.

In California certain shale formations have been oil-producing (notably the Monterey shale, of Tertiary age). Diatomaceous shales have been a source of oil to such an extent that many geologists have come to regard the diatoms as the organic source of the oil. It is not, however, fully proven. Diatoms—minute organisms so small that they cannot be distinguished by the naked eye—have lived in myriad numbers on the sea bottoms, and their tiny skeletons now make up vast beds of shale rock. Diatoms were living things, their bodies composed largely of carbon and hydrogen, their skeletons or tiny shells being of mineral matter (mostly silica). Diatoms, it may be explained, are minute organisms, microscopically small, that are near the borderland between plants and animals. Careful study by specialists has determined that diatoms give off (exhale) oxygen in their life processes and take up (from the air or from water) carbon dioxide. Carbon dioxide is a chemical combination of carbon and oxygen, which is given off (exhaled) by animals. In fact the dividing line between plants and animals is right there. Plants breathe in (inhale) carbon dioxide and exhale oxygen. The carbon is built into plant tissue. Animals inhale oxygen, which in their bodies is combined with carbon, hydrogen and nitrogen to form animal tissue. Some of the carbon in animal bodies is burned or oxidized and is given off (exhaled) as carbonic acid (CO_2). Thus plants and animals thrive together—plants give off oxygen, which animals need, and take up carbon dioxide, which animals throw off (exhale). This explains why house plants are desirable in living rooms. They give off oxygen and take up the poisonous carbon dioxide which has been exhaled by human beings.

So because they throw off oxygen and breathe in carbon dioxide it has been found that diatoms are of vegetable character. Myriads of animals have lived during the geologic ages, and their bodies are composed mainly of the elements carbon, hydrogen, oxygen, and nitrogen. Whether oil has been distilled from myriads of animal forms again we do not know. That great numbers and great variety of animals and plants have lived during the geologic ages is known. But no oil has ever been discovered in many formations in which great numbers of organic forms lived. So, where the oil comes from we do not know.

Oozes in Tertiary Formations

At the time of deposition of the Tertiary formations in California in which petroleum now occurs the seas swarmed with countless numbers of minute organisms, which on dying dropped to the bottom and accumulated in the silts or in some places formed oozes consisting almost entirely of their own remains. Of these organisms the diatoms were the most numerous, microscopic vegetable organisms which secrete siliceous tests having a great variety of shapes. The foraminifers, somewhat larger than the diatoms, have tests of various rounded and elongated shapes made of calcium carbonate (lime). A few radiolaria also occurred. The oozes which these organisms formed are probably comparable to the globigerina, diatomaceous, and radiolarian oozes now forming in the ocean. The organic matter within the calcareous and siliceous tests slowly decomposes and undergoes chemical change. The exact chemical changes are not known, but it is thought they have been influenced by geologic conditions, as of pressure and heat.

The Monterey Group of Formations an Important Source of Oil

Oil occurs in many places in California. But it never occurs in some rocks—never in old granite, not in most of the older geologic formations. Most of the oil in California has been obtained from the Monterey group of formations, directly or indirectly. California has been much rent and fractured. A fault or break in the rocks may have caused the oil to drain from its original source and accumulate in some other formation. The rocks that have been grouped under the name Monterey, however, have come to be recognized as the principal source of oil in California. The studies of Arnold, Anderson and Johnson (see appendix) have shown that without much doubt foraminiferous and diatomaceous shale is the source of California oil. In fields on the west side of the Coast Ranges the diatomaceous shale is carried in Monterey (Middle Miocene)

Photo by Ralph Arnold, U. S. Geol. Survey

FIG. 81. Oil wells in Whittier oil field ten miles east of Los Angeles.

shale, and much the greater part of the oil in these fields occurs in that formation or in other formations in contact with or near to that formation.

On the east side of the Coast Ranges the formations have different characteristics and consequently different formations are regarded as the source of the oil. On the east side of the ranges in the San Joaquin Valley the Monterey formation is absent in some fields, but other formations carry diatoms or foraminifera, and in each case the oil is found only in these or closely associated formations. There is no doubt that the petroleum in the Santa Maria district is indigenous to the Monterey shale. Bitumen is a characteristic part of that formation throughout its wide extent over an area covering hundreds of square miles. On the west side of the Coast Ranges the Monterey shale is the principal formation containing diatomaceous and foraminiferal material, and is the source of most of the oil. On the east side the Monterey is the source of oil only when it is diatomaceous. But other formations partake of this characteristic, and when they do are regarded as sources of some of the oil. In the Coalinga district the oil is believed to be derived from organic shales of the Upper Chico formation (Upper Cretaceous) and upper Tejon (Eocene, Tertiary). It is believed that the oil originated from organic matter, both animal and vegetable, once contained in these beds. The shales consist of tests of foraminifers and diatoms and some others in such abundance as to warrant assumption that the animal and vegetable material that must have been contained in them was adequate to furnish the hydrocarbons more than equivalent to the quantity of petroleum found in this field.

Oil from Minute Organisms in Monterey Shale

The conclusion is unavoidable that some ingredients of the Monterey shale gave rise to the oil. Diatoms were the chief source, although animals and perhaps other plants also contributed largely. It seems to be apparent that these organisms were the ultimate source of the oil. It appears that the source of the oil is different in the different fields, depending upon the amount of diatomaceous and foraminiferal material in the formations. From the relationship between the diatom-bearing formations on the two sides of the Coast Ranges it seems to be apparent that these organisms were the ultimate sources of oil, as claimed by the geologists Arnold, Anderson, and Johnson. If this is granted it will stand out as one region in which, and one case in which, it has been possible to make a positive determination regarding the origin of oil, and to these geologists will be the distinction of being the first to do more than theorize concerning it (M. R. Campbell, see appendix).

In California diatoms have existed in the geologic past in such numbers that "diatomaceous shales" have been formed over wide areas. Diatoms formed the deep sea ooze of the ancient sea bottoms. The ooze became compressed into shale. Sometimes these shales, consolidated diatomaceous ooze, have been upheaved, bent, and folded, and now are seen in rock outcroppings, as in the Berkeley Hills, Mount Diablo, and many places, but oil is not always associated with diatomaceous ooze (shale). It may never have been there, and it may have migrated—drained away.

Oil-bearing Formations Largely Porous Sandstones and Conglomerates

A large proportion of the oil-bearing sedimentary formations of California are highly porous sandstones and conglomerates, which make exceptionally good reservoirs for petroleum. The presence in California formations of many angular unconformities afford opportunities for the accumulation of oil and asphalt, or for the migration of these substances from one formation to another. "Large accumulations in anticlines may be accounted for primarily by the cavities offered by the strata along upward folds, and secondarily by the presence of less pervious beds arching over such folds and affording favorable conditions for the confinement of oil and gas tending to escape (M. R. Campbell).

Geologic conditions in California fields are so complicated that it is extremely difficult to formulate general laws regarding migration or occurrence of oil and gas. The element of time also enters into the question, for since the deposition of Tertiary rocks sufficient time has not elapsed for the escape of all the hydrocarbons, whereas in the Palaeozoic rocks of the east time has been so great that there has been opportunity for the escape of all hydrocarbons in the rocks wherever the minutest fracture occurs. Owing to the complicated conditions in California it it doubtful if the laws governing the movement of oil and the full effect of local conditions will ever be fully understood.

Rock Structure Controls Accumulation of Oil

A study of the rock structures shows that the anticline is the dominating factor controlling the accumulation of petroleum irrespective of topography. The close association of oil with structural features of this type is not unique to California, but is found in all the larger fields of the world. The presence of anticlines can of course only be of importance where rocks known to be oil-bearing are involved in or near the folds, and where part of the strata are porous enough to act as reservoirs. The original anticlinal theory assumed that oil, being lighter than water, rises above it, following porous beds to the highest part of the anticline, where it is trapped below impervious strata that cover the oil-bearing sands. In the east flank of the Coast Ranges anticlinal folds are the dominating factor influencing the accumulation of oil.

Another theory advanced by competent geologists is that the orogenic (mountain making) forces which have so greatly disturbed the rocks of the earth's crust are the most potent cause of the migration of oil along lines of least resistance. This force may have some connection with the migration of oil in highly disturbed regions such as occur in California, but even where the oil occurs in folded strata its accumulation is in no way proportional to the amount of deformation which the strata have undergone. In fact in most places very highly inclined beds are known to be detrimental to the accumulation of oil in large quantities.

Photo by Ralph Arnold, U. S. Geol. Survey

FIG. 82. Topatopa Anticline, in Hopper Canyon, Ventura County. Shale and sandstone of Miocene age, Modelo formation.

Other geologists have arrived at the conclusion the migratory faculty of petroleum may be ascribed entirely to the presence of the associated gas, which would cause the oil to fill every crevice offering a point of escape. The hydraulic hypothesis (water pressure) contemplates that the action of underground circulating water, together with the capillary action of water, drives the oil before it, and the oil then accumulates in pools. The formations in California generally are not regarded as favorable for the circulation of ground waters. It is the opinion of some geologists that circulating artesian water is of considerable importance in the migration of oil in California fields, and that certain structural features, such as faults and anticlines, have acted as traps in which the oil was caught.

Under ordinary conditions in California petroleum has not accumulated in the same rocks in which it originated, but has migrated to porous sandstones which act as a reservoir, yet no definite general conclusion has been reached as to the cause of the migration of oil.

Oil Fields Are Not Inexhaustible

It may be regarded as unfortunate that oil-bearing geologic formations occur under some cities and towns, and under fertile and productive lands, whose industries and whose beauties have been marred or may be destroyed by the development of the petroleum industry. If oil could have been formed under the barren rocks of the deserts instead of under Los Angeles and Long Beach and Carmel-by-the-Sea how much nicer it might have been! But we should not weep. Geologic time is long. We do not know much about the origin of oil or how long it was in forming, but pools or lakes of oil are not inexhaustible, and it is not likely that more oil is being formed to take the place of that which is pumped out. In a little while (geologically) the oil will have been forgotten. The machinery will all have passed from the scene. The land will in time come back to its own. Not in our day, you will say. No, but there are more generations to come. The diatoms and foraminifers from which the oil probably came lived long ago. They had their day. They left their inheritance. If we bore down and tap their ancient tombs in a short time the accumulation of ages is taken away. Then we will go to search for other fields. Petroleum geologists will scout the earth for more "oil sands" somewhere. They may be found in the cold wilds of the arctic regions or in the hot and arid tropics. But they will probably be in formations that are younger rather than older. So it will be needful that we study geology and locate our industries and our cities where the geologic conditions are right. The petroleum geologist will keep on with his work as will the engineers of other industries. It will be realized more and more that the study of geology is fundamental to the soundest understanding of the earth's resources and of the utmost importance in locating and establishing the industries of the world.

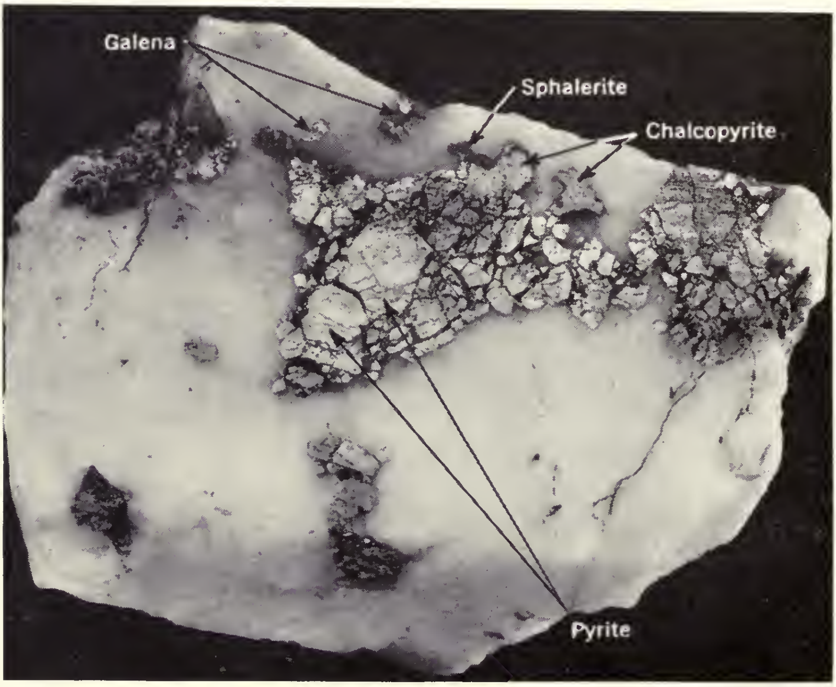
Chapter XXI

GOLD

Gold Geologically an Obscure Metal

What is gold? It is one of the so-called precious metals. Why precious? Principally because it is not common, yet possesses qualities of great importance. For it men have traversed the earth. The search for gold has lured mankind into unimaginable hazards. What is the source of gold? To say the profound depths of the earth is not saying much, but is about all that can be said. The struggle of men to find the precious metal has been in a sense paralleled by the geologic stresses by which the metal has emerged from the depths of the interior of the earth. But for tremendous convulsions by which the crust of the earth has been rent, upheaved and broken, rocks shattered and fractures formed, probably man would never have known the yellow metal other than as a chemical curiosity. Yet contrariwise as it may seem, gold is widely distributed throughout the rocks of the earth, and is even present in solution in the waters of the seas. Widespread though it is, yet because its occurrence in commercially paying quantities is so rare, and its behavior as one of the constituent minerals of the earth is so obscure, and because it possesses properties that render it of great practical value in the arts, it is ranked among the precious metals.

Gold is one of the elementary substances of which the earth is composed. It is one of about 90 elements which make up all the rocks, minerals, water and air of the earth. A wide range of studies tends to show that gold occurs in all geologic formations of all ages. The gold contained in the rocks of the earth's crust is estimated to represent a value which would be expressed in tenths of a cent per ton of rock. Shales are the commonest of the sedimentary rocks. The average gold content of 4 shales from widely separated regions of the United States represented a value of a little more than half a cent per ton of rock. The average gold content of shales, so far as known, is twice that of limestone. The average for sandstone is one and one-half times that of shale, or three times that of



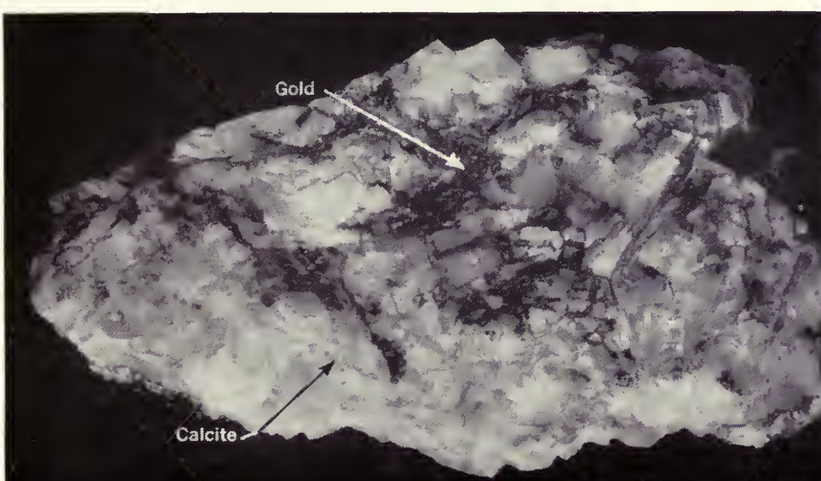
Courtesy U. S. Bureau of Mines

FIG. 83. Typical ore from Mount Gaines Mine. (Actual size.)

limestone. Coarser sedimentary rocks have a higher gold content than finer, conglomerates having the highest content, and the coarser the conglomerate the greater the gold content. This seems to indicate that, in the process of sedimentation, gold tends to concentrate by lagging behind.

Gold Content in Igneous Rocks Variable

There is very great variation in the gold content of igneous rocks. In 48 tests of igneous rocks the gold content varied between extremely wide limits. Wide variation exists between the amounts of gold in similar rocks of different localities. Moreover, the same rock from the same locality frequently shows equally marked variations. In six granites containing gold thought to be primary the highest contained 67 times more gold than the lowest. The evidence at present available tends to show that the average gold content of igneous rocks is about six parts per one hundred million, equivalent to about 3½ cents per ton. No placer deposits where gold has been derived from the primary content of igneous rocks have proved of economic value. Gold is distributed in the mass of igneous rocks approximately evenly throughout its mass. Important concentration begins with the destruction of the igneous rocks by erosion. Gold tends to gather in sediments, more in coarser and less in finer sediments. If there were any considerable bodies of igneous rocks assaying 35 cents per ton some of them certainly would have produced placers of economic importance. No such ores have been found.



Courtesy U. S. Bureau of Mines

Fig. 84. Bonanza Ore, from Gold Bug mine, showing free gold in calcite (slightly reduced).

No Gold in Volcanic Emanations

No gold has been found in volcanic emanations, or in the products of the same. What are known by the terrific name pneumatolytic deposits—that is, deposits formed from hot vapors or superheated liquids under pressure—frequently contain gold of economic importance. From this it has been inferred that plutonic emanations—molten rock poured out from fissures or vents in the earth's crust—contain gold, but it has not been proved.

Primary gold in metamorphic rocks has been found in only two recorded instances.

Gold Occurs in Sea Waters in Variable Amounts; Not in Fresh Surface Waters

Determinations of the gold content of sea waters show an extreme irregularity and wide variation in samples taken from widely separated seas. Eleven determinations of gold in sea waters gave an average value of 1 2/3 cents per ton. The extreme irregularity or variation of the gold content of sea waters is as noticeable as in the case of igneous rocks.

Gold has not been detected in fresh surface waters, but its presence in ordinary surface waters is inferred from the fact that gold has been detected on the roots of plants and trees. The absorption of gold from solutions by growing plants has been experimentally proved. Ashes from trees that grew in a gold-bearing region contained gold. Coal has been frequently found to be auriferous (gold-bearing). A Wyoming coal is stated to contain gold of a value of $1.00 to $5.00 per ton. Ashes from Utah-Wyoming coal is reported to yield 60 to 80 cents value per ton.

Gold-Bearing Veins Formed from Heated Waters from Great Depths

Gold has been identified in circulating waters of the earth's crust. Heated waters rising from great depths are known to contain gold. It is inferred that the majority of veins have been formed by such waters. Lodes are formed whenever circulating waters act as solvents in one part of their course and as precipitants in another. Gold-bearing veins have been found in rocks of all compositions and of all geologic ages. Lodes, which are mainly the result of cavity fillings, are more likely to occur in rocks which break easily, producing cavities,

FIG. 85. Ore face in Malvina mine showing typical ribbon vein structure.

such rocks as slates and schists, or in rocks which are so hard that when fractured the cavities will remain open giving circulating solutions a good chance—as granites and gneisses.

Lodes Formed from Solutions Deep in the Earth

After extensive gold deposition in pre-Cambrian time there has been no widespread formation of gold-bearing lodes until late Tertiary time. Theoretically a lode is a vein of mineral matter that fills a space formed by the fracture of the rocks, or a space from which some other mineral or minerals have been dissolved out, a space between walls of rock occupied by mineral matter that has been carried from below in solution, and deposited in the space between the walls.

Mother Lode Not a Single Vein

The Mother Lode is not a single vein but a remarkable linear system of interrupted and overlapping veins. The far-famed Mother Lode of California is embraced in a belt of ancient sedimentary rocks that form the foot hills of the lower western

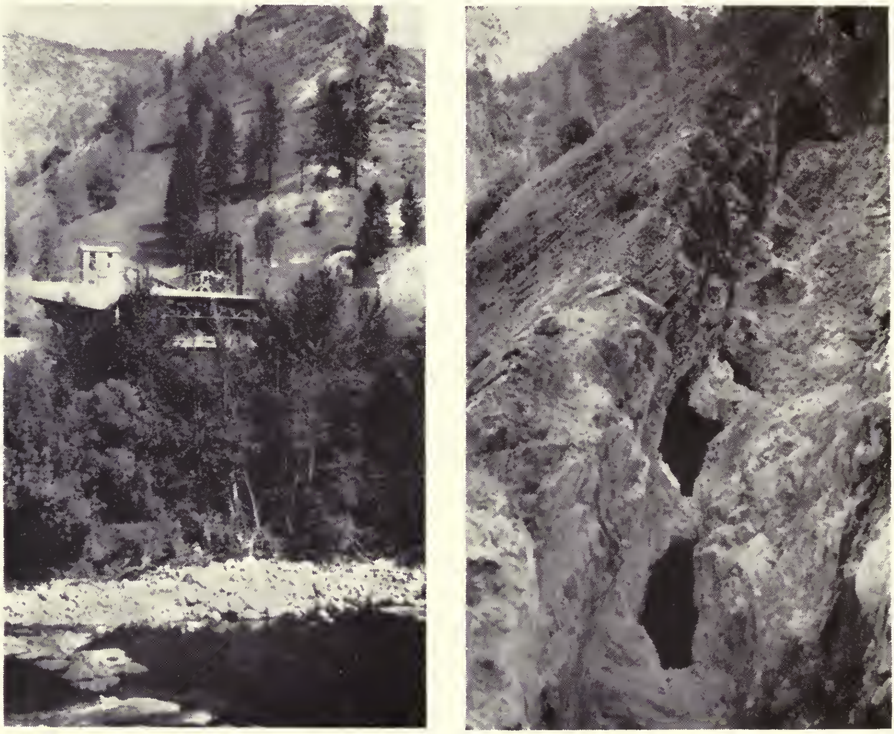
FIG. 86. Sketch map of the Mother Lode region, in Calaveras, Tuolumne, and Mariposa counties. The first gold-quartz vein found in place in California was discovered at Mariposa in 1849 (A. Knopf). The Mother Lode belt is for the most part a hilly country. The topography is rolling except where the belt is crossed by the larger streams, viz., South Fork American River, Mokelumne, Stanislaus, Tuolumne, and Merced.

slope of the Sierra Nevada Range. The rocks are old geologically, and are much folded, crumpled, and fractured. Much folding, upturning, and crumpling of the rocks occurred before the gold was deposited. The gold of the Mother Lode district occurs both in gravels of overlying formations, the superjacent series, and in veins of the bed-rock. The gravels were first exploited, and this was followed by mining upon the gold-quartz veins.

What is known as the Mother Lode is a comparatively narrow belt extending in a nearly northwest-southeast direction along the western foot-hills region of the Sierra Nevada Range. The district is about 6½ miles wide and 70 miles long. It contains the principal mining districts of Amador, Calaveras, and Tuolumne counties, and a small part of Mariposa County. It is a vast belt of rocks that has been fractured, and mineral matter deposited from solution in the spaces between the walls. Fractures and filled veins ramify in varied fashion throughout a great belt. Branch veins go off from larger veins, and pinch out and cease, and re-occur in no known definite relation. The boundaries of the Mother Lode region are arbitrary lines. There are other gold-bearing regions both north and south of this belt, but by far the largest quantity of gold has been produced within the limits of what is called the Mother Lode.

The following description of the Mother Lode is from Julihn and Horton, U. S. Bureau of Mines, Bull. 424:

"The Mother Lode of California is a zone of rock fracture and mineralization ranging in width from several hundred feet to a mile or more. It is often flanked on each side by a similar zone of lesser width. The lode is characterized by quartz that contains some gold. The quartz occurs predominantly in veins or lenticular masses of limited extent. The zones of fissuring occur in rocks that are predominantly folded sedimentaries of the Calaveras and Mariposa formations, the former being of Carboniferous, the latter of Jurassic age. After the Calaveras was formed a period of metamorphism succeeded that was accompanied or closely followed by intrusions of diorite. The Mariposa rocks likewise were intruded and metamorphosed in late Jurassic or early Cretaceous time. The Mariposa rocks were folded, closely crowded together, and complexly infolded with the Calaveras rocks. After the rocks had been folded and



Courtesy U. S. Bureau of Mines

FIG. 87. Barite mine and mill. National Lead Company, on Merced River near El Portal (left). At right, open-cut in barite mine, with openings into stopes.

given their steeply dipping attitude great volumes of magma invaded the crust.

"The fissuring of the Mother Lode is regarded as due to compressive stresses. The stresses that caused them were related to the mountain building of the Sierra Nevada, lying to the east. The compressive stresses were so great that the rocks in their path yielded to the intense folding. The stresses, though resist-less, are thought to have been so slow that they attained their effects by persisting through a vast period of time. The Mother Lode fissuring may logically be regarded as a very late manifestation of these stresses after their intensity had become greatly reduced. Instead of effecting further folding of the rocks enough relief of the stresses was afforded by fissuring and slight movement localized in the zone of weak rocks that became the Mother Lode.

"The position of that zone of weakness, and hence the general course of the Mother Lode seems to have been determined by the winding course of the Mariposa formation that previously had been infolded within the Calaveras. The mines of the lode definitely follow this course of the Mariposa rocks. The width of the Mariposa exposed along the lode is not great, averaging less than a mile, and through long distances not half that width, yet the number of mines in the Mariposa or very nearly adjacent to its contacts exceeds the number of all other mines."

What is known as the Gold Belt includes other gold-bearing regions both north and south of the Mother Lode. It extends along the lower western slope of the Sierra Nevada from Plumas County on the north to eastern Mariposa County on the south, and is bounded on the west by the San Joaquin and Sacramento valleys. The area embraces about 9,000 square miles. At the northern limits of the belt the gold deposits are scattered over nearly the whole width of the range. At the south the productive region narrows to a strip which extends for some miles south from the main belt.

Some Questions Not Answered

The question naturally arises why gold in such unusual quantities should occur in this particular region. What is the Mother Lode? This can be definitely answered. *Why* is the Mother Lode; why gold came to exist in a great aggregate of mineral veins along a somewhat irregular belt on the lower flank of the Sierra Nevada range; and not on the crest of the range or in the valley at its foot; or in other regions surrounding, may not be so definitely answered.

Gold is widely distributed, and occurs in rocks of all sedimentary geologic formations of all ages. Yet here, in a comparatively narrow belt extending in a general way parallel with the crest of the mountain range but along its lower flank only, discontinuing in a narrow strip at the south and thinning or ceasing under deep beds of lava at the north, is a region which has been one of the outstanding producing fields of the world. To the lay reader as well as to the geologist the question why is bound to arise. The only explanation that can be given in the present state of knowledge of the geology of the earth lies in what has been deciphered from a study of the rocks, the geologic history and processes involved.

Two Groups of Rocks in Gold Belt

Briefly stated, two belts of old sedimentary rocks lie along the lower flanks of the mountain range. These rocks are much bent, folded, and crumpled, tilted sometimes to a nearly vertical position. They were deposited as sea sediments, that is, muds, sands and lime. In the disturbances of mountain building they have been baked and transformed (metamorphosed), and now appear as slates, quartzite, and marble (crystalline limestone). These rocks are a remnant of the ancient roof rocks that were uplifted when the great batholith of molten rock (now the granitic rocks of the Sierra Range) was forced up under the sedimentary formations that had been laid down during the long periods of Palaeozoic and Mesozoic time. That they have been terrifically squeezed and compressed is shown by the way the strata are now folded and crumpled. The geologic complexity of these rocks is said to be greater than that of any other equal area of the western Sierra slope.

"The rocks that make up this belt of folded and crumpled formations, this remnant of the ancient roof rocks of the Sierra

Nevada uplift, fall into two groups in point of age. The eastern half of the belt, and higher up on the Sierra slope, is much older than the western and lower half. This has been determined from a few fossils that have been found, chiefly in the limestones and sandstones. From these it has been established that the eastern portion of the belt, that higher up the slope, is of Palaeozoic (Carboniferous) age, the Calaveras formation. The rocks of the western and lower portion of the belt are of Mesozoic (Jurassic) age, the Mariposa formation. It is thought that formations representing all the periods of Palaeozoic time may be included in the group of Calaveras rocks.

Courtesy U. S. Bureau of Mines

FIG. 88. Barite ore, from National Lead Company's mine near El Portal, showing intense folding (actual size).

"The rocks of all the formations, the Calaveras and the Mariposa, together with intercalated lavas which were poured out during the time of formation of the latter, all are intensely folded and compressed, and are much alike in general aspect. However, they belong to two different systems. In the greatly deformed structure of these two distinct series of strata there is clear evidence of the former existence of two successive mountain systems. The rocks that we see today are the "roots," so to speak, of the earlier mountain systems. Each of the ancestral mountain systems must have been in existence a very long time for each was reduced to ridges and hills of only moderate height. The time required for the wearing down of these mountain systems is thought to have been between 50,000,000 and 100,000,000 years for each system.

Roots of Two Mountain Systems and Granitic Batholith Form Bed-Rock

"The first of two ancestral mountain systems came into being near the end of Palaeozoic time, more than 200,000,000 years ago. It was formed by the uplifting and folding of a great series of layers of slate, shale, and sandstone, originally mud, silt, and sand. Folded in with these sediments, thousands of feet in thickness, were beds of lime, now metamorphosed to marble. In the long streaches of time the wrinkles in the earth's crust were in large part worn away, and finally the region sank below sea level and sediments, together with beds of volcanic material, were deposited upon the submerged remnants of the first mountain system. Then, at the end of the Jurassic period, about 130,000,000 years ago, there came another upheaval, and the deposits which had been formed were folded and crumpled and invaded by molten granitic magma from below. Thus a second system of mountains arose. Throughout the Cretaceous period, which followed the Jurassic, this second mountain system was worn down to ridges and hills of moderate height. The rocks which were deposited during the time of submergence referred to, and were folded and crumpled during the later mountain upheaval, are what make up the Mariposa formation.

"It is in the folded and crumpled rocks of these two formations, the Calaveras and the Mariposa, that the gold-bearing veins of the Mother Lode occur. The rocks of these two formations, together with the lavas and injected granite of the intruding batholith, make up what is called the Bed-rock series of rocks, or Basement Complex. Distinction is made between the Tertiary and Recent rocks—called the superjacent series—and the pre-Tertiary rocks, called the bed-rock series. The latter contain the quartz veins, the former the placer deposits resulting from the disintegration of the veins. In the intrusions of molten rock from below, and the uplifting, folding and compressing of the sedimentary and injected igneous rocks, veins were formed, and into these veins mineralized solutions were driven under great pressure and in superheated condition. During the slow process of cooling minerals crystallized out of the solutions, and gold came to be a part of the filling of the veins.

"The compressive stresses to which the range was subjected after the intrusions of molten granitic rock (granodiorite) produced joint systems in different directions traversing all of the rocks of the bed-rock series. Sometimes the joint planes are thin; at other places the spacing was much larger, and a series of parallel fissures was produced. The faults on the veins are in general small, but in one notable case (the Merrifield and Ural veins) great movement has taken place resulting in a throw of over 1,000 feet, measured along the dip of the veins. The origin of the fissure system is shown to be compressive stresses."*

Gold-Bearing Quartz Veins Occur at All Depths

Quartz with native gold and metallic sulphides of other minerals is one of the products of the vein-forming agencies. The great veins are formed by deposition in the open spaces along the fissures and constitute the richest and generally the only kind of ore. The gold is generally in a finely divided state, though in many mines coarse gold also occurs. Free gold occurs at all depths, and is generally associated with suphides of other metals. The average width of large veins may be from

* F. E. Matthes, U. S. G. S. Prof. Paper 160.

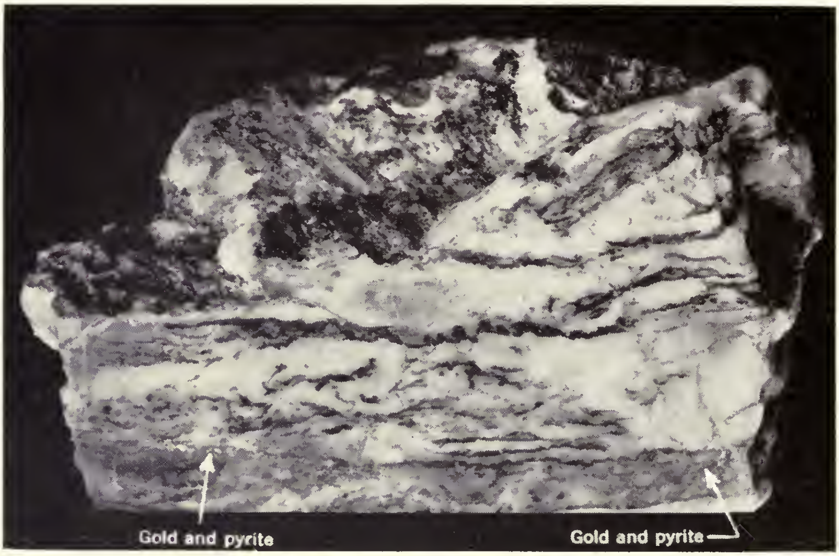


Fig. 89. Rich gold ore from Malvina mine.

Photo by G. K. Gilbert, U. S. Geol. Survey

Fig. 90. Manzanite hydraulic mine, near Sweetland, Nevada County. The bed-rock is granodiorite.

two to three feet, but the width of the far larger number is very much narrower. Some of the most productive veins average but little over a foot in width. No distinct relation between the country rock and the contents of the veins can be recognized. Veins occur in practically all rocks. The character of the filling—the quartz—varies greatly, and is not constant for the same rock. It even varies in different parts of the same vein in the same rock. The concentration of deposits in and about the granodiorite indicates that the veins are genetically connected with this large intrusion of magma.

Primary Gold in Quartz Veins; Secondary Gold in Placers

This in brief is the explanation of the origin of the gold ores of the veins of the Mother Lode. It is a feeble explanation, for it does not explain the real origin of gold, but only how it comes to be there. All the "pay ore" that has ever been discovered has been in veins or derived from veins. Pay ore in a vein, lode, or pocket, derived, as has been stated, from solutions that rose from the depths of the earth, is called primary gold. All quartz-vein gold is primary gold. As the rocks decompose and weathering and erosion break down the rocks, primary gold is released and carried by streams or otherwise down slopes. It then becomes secondary gold. Placer gold—gold that is buried in stream gravels—is secondary gold. Of all commercially paying deposits of gold none have been in geological formations—country rock—sedimentary, igneous, or metamorphic. All the gold has come from veins. Veins may and do occur in all kinds of rocks—sedimentary, igneous and metamorphic. Veins disregard formations. They cut through rocks of all kinds and all ages. A younger vein, that is, one later formed, may cut across an older vein. Up through the veins have come solutions which contained gold. Here school closes! Where the gold of the solutions comes from we do not know. If somebody imagines that there is a "pot of gold" at the center of the earth who is going to *prove* that it is not so?

Photo by J. S. Diller, U. S. Geol. Survey

FIG. 91. Hydraulic mine at Cherokee, Butte County.

Secondary Gold Sought in the Days of '49

In the mad rush for gold in '49 and years following it was secondary or placer gold that first attracted attention. Later as the placer deposits were "washed up" search was made for the source from which the gold came. Secondary gold came from primary veins. The Tertiary gravels were rich in secondary gold. Here is another chapter in the story.

The old rocks of the Calaveras and Mariposa formations, long after the stresses of the earth by which they were so violently squeezed, folded, upheaved, and shattered, were weathered by wind and storms and eroded by streams, then later were submerged and covered by the sea. An entirely new series of sediments was deposited over the broken edges of the tilted and folded rocks. These formations constitute what is called the Superjacent series as distinguished from the bed-rock series of the older formations. An upheaval in Cretaceous time made these later sea sediments dry land. Then streams began the work of eroding and carrying away the thousands of feet of sediments which had been deposited and solidified into stratified rock formations. During Tertiary time (which followed Cretaceous) streams carried down the slopes from the Cretaceous mountains vast loads of gravel. In these gravels was deposited gold from veins which had been formed in the rocks which had been upheaved in the great disturbance, and this secondary gold was what first made California famous.

Placer Gold Buried by Lavas

But it was not all so simple. Volcanoes broke into action along the crest of the Sierra range. Vast floods of liquid molten lava were poured out and flowed down the valleys. The lavas cooled in time and became hard rock. The lavas which had flowed down the valleys buried the gravels. Thus the gravels with their secondary gold were entombed. The period of maximum intensity of volcanic activity appears to be contemporaneous with or a little later than the close of the Jurassic period.

But time is long and things in nature never stay still or stationary. The outpourings of lava ceased. Rains continued to fall, and erosion of streams kept incessantly on. Rivers formed channels in the beds of lava. In some places gravels that had been buried were uncovered. The lavas, however, were hard and resistant to the wearing action of streams. New river courses were established down the slopes of the later formed mountains. These streams disregarded the former valleys, which had been filled with lava. Table Mountain in Tuolumne County is a tremendous example of a valley that was filled with lava, which in turn became hard resistant rock. Because it was hard streams cut channels around it. These channels became

Courtesy U. S. Bureau of Mines

FIG. 92. Gold nuggets from Tuolumne River. (Actual size.)

deep valleys because the slope gave to the streams great eroding power. Finally Table Mountain came to be the top of a great plateau underneath which were gravels that were deposited on the bottom of the earlier stream, and in the gravel was secondary gold from veins higher up the slope. These gravels are now high up in the hill or ridge of the great plateau, far above the bottom of the valleys that have been eroded alongside. So what had been stream beds or valley bottoms stand now high on hills and ridges. Into such hillsides the lure of gold has led man to construct tunnels into the buried gravels in quest of the buried treasure of secondary gold.

The following is from Julihn & Horton, Bull. 424, U. S. Bureau of Mines: "Nowhere in the world has so much gold been taken from so small an area of placer ground as in the Columbia Basin of Tuolumne County. There on an open flat within a radius of a single mile $55,000,000 in nuggets and gold dust was

Photo by G. K. Gilbert, U. S. Geol. Survey

Fig. 93. Limestone, at Columbia, Tuolumne County. The limestone was sculptured by erosion, later buried by gold-bearing earth washed from higher lands, then exposed by placer mining.

panned, rocked, or sluiced by miners from 1853 to 1870. Today there is no active mining within the basin, where only the white pinnacles of the deeply eroded limestone bedrock serve as monuments to the once thriving placer industry.

"This richest of the world's known placers resulted from a fortunate combination of geologic causes. Natural riffles of irregularly eroded white, crystalline limestone bedrock about

1½ miles wide lay in the path of a stream that carried the debris of gold-bearing rocks. The source of the alluvial debris was near-by in slates such as are seen on both sides of the limestone. These slates contained and still exhibit numerous narrow seams and stringers of gold-bearing quartz with occasional small pockets of exceedingly rich ore. Erosion of the slates by tributaries of the main stream finally brought down to the main valley the gold and quartz together with the softer slates of the

Courtesy U. S. Bureau of Mines

Fig. 94. Crystallized gold from Nigger Hill, near Jamestown. (Actual size.)

hills. Much of the gold was retained on the limestone riffles of the Columbia Basin. As the gravels of the basin have been formed locally, they consist largely of sub-angular and little worn fragments of quartz. These gravels with their accompanying gold found ideal lodgment in the crevices and potholes of the eroded limestone bedrock, and there remained until discovered in 1853. The gold was very coarse, and the finding of a nugget weighing a pound or so was so usual as to attract little attention. Five nuggets weighing from 33½ to 72 pounds are recorded as having been found at Columbia during the early days. On the bedrock of the Columbia Basin southwest of Columbia stands St. Anne's Church. The land on which this church stands, and the little cemetery that adjoins it, today constitute the only tract of unmined ground in the whole basin."

Question of the Origin of Gold Still Unanswered

The answer to the question of the origin of gold has not been found. The rock formations, upheaved, folded, tilted to high angles, squeezed into compressed pleats, broken by joints that resulted from the tremendous earth stresses, are cut by veins; the veins are filled with mineral matter, and in the mineral matter is intermixed metallic gold in a great variety of forms; gold in minute crystals that are not visible to the naked eye; gold mixed with crystals of other minerals; gold imbedded in and adhering to the surfaces of crystals of minerals formed out of solutions; gold that cannot be detected with the most powerful microscope, yet present in some obscure manner. Yes, we know *what* gold is; we know *where* it occurs; we know *how* it occurs; but we do *not* know what is its origin or source.

Chapter XXII

AGRICULTURE

Soil the Chief Source of Wealth

Gold in the hills? Oil deep down below the rocks? Yes, but more important by far from the economic standpoint, from the standpoint of dollars and cents, is the hidden inexhaustible wealth of California's soils. Long after the gold diggings shall have ceased; long after the lakes and pools of oil shall all have been drained away; long after "prospecting" for gold and "wild-catting" for oil shall have ended and been forgotten, and during long aeons of time to come, the soils of California will continue to yield their increase. The palm, the olive, the grape-fruit and the orange, the apple, the grape, yes, and the alfalfa and the grasses, the vegetables of uncounted variety, will continue to bring wealth to the producers and food to the multitudes of the earth.

Geology a Science of Fundamental Importance

And all this great potential wealth depends upon geology. But for geology—earth processes—there would be no soils, no crops. There would be no Golden Gate, no Sierra Range, no Yosemite Park, no citrous orchards, no vineyards, no cotton fields, no olives, dates or palms, no blooming desert, no San Gorgonio Pass, no gold, no oil. Land of extremes, as has been stated before, the geology of California is the most complicated of any State in the United States of America; highest in the air (Mount Whitney), farthest below sea level (Death Valley); most intensely tropical at Indio and Mecca; perpetual snow on the crest of the Sierras; dry ice in the hot arid desert on the shore of the Salton Sea; smoldering sulphurous fires from Lassen

Peak; broad level fields of fertile soil in San Joaquin Valley and a modern garden of Eden in the Imperial Valley; rough ragged lava rocks at Bumpass' Hell and Chaos Crags at the foot of Mount Shasta; and the greatest range in variety of agricultural crops of any State.

Courtesy Orange Community Chamber of Commerce

FIG. 95. Oranges at Orange.

A Bee-line of nearly 900 miles from El Centro to Yreka traverses a greater variety of agricultural and geological phenomena than any other line of equal length in any State. Trees that date back to time before time began to be counted in centuries; trees the largest and oldest in the world, others persisting against altitude and snow till perfect botanical specimens of willows, birches, and pines dwarfed to one inch in height on the snow-capped mountains occur.

Plant Food from Rocks

"I will lift up mine eyes unto the hills from which my strength cometh" sang the prophet. Lo! the strength of the hills is seen in the luxurious fields of alfalfa, the gardens of vegetables and flowers, the acres of oranges, dates, and palms—then across an enclosing fence or beyond a highway is the abject desert. Yes, strength comes from the hills! From thence comes the life-giving waters, and hence the gardens, the fruits,

Courtesy U. S. Bureau of Soils

FIG. 96. View on Tres Pinos Creek, San Benito County. Alluvial bottom land. Apricot trees in foreground; alfalfa in centre; Diablo Range in background.

the flowers, the alfalfa. Were it not for the great geologic forces by which the mountains were uplifted there would not be the streams. Were it not for the long processes of erosion and weathering of the rocks there had not been the soil in the valleys and on the slopes. We bewail the deserts, the waste land. Yet in the very conditions that have resulted in the soils of the desert lies the secret of the great fertility of the soils. The soils are decomposed rock. Rocks are composed of a great variety of minerals. The minerals are composed of the chemical elements that enter into the tissues of plants and compose the bodies of all animals. The conditions under which the soils have been formed from the rocks, the slow breaking up of the rocks with little rainfall (arid desert conditions) have left the soluble mineral elements of the rocks in the soils. In regions of greater rainfall the soluble mineral elements are leached out and carried away in solution. Hence the richness of desert soils.

The explanation of the great agricultural empire of the Great Valley of California is a chapter in geologic history. Geologic formations miles in thickness that once lay where the Sierra Nevada mountains are now, have been weathered and eroded and the broken rock carried by streams and deposited in a sea which covered what is now the plain of the Great Valley. These sediments form one of the world's great producing valleys.

Greatest Variety of Products Known to Ancient or Modern Times

A greater variety of fruits, flowers, trees, shrubs, grains, grasses, vegetables, cotton, and forage feed crops, is not known to any land. About every known edible fruit and vegetable, except papayas and bananas, are grown in this western sunset land—and not only grown but produced in quantities so great that they are shipped to the remote corners of the earth. Flowers—no one really knows flowers till he has seen the deserts of California in bloom. The geologically formed mountains which keep off the winds and rain, but which deliver moisture from their crests and down their slopes, have yielded the mineral elements of the highly fertile soil which by the alchemy of blazing sun in turn results in the brightest and most splendid galaxy of colors known to the traveler's eye. Yes, the geology of soils is the magic key. The weathering processes that have been going on during the ages, while the mountains were being uplifted and the crust of the earth rent and fractured by faults, and mineral matter poured out in molten form from the depths of the earth, have resulted in a varied and complex series of soils on which have been built up the widest and most varied system of agriculture known to ancient or modern times.

The geology of California is very complex. The soils, which are derived from the rocks, are therefore very varied. Two factors determine the crops that can be grown in any locality, viz., soil and climate. The soils are varied, as the rocks

Courtesy U. S. Bureau of Soils

Fig. 97. Young prune orchard, with interplanting of onions for seed, on silty clay loam. North of San Juan Bautista.

are varied. The climate covers the extremes from the highest livable temperature (118° F. or higher) to the temperature of perennial snows. Rainfall varies from less than 3 inches annually in the desert lands of the south to more than 50 inches in the northwest. Agriculture everywhere depends upon the character of the soil and the climatic conditions. To the great variety of soils and the extremes of temperature, the great variety of crops grown in California is due.

Soils Classified According to Origin

Soils are classified according to their origin into series, and into types as to texture and chemical characters. The rocks of all formations disintegrate under the weathering action of climatic influences, as heat and cold, wind and rain. Erosion carries the soil, broken rock, from mountains, hills and slopes, to lower lands. Broken rock becomes soil when it remains in one place long enough for a definite cover to gather at the surface where plants may gain a foothold. Thus broken rock

Courtesy U. S. Bureau of Soils

FIG. 98. Vineyard near Hollister, San Benito County. Gravelly sandy loam. Diablo Range in background.

becomes soil when it holds still long enough for vegetation to become established. Sunshine and moisture combine to transform the minerals of the rocks into plant food. Soils are classified into *series* on the basis of origin, color, topography, and structural characteristics. Residual soils are derived from consolidated rocks by weathering, on hills and slopes. In the northern part of the State soils derived from sedimentary rocks form the Altamont series; soils from igneous rocks, the Lassen series. Soils of the old valley-filling deposits are formed by weathering in place of the unconsolidated materials that have been brought down from the hills by streams. These are classified into several series. Recent-alluvial soils have been derived from materials washed down in recent time, and have not been much affected by weathering. These also are grouped in several series. Valley-filling soils are grouped into series on the basis of age, represented by the degree of weathering, as young, mature, or old.

The soils of many provinces of the State have been studied and classified by the U. S. Bureau of Soils and the State Experiment Station. In the desert region of the Coachella Valley 17 soil *types* have been named. In the lava-covered region of the far north, in the Big Valley area of Modoc and Lassen counties, 18 types have been named. In the Napa Valley no less than 52 types have been described; in the San Joaquin Valley, Fresno area, 26 types. In the Placerville area, where soils have been washed extensively for gold, 15 agricultural soil types have been identified. In the Riverside area, representative of the vast citrous fruit orchard lands, 36 types have been distinguished.

Soils from Rocks

The soils of all these regions have come from the rocks that occur in those regions. In the mountain regions there may be no soil, none having yet formed, or washed away as fast as formed. On the slopes occur stony loam. Farther down the slopes are soils grading in texture from stony loam through gravelly loam, sandy loam, loam, clay loam, till finally the particles of broken rock are so impalpably fine that the stone particles are indistinguishable, and the soil is a *clay*. Thus in texture soils range all the way from coarse fragments of hard rock to plastic clay. So it is seen that soil is a form of rock. It is a geological specimen. Its origin and character are determined by geologic processes.

Out of rocks, sunshine and moisture (water) come all our agricultural resources. Sunshine we cannot control; water can be controlled only within certain limits. The soil is as the Lord made it. Since all plants do not thrive on all soils, it is important to know something of the nature of the soil before undertaking the growing of any particular crop on that soil. Many a heartache and bitter disappointment have come to honest investors who, because they did not know the nature of soils, and maybe listened to the promotion arguments of a not too scrupulous sales agent, undertook to raise some kind of fruit on a soil and under sunshine and moisture conditions where this particular fruit was not at home.

Courtesy U. S. Bureau of Soils

FIG. 99. Onion field, on the fine sandy loam of the Coachella Valley.

It is true that low prices on the world's markets may become such as to make the growing of a particular crop unprofitable, but that does not explain or excuse loss from planting orange, peach, plum, or apple trees on land not suited to those crops, or grapes on land where, under given sunshine and moisture conditions, vineyards could not be made to thrive. Why are onions grown on so tremendous a scale in the Coachella Valley and not in Fresno or the Napa Valley? Why raisins from grapes at Fresno, and wine from grapes in the Napa Valley, but not raisins? With sunshine and moisture what they are it is clear that the nature of the soil determines the character of the crops that can be most successfully grown. In other words, the husbandman must needs know soils; he must be a practical geologist (though he may not know it by that name). When in some locality prune trees are seen being destroyed; apple trees in another being pulled out to be replaced by something different; grape vineyards destroyed because they are unprofitable; peach trees removed to give place to strawberries or other crop; because these various plantings proved to be on soils not suited, this is heartbreaking. It represents years of hard labor and untold investment totally lost. Experiment stations supported by public taxation have done much to determine what can and cannot be successfully done on given types of soils under known conditions of sunshine and moisture. But not all men listen to the advice of specialists, and indeed specialists may err. The unscrupulous sales agent paints a glowing picture that skillfully avoids any reference to the geology of soils. Hence grief has come to honest investors, not only in California but wherever new enterprises in the production of special crops have been launched and promoted without due regard to what nature has done in the geological processes of soil making.

Who has not witnessed the painful struggle of the attempt to grow oranges on land that, with a sensible knowledge of the geology of soils and of climatic conditions, should never have been planted to orange trees? But somebody wanted to sell land and somebody wanted to raise oranges!

The Farmer a Practical Geologist

Farmers, those who till the soil, are practical geologists. They may not know it. They may not "believe" in geology. In the Napa Valley grapes are widely grown for the production of wine. But wine-producing grapes do not grow on all kinds of soil. Some thousands of acres of wine-grape vineyards are on the "floor" soils of the Napa Valley. Certain varieties thrive on the lower slopes of the mountains. The valley bottom soils are the result of geologic processes that have been long going on. The valley soils are composed of innumerable millions of particles of broken rock—granitic rocks, lavas, sedimentary rocks. The soils have become "mature" under the action of sun and moisture during long periods. From deposits of "raw" rock fertile soils have been developed. They are "rich" because they have not been leached of their soluble minerals. Chemically the minerals of the rocks have been released in the long

Courtesy U. S. Bureau of Soils

FIG. 100. Century-old pear trees, near San Juan Bautista, on Yolo silt loam. These trees are the remnant of a pear-and-apple orchard planted shortly after the founding of the San Juan Bautista Mission, in 1797.

slow processes of the "maturing" of the soils from broken fragments of rock. The soils have been formed from the "wash" of the mountains surrounding during long ages. During the long time since they were deposited the stone particles have been acted upon by weathering agencies, and organic matter has accumulated in the soil layers near the surface. Subsoils have compacted, thereby giving water-holding quality, but soils from all kinds of rocks do not behave in the same manner. A "granite" soil is one thing; a limestone soil is another; a sandstone soil is different again; and a shale becomes a soil differing from all the others.

Granite Rock Breaks up into Clay and Sand

Granite rock, generally speaking, is composed of quartz, feldspar and mica. Granite is thought of as a hard and durable rock. Under the action of weathering agencies the hardest granite crumbles and decays. The mica decomposes and becomes clay; feldspar, hard when fresh, breaks down into blue clay; quartz, the hardest and most resistant to any dissolving influences of weathering, persists, and the tiny particles become the common sand of the soils. Thus granite rock decomposes into *loam*—a mixture of sand and clay. Shale, which when metamorphosed by heat and pressure is slate, decomposes under the action of the weather (frost, air, heat and moisture) and becomes clay. Sandstone, which is quartz grains cemented together, becomes sand when the cementing material is dissolved. Limestone, which when pure is calcium carbonate ($CaCO_3$), dissolves in percolating soil water, carbon dioxide escapes as a gas, and the lime, being soluble in water, leaches away. Lavas, as rhyolite and basalt, break up under the action of sunshine and rain and become clay, with some quartz sand.

All the various types of rocks break up wherever exposed to the action of the elements, and intermingle as they are washed down the slopes, and hence the many types of soils in the valleys. Humus, or decayed organic matter, gathers in the soils in the process of time, and thus the great variety of soils is formed, differing widely in fertility or productiveness according to the varying conditions under which they form and the variety of materials of which they are composed. Iron, an element widely distributed in the rocks of the earth, oxidizes to a reddish color, and so gives a reddish-brown color to the soil. The mineral element of humus is carbon, which is black in color, and this gives a black color to the soil. Other minerals oxidize to different colors, adding to the complexity of colors in the soil and adding various plant food elements. Sodium carbonate, or black alkali, is a common mineral in many soils. It is soluble in water, and when it accumulates through lack of sufficient drainage becomes a detriment in the soil. Sodium carbonate is white in color, but as it combines with the tissues of plants it burns or oxidizes these and leaves the black carbon of the plants. It is therefore called "black alkali."

A Great Variety of Seeds on a Variety of Soils

Onions are grown on an immense scale on Indio very fine sandy loam in the Coachella Valley; lettuce abounds on what is classed as Salinas clay soil in the Salinas Valley; in the Riverside area 90% of the very extensively grown orange crop is grown on soils of sandy and gravelly type; and peaches, of which there is a large acreage, are grown on soils which are technically classified as sand (Hanford and Tujunga sands). Sugar beets are extensively grown on silt loam soils in this territory. In King and Tulare counties cotton thrives on the sandy loam soils. In the Santa Clara Valley vegetable seeds are very extensively grown on soils of heavier texture of the Yolo series, soils that have been formed from recently-transported materials carried down from the sedimentary (or metamorphic) rocks of the adjacent mountain slopes. Ninety-five per cent of the lettuce seed, nearly all the radish seed, and 75% of the onion seed, used in the United States are grown in this region. About Auburn peaches constitute the largest commercial crop shipped out of that area. The peach orchards are largely on well drained sandy residual soils derived from granitic rocks, technically known as Aiken clay loam. At Placerville pears on

Aiken clay loam are the outstanding crop. On the lava soils of the far north, in the Big Valley district of Lassen and Modoc counties, the livestock industry predominates, cattle leading and sheep next, based on the production of alfalfa and other forage feed crops. The farms are large, ranging from 1,000 to 2,000

Courtesy Salinas Chamber of Commerce

Fig. 101. Lettuce field in Salinas Valley. Gabilan Range in background.

acres. This contrasts with the one to five-acre farms or "ranches" of many valleys farther south.

Climate and Character of Soil Must be Recognized

In imagination change places with these crops, and it is plain that the results would be disastrous. The two factors, soil and climate, determine what may and may not be grown. The farmer who brings with him the methods, and plans to use the crops, with which he was familiar, and which he found successful in another State, cannot transplant these crops and methods to these fundamentally different conditions without great disappointment and loss. No, he must meet nature on her own ground. He must first recognize the climatic conditions and the nature of the soil (he may not call the latter by the name of geology, but that is what it is).

The basis for the understanding of soils is a knowledge of geology. The rocks of the earth are the source of the soils. The processes by which rocks are broken are the processes by which soils have been formed. Soil, in conjunction with water and climate, is the basis of agriculture. Agriculture, by and large, is the source of the world's food supply. Thus, upon geology and geologic processes rests the future of civilization and the existence of the human race.

Chapter XXIII

GEOLOGY FROM A MOTOR CAR

A Guide for Tourists

To use this "guide," read *down* or *up* according to whether going north or south. For example: if going north from Los Angeles to San Francisco turn to p. 370 and read *down*. If proceeding south from San Francisco to Los Angeles via the Coast route, turn to p. 384 and follow the paragraphs in succession backwards, or *up*. If starting from San Francisco to cross the Sierra crest, read *down* from p. 387. If entering the State from the east via Donner Pass, turn to p. 398 and read paragraph by paragraph backward, or *up*. To use the guide in planning any trip see the "Guide for Tourists" on this page. By reading the paragraphs *down* or *up* "what to see" on any trip may be followed. For any place on any route see the general index at the end of the volume.

Not all the scenic routes in California are described in the 2,638 miles covered by these tours. To adequately describe all would require a large volume. Geologic facts of interest are pointed out on some important highways for the benefit of those who wish to *see* what they look at as they go. Do not be in a hurry. To *travel* from one place to another is one thing. To really see and enjoy the landscape is another. Speeding at 60 or 70 miles an hour, with stops only for gasoline, may be "travel"; it is *not* seeing the country. There are those who travel for the sole purpose of getting to some other place (generally in a hurry). Others enjoy what they see as they go. The following pages are for the latter class.

There is no particular reason why these "tours" should begin at San Diego. It was from there that the author made his first auto tour "seeing California," and this remains in his mind as a "gem" tour. But any trip anywhere in California may be a "gem tour" if only one "has eyes to see,"—and is not in too much of a hurry.

Route A. San Diego, via Salton Sea and Palm Springs to Los Angeles. 390 Miles

The San Diego Coastal Plain

San Diego to El Centro, 123 miles. The route lies across the Peninsular Range of mountains. (See Chap. XVII.) The city is about 50 feet above sea level. In Quaternary time, geologically yesterday, the land was about 200 feet higher than now. Rivers entering the ocean cut deep valleys. Later the land sank about 100 feet lower than now, and the river mouths were "drowned." San Diego Bay is cut off from the ocean by the filling of sediments carried down by the streams and which have not been carried away since the land was elevated to its present height. Mission Bay, north of the city, is the drowned mouth of San Diego River. Rising above the city to the east are mesas or terraces and wave-cut cliffs 75 to 100 feet above sea level, cut by the waves when the land was 100 feet lower and extended farther west than now. The Peninsular Range is a vast block of the earth's crust that was uplifted, broken by faults on the east, and rotated, that is, lifted more on the east and less on the west. The coastal plain, extending 8 to 12 miles to the east from the ocean, was in comparatively recent time geologically (Quaternary) depressed so that it was covered by the sea. Just how far what is now the Peninsular Range was affected by these earth movements is not known, but the coastal

Photo by A. J. Ellis, U. S. Geol. Survey

FIG. 102. Wave-worn pebbles, Encinitas. (A fine beach is at Oceanside.) Pebbles carried in seaweeds by tides.

belt was depressed below sea level. This is now the belt of flat, high upland benches or terraces, popularly called the mesas. Linda Vista mesa, to the north, stands 400 to 500 feet above sea level. Terraces range in height from 20 feet to 1200 feet above sea level, but range generally from 300 to 500 feet.

Mounds or hummocks on Linda Vista mesa have attracted much attention, and may be observed from the highway. They are thought to be wind-formed, the product of desert winds. Clumps of vegetation serving as anchors have caught the drifting sands and caused the mounds to form.

Across the Peninsular Range

The route is across the Peninsular Range of mountains. LaMesa, 11 miles from San Diego, is 539 feet above sea level. El Cajon Valley (17 miles) is slightly lower (450 feet), with Mount Helix rising conspicuously south of the highway. The mesa floor rises again to 490 feet at Bostonia (19 miles). Winding over a fine mountain highway Alpine (31 miles) is reached at an altitude of 1,860 feet. The mountain climb continues to 3,540 feet at Descanso (43 miles). Proceeding east, a few miles to the north is Cuyamaca Peak (altitude 6,515 feet), and immediately south of the highway is Gautay Mountain (5,300 feet). Here is the axis or summit of the Peninsular Range, and the descent of the eastern slope begins. The elevation at Laguna Jct. (49 miles) is 4,050 feet. Turning southeast in Cottonwood Valley the eastern fault scarp of the Laguna Mountain range stands boldly out on the west. Swinging far south around the south end of the Laguna Mountain range, crossing McCain's Plateau, Jacumba is reached (2,800 feet; 76 miles), one-half mile north of the Mexican Boundary. To the north is Carrizo Gorge, which is followed by the railroad but not by the highway. The gorge is eroding its way backward into the soft Tertiary sediments from the north end of Jacumba Valley. After passing Smugglers' Cave, turn north and pause for a look at the rocks in Boulder Park, at the foot of the Jacumba Mountains. Jacumba Valley is a faulted valley, and withal has been overwhelmed by outpourings of volcanic lavas.

Points of Interest on East Slope

Take time to enjoy Inkopah Gorge after passing Boulder Park and Mountain Springs Park. Stop and take a drink at Coyote Wells, and turn south and visit the Petrified Forest if time will permit. It will not be possible to see everything that would be of interest on one trip, but pause at Coyote Wells and make a side excursion north into the Coyote Mountains (Coyote Peak stands 2,420 feet above the plain to the east) if you are interested to see the coral reefs in the cliff sides, relics of animal life of the ocean that was here when the rocks were laid down as sediments on its bottom (in Tertiary time). Painted Gorge has been eroded in the soft sedimentary rocks by the small stream which crosses the highway at Coyote Wells. Outcropping oyster beds occur southeast of Coyote Wells.

The Imperial Valley

Continuing out upon the plain of Imperial Valley to Plaster City, cross Bullhead Slough and New River to Seeley (there is a good bridge over the slough, so you will not need to get mired). New River carries water (sometimes) to Salton Sea from Colorado River. And here is El Centro, in the heart of Imperial Valley, 50 feet below sea level, or 100 feet lower than San Diego. The route has been over a vast mountain range, the highest peaks of which rise above 6,000 feet above the sea. The descent after crossing the axis of the range winds down the fault walls that form the eastern side of the range. The vast broad flat of the Imperial Valley is the bottom of the sunken valley that was probably depressed below sea level at the time when the great Peninsular Range was broken off and uplifted. The fault walls form the mountain sides which bound the valley on the west, the Elsinore fault, which extends far to the north through San Gorgonio Pass and beyond.

Before turning north from El Centro it may be of interest to swing south a few miles to Calexico, at the International Boundary, and of course to Mexicali across the line! The highline canal is crossed by which water from the Colorado River is carried to this modern Garden of Eden, appropriately called Imperial Valley.

El Centro to Brawley (elevation–115 feet), 14 miles; Travertine Rock, 45 miles; Palm Springs, 102 miles.

Miniature Volcanoes in Action

It will be well if time will permit to rest at the Barbara Worth Hotel and make side excursions to points of interest, the like of which will not be likely to be seen anywhere else. Mud geysers occur along the axis of the valley from Imperial Jct. (Niland) south to Volcano Lake in Mexico. Innumerable small mud cones, solfataras, and boiling pools of mud and water emit steam, smoke and sulphurous gases, accompanied by a dull rumbling sound. The "dry ice" plant is a little way off the main highway. Here the natural gas (carbon dioxide) is caught as it escapes from a well, and carloads of ice that will blister your hands if you touch it are shipped out.

Shore-Line of Lake Cahuilla

Proceeding north along the shore of the Salton Sea, an eroded ridge, the beach or shore-line of ancient Lake Cahuilla (see Chap. IX) will be observed at many points at the left. This old beach line is about 40 feet above sea level. The level plain over which we are passing is the ancient lake bottom. The present Salton Sea, from which the evaporation is at the rate of more than seven feet per annum, whereas the annual precipitation is less than three inches per year, lies in the axis of the ancient lake bed.

Fossils in Rocks of Carrizo Mountain

Superstition Mountain, 15 miles west of Brawley, rises 764 feet above the ancient lake bottom. It is a granite core surrounded by low hills of sandstone and clay (the latter of Tertiary age). Carrizo and Black Mountains, called also Coyote and Fish Creek Mountains, west of Superstition Mountain, are outliers of the Peninsular Range. They are islands of granitic and metamorphic rocks, which rise through encircling terranes of sedimentary and volcanic rocks of Miocene or later Tertiary age. The unconformity between these later deposits and the granitic bed-rock is very marked, but it is necessary to depart from the main highway to study these features. Carrizo Mountain has become noted because of the occurrence of fossils. The most conspicuous fossil localities are on the northern and the southern slopes of this mountain. The shells or their casts have weathered out and strew the slopes in great profusion. Corals, sea-urchins, oysters, mollusks (scallops), and snails or conchs (gasteropods) are everywhere. The fossils occur in coarse-grained sandstone of Miocene (Tertiary) age. A fossil coral reef is near the head of Barrett Canyon, on the south slope of Black or Fish Creek Mountain, lying directly upon the igneous rocks which form the bed-rock on which the Miocene sediments were laid down. These fossil beds can be reached from the old stage road between Plaster City and Carrizo, about 15 miles.

Travertine Rock and Ancient Shore-Line

Travertine Rock, 45 miles from El Centro, is two or three miles from the present shore of Salton Sea. The granitic rocks of the Santa Rosa Range here projected into Lake Cahuilla, and were washed by the waves when the beach, which is marked by the ridge seen at the left of the highway, was being formed. The old beach line is about 40 feet above sea level, or about 315 feet above the present surface of Salton Sea. Travertine Rock is named for the deposits of travertine (calcium carbonate) deposited upon the rocks from the waves of the ancient Lake Cahuilla. The rocks extend out half a mile northeast from the eastern end of the Santa Rosa Range.

Coachella Valley Lies Ahead

Turning from the main highway at Oasis, about seven miles north of Travertine Rocks, the famed Coachella Valley lies ahead. Mecca (–197 feet), Arabia, and Indio (–22 feet) suggest Oriental Asia. Thermal, six miles north toward Coachella, means "heat." Turn left at Indio for Palm Springs, but do not fail to visit the date gardens. Good tourist accommodations are available, and the dates, the magnificent palm trees, the tropical fruits, will make a stop here enjoyable and not to be forgotten. South from Indian Wells a few miles is unique La Quinta with its typical Spanish architecture close against the foot of the San Jacinto Mountains. Cathedral City and Palm Springs lie ahead.

Here Is Palm Springs

And lo! here is Palm Springs! Here are the finest and most modern accommodations in the midst of the most abject desert. From sage-brush, greasewood, and cacti, horned toads and the parched arid land, suddenly the most modern buildings and verdant vegetation loom before the astonished gaze. If the enchantment of this marvelous city in the desert leaves any longing for the wild go up Palm Canyon, or explore any of the canyons which serrate the rugged sides of San Jacinto Mountain. Palm Canyon extends almost due south 25 miles, having its head on Santa Rosa Peak. The west fork of Whitewater River follows the line of a fault and has eroded the deep gorge. On the east side of the gorge the rock wall is metamorphosed sedimentary rock; the west wall is the gneissoid-granite of the San Jacinto Mountains.

Mount Jacinto and San Andreas Fault

San Jacinto Peak (10,805 feet) towers overhead. From Indio north, off to the right for several miles, the steep perfect scarp of the Indio fault faces the valley, 100 to 300 feet high. Two ranges of hills, the Indio Hills north and Mecca Hills south, face the valley on the east, the ranges rising to a height of about 1,000 feet above the plain. The hills are eroded to a magnificent type of badland topography. The Indio fault, which determines the east wall or side of the valley, is regarded as the continuation of the San Andreas fault. Mud volcanoes extend along a line through the axis of the Imperial Valley to Volcano Lake in Mexico. The heat of the mud volcanoes, boiling mud pots, and mud geysers, is thought to be related to the San Andreas fault, and to be derived from the volcanic heat associated with that great break or fracture in the crust of the earth.

Alternate Route (a), Palm Springs to Los Angeles via Palms-to-Pines Highway, 167 miles. (Alternate Route (b), via San Gorgonio Pass, 107 miles, see p. 345)

Leaving Palm Springs via Palms-to-Pines Highway the route is over the San Jacinto Mountains, and is most charming. Retrace the course to the date gardens, 13 miles, then turn up Dead Indian Creek, a typical desert canyon or arroyo, and begin the climb over the San Jacinto Mountains. There is no need to get dizzy on the winding ascent provided the driver does not round the curves too fast. It is a fine ride up and over Black Mountain, past the head of Deep Canyon, then swinging around the base of Sugar Loaf Mountain (4,780 feet) onto Pinyon Flat. This is a high mountain "flat," not a valley proper. Crossing a low ridge between mountains, beyond is Vandeventer Flat. Swing around the north base of Lookout Mountain (5,535 feet), thence northwest past Bunker ranch, down a faulted valley, past Gleneagle (4,665 feet) and Kenworthy Ranger station to Hemet Lake (elevation 4,350 feet). Thomas Mountain is off to the left (6,823 feet). A fork of San Jacinto River follows the San Jacinto fault zone (called also the Thomas Mountain fault) through Hemet Valley to Hemet Lake. Off the highway to the right are Tahquitz Lodge and Idyllwild, in San Jacinto mountain forest surroundings. In the distance to the north (right) are Tahquitz Peak (8,826 feet) and San Jacinto Peak (10,805 feet). The granite rock which forms the great core and body of the San Jacinto Range is on either side of Hemet Valley, broken here by the Thomas fault southwest of the lake and valley. The Hot Springs fault is along the northeast side of San Jacinto Valley east of Hemet (city), the uplifted granite wall above and loosely consolidated sandstone and shale flanking the mountain below (at the left). West of Tahquitz Lodge and the junction of the highway that leads by Idyllwild over the mountain range to Banning the highway winds along the valley of San Jacinto River, which is eroded in the crushed and fractured rocks of the fault zone. Hemet (67 miles from Palm Springs) is on the broad alluvial plain of San Jacinto Valley. San Jacinto (town) is three miles north.

The Perris Plain

The route west to Perris (14 miles) is across the eroded rolling granite plain (described in Chap. XVIII). From Perris the highway north leads via March Field to Riverside (17 miles). Turn left (southwest) at Perris, over the rolling granite-knobbed plain to Elsinore (11 miles). Lake Elsinore lies in the valley which was formed by the sinking of the land east of the fault that bounds the Santa Ana Mountains on the east. This is known as the Elsinore fault. Temescal Canyon lies along the foot of the fault scarp, which is the eastern steep rugged face of the Santa Ana Range. The fault extends for 50 miles, and joins the Whittier fault in the north. The Elsinore basin is the result of a downward movement of the rock floor east of the fault.

Temescal Valley and Clay Deposits

At Alberhill, seven miles north of Elsinore, are clay deposits which form the basis of an important ceramic industry. Glazed and unglazed tile and brick are manufactured on a large scale. As much as 100,000 tons of clays of many distinct varieties are used yearly. The clays come largely from three different localities, though there are many pits occurring in an area 30 miles long and two miles wide. The clays crop out in irregular patches among sandstones and shales. They lie directly upon or close to the basement bed-rock of granite, and are of early Tertiary age.

Down Temescal Valley to the north the land slopes at a high angle up to the foot of the eastern escarpment of the Santa Ana Mountains. The escarpment is steep and highly dissected. At its base low fault scarps indicate that movement along the fault plane has occurred in recent time. About Corona the land is extensively cultivated and planted largely to orange trees.

If it should be desired to cross the high crest of the Santa Ana Mountains a highway turns west one mile south of Corona and crosses the high range to Orange in the Santa Ana Valley. (See Chapter XVII.)

Santa Ana Canyon and Terraces

Turning west at Corona the head of Santa Ana Canyon is reached. Beds of Tertiary age are followed by cliffs of greenish shale interbedded with brown sandstone (Cretaceous) for two miles. Terraces of gravel built by the meandering Santa Ana River are crossed. A monument at the south end of the bridge across the Santa Ana River marks the place where the first public school in California was opened in 1867. A broad sand wash of Santa Ana River extends to gravelly terraces formed by the side-cutting of the river. To prevent overflow of these bottom lands in times of flood an attempt has been made to obviate this danger by construction of a dam at Prado, near the eastern end of the canyon.

Coyote Hills and Whittier Fault

Fullerton is situated in the heart of the orange belt, at the foot of the southern slope of the East Coyote Hills. Five miles north of Fullerton East and West Coyote Hills are separated by a low divide. These two low hills are anticlinal ridges of folded Fernando (late Tertiary) beds. The highway crosses this low divide to La Habra. Eight miles west is Whittier. Northeast of the town of Whittier, at the lower end of Turnbull Canyon, a section is exposed which shows the result of tilting and folding of the rocks due to movement along the Whittier fault zone. The Merced Hills at Montebello were elevated as a result of folding along the northwestward continuation of the Whittier fault zone.

Alternate Route (b), Palm Springs to Los Angeles via San Gorgonio Pass

The flat arid plain of the desert continues north from Palm Springs, the lofty peak of San Jacinto towering high on the left. The gravelly "wash" of Whitewater River spreads across the valley to the foot of the Indio Hills. Whitewater River comes from far north in the San Bernardino Mountains, and at flood seasons carries a tremendous volume of water, with the result that the valley is strewn with the rock fragments of the "wash." The water of the stream may reach the Salton Sea at such times, but otherwise, and during most of the year, the water disappears in the gravels of the wash.

The town of Whitewater is 12 miles from Palm Springs, at the eastern end of the pass discovered by Wm. P. Blake in 1853, and haled as the much sought accessible route for a railroad between Los Angeles Basin and the interior of the continent. The discovery of this pass by the Blake party determined the construction of the Southern Pacific Railroad. Blake and his party entered the Pass from the west, observing with great joy that the summit elevation was 2,580 feet, between the towering peaks of San Gorgonio on the north and San Jacinto on the south. Here was the true gateway from the interior to the Pacific Ocean. Said Professor Blake, in writing afterward of his experience in 1853: "Here, at last, was discovered the greatest break through the western Cordilleras, leading from the slopes of Los Angeles and the Pacific into the interior wilderness."

Side Trip to Devil's Garden

It will be interesting to pause at Whitewater and enjoy a side trip into the Mojave Desert, which is just across the San

Bernardino Range to the north, via the Morongo Valley. The "forest" of Joshua trees in the park, which has been appropriately (and wisely) established as a national monument, will stand in the memory as a unique desert feature, and Twenty-nine Palms, claimed to be the only oasis (naturally fertile area in a desert) in the State, will repay the journey of 47 miles from Whitewater.

At any rate visit the Devil's Garden before proceeding westward. You will say the Devil's Garden is rightly named! But this was "advertised" as a *desert* trip! This is the last real taste of desert before entering the San Gorgonio Pass. It may seem incredible that rock fragments of such size, huge boulders weighing many tons, and in such abundance, should be moved by running water, but remember the formula (for the carrying power of streams) figured out by physicists: the transporting power increases as the sixth power of the velocity. The rocks of the Devil's Garden are the product of torrential floods of Mission Creek.

San Gorgonio Pass a Sunken Valley, or Graben

Proceeding westward through San Gorgonio Pass, Cabazon (eight miles from Whitewater) Banning (14 miles), and Beaumont (20 miles) are in the famed sunken faulted valley which lies between the lofty San Gorgonio Peak on the north, and San Jacinto Peak on the south. This valley is what geologists call a "graben," that is, a valley floor depressed between uplifted fault walls. The San Andreas fault marks the wall of the uplifted San Bernardino Mountains on the north and the great uplifted block of the San Jacinto Mountains on the south. The alluvial fans that have been formed by streams flowing down the steep mountain walls have been described in Chapter XVII. The ride through the Pass will be delightful (if you are not in too much hurry). At Cabazon and Banning fine orchards will be observed on the lower slopes of the fans which occur at the mouths of the mountain streams.

Islands of Schistose Rock and Badlands

Near Beaumont the "divide" (2,580 feet) is crossed, and the highway descends to Redlands (1,350 feet), crossing Yucaipe Valley. The mountain slope above Beaumont is no longer the hard granite of the San Jacinto Mountains, but is the soft friable Tertiary formation, with "islands" of granite or metamorphosed schistose rocks rising above the general surface. Crafton Hills, to the north of Yucaipe Valley, is an "island" of schistose rocks, and a smaller "island" of similar rocks is east of Redlands Heights. Redlands Heights, north and east of San Timoteo Canyon, owes its "height" to elevation or uplift of the soft and friable strata, which dip toward the north from San Timoteo Canyon.

South of San Timoteo Canyon are the Bad Lands, well worth a trip down the Morena grade (from one mile west of Beaumont). The Bad Lands are thought to represent the eastern continuation of the fold or upbending of the rocks by which the Bunker Hill Dike was formed. This uplift or fold in the formations forms the divide between San Timoteo Canyon and the San Jacinto Valley. The rocks are soft and friable shales and sandstones, and so, being uplifted, are rapidly eroded. San Timoteo Canyon is cut along the north side of the Bad Lands belt. The Bad Lands topography is purely a result of erosion in soft friable rocks.

San Bernardino and the Rim-of-the-World

San Bernardino (El. 1,073 feet) is located on the cienaga formed on the depressed floor of the sunken basin at the foot of the mountain escarpment of San Andreas fault. The basin is filled with "wash" from the mountains, and this becomes saturated with water, forming the cienaga. The Bunker Hill Dike acts as a dam holding back the water. (See Fig. 75.)

A side excursion from San Bernardino over "the rim-of-the-world" highway to Arrowhead Lake (elevation 5,100 feet; distance from San Bernardino 22 miles) and Bear Lake (El.

6,750 feet; 47 miles from San Bernardino), is one for the safe and sane driver. A fine paved road with hair-pin curves winds up the mountain slope and along the rim of the plateau. If you are in a hurry do not go. Splendid hotels and excellent accommodations, with facilities for entertainment, are available.

West through San Gabriel Valley

From San Bernardino west two principal highways vie with each other to give the tires of your car footing. The San Bernardino Mountains are separated from the San Gabriel Range by Cajon Canyon, through which runs San Andreas fault. The south wall of the San Gabriel Mountains is the escarpment of the Sierra Madre fault. This fault extends west to Glendale and the San Fernando Valley. Cajon Canyon, which separates the two mountain ranges, meets Lytle Creek, and the two streams debouch upon the plain in a broad alluvial apron or "wash." The gravelly "wash" or apron formed by the combined detritus of Cajon and Lytle streams is about 10 miles across, and extends to the Santa Ana River. To the east of the Cajon-Lytle Creek wash is the San Bernardino Basin. To the west, along the foot of the fault scarp of the San Gabriel Mountains, is the so-called San Gabriel Valley. The "Valley" is the sunken plain which was depressed (probably) at the time the San Gabriel Mountains were uplifted, and which has since been filled by detritus washed from the mountains. The floor of the valley is approximately 1,000 feet below the present surface. The plain of "San Gabriel Valley" is a succession of alluvial fans formed by the mountain streams which descend from the high lands through steep-walled canyons, and debouch upon the plain of the "Valley."

Alluvial Aprons or "Washes" Make up Floor of San Gabriel Valley

Many fine orchards of citrus trees and grape vineyards flourish on the sandy "wash" soils of the alluvial plain of the

"Valley," which slopes from the foot of the escarpment toward the south. At the mouths of the canyons coarse gravel and rock fragments of great size have been deposited by the torrential streams at flood seasons. Great damage is done by uncontrollable floods which pour from the canyon mouths in seasons of exceptional precipitation.

If the foothill route is followed from San Bernardino to Los Angeles a nearer view of the mountains will be afforded. For convenience the towns en route and the more important canyon mouths that will be passed are indicated. Citrus orchards, grape vineyards, hot-dog stands, wine refectories, gasoline filling stations, and other "filling" stations, divert the attention from the great fault scarp of the mountains, but the drive will be exhilarating, and will be greatly enjoyed by lovers of nature; by those who see beyond the rocks to the forces that have been long working in fashioning the landscape, over which it is possible to travel at so great speed that what is looked at may not be really seen.

San Bernardino to Fontana (six miles); Etiwanda (12 miles); Day and Deer canyons are to the north. Cucamonga (15 miles); Cucamonga Peak (El. 8,911 feet) frowns from the San Gabriel Range, while the vineyards at the foot of the mountain yield wine to cause a smile. Upland (21 miles); Claremont (25 miles); on the alluvial fan of San Antonio Creek, which pours out of Icehouse Canyon from the foot of Mount San Antonio, locally known as "Old Baldy" (El. 10,080 feet). San Dimas wash, from San Dimas Canyon, and the fan of Dalton Canyon, are crossed east of Azusa (36 miles). San Gabriel River flows from far up in the San Gabriel Mountains through a steepwalled canyon cut in hard diorite and metamorphosed sedimentary and igneous rocks, and flows directly across the San Gabriel Valley, and has built an extensive alluvial apron or "wash" of boulders, gravel and sand, south and west of Azusa. West of Arcadia (45 miles) turn southwest on Huntington Drive, to Alhambra and Los Angeles. North and west from Arcadia is Pasadena (eight miles) and beyond the Arroyo Seco is the faulted valley of La Canada. The Verdugo Mountains and San Rafael Hills are cut off from San Gabriel Mountain pleateau by faults and the depressed valley of La Canada.

Route B. San Bernardino, via Cajon Pass and Mojave Desert to Death Valley. 377 Miles

San Bernardino is on the depressed floor of the valley or basin that lies at the foot of the San Bernardino Mountains. The mountain range has been uplifted about 6,000 feet along the line of fracture of the San Andreas fault. This journey is over a mountain range, from the valley where orange orchards and vineyards flourish, to the desert where the cactus and sage brush grow scantily on the arid soil through which the highway passes. Cajon Canyon is a notch cut in the mountains where the fractured rocks of the San Andreas fault made the rapid erosion of the deep canyon possible.

Baked Sandstone and Shales in Cajon Canyon

At the left, as the ascent is made up the canyon, tilted outcropping strata of metamorphosed sandstones and shales (probably of Palaeozoic age) stand out in grotesque monuments. Cajon Canyon and the San Andreas fault, which runs through it, mark the line of separation between the San Bernardino and San Gabriel mountain ranges. Over the gravelly sandy wash of the lower canyon the highway rises from 1,073 feet at San Bernardino to 4,301 feet at Summit Pass, 18 miles. Mountain rivulets from the summit carry water northward to Mojave River. Arrowhead Lake, on the rim of the mountains near the summit 10 miles east of the highway, is at an elevation of 6,100 feet. Its waters drain southward to the Santa Ana River and the Pacific Ocean. Lone Pine Canyon marks the line of the San Andreas fault to the northwest. The elevation of the head of the canyon is 6,050 feet, and descends to 2,650 feet at the junction with Cajon Canyon. Lone Pine and Cajon canyons join near Cosy Dell. From Cosy Dell the highway leads up Cajon Canyon over the summit or rim of the mountains to the broad arid plain of Mojave Desert, to Victorville.

Upper Mojave Valley Superimposed upon the Plain

The upper Mojave Valley is a great alluvial plain that slopes gently northward from the San Bernardino and San Gabriel Mountains. The plain has been formed from disintegrated rock debris washed down from these and other mountains. The upper Mojave River flows through a channel eroded in the deep alluvial soil. It is somewhat of a surprise to find that the river has cut through hard granitic rocks at the Narrows, north and south of Victorville, instead of going around them. The river is what geologists call a superimposed stream, that is, one let down upon the landscape regardless of the character of the rocks. The river formerly flowed at a higher level, its channel cut in the soft alluvial soil of the plains. As the plain was lowered by erosion the river cut down its channel, and when the hard granitic rocks were encountered, its channel having been established, the river cut down into the rocks as fast as the land rose. Hence the river now follows its original course through the rocks rather than around them.

Desert Plain Broken by Many Mountains

The surface of the Mojave desert plain is broken by many mountains, hills, and ridges. Loosely consolidated alluvium is widespread over the valleys, "wash" from the mountains and hills. Sheet erosion—the action of wind, rain and heat—under arid conditions results in the slow crumbling of the rocks and the accumulation of gravel, sand, and clay in the valleys. The vast plain of the desert stretches far to the north and east. Granitic mountains rise above the plain. Alluvial wash, gravel, sand and clay, fills the basins between the mountains, ridges and hills. Well borings to depths of 500 to 900 feet have not reached the bed-rock. Coarser gravel skirts the mountain slopes, and finer detrital material lies farther from the rocky uplands. The Mojave River has cut its channel 75 to 100 feet below the surface of the alluvial plain. The alluvium is sufficiently indurated (solidified) so that the walls of the river channel stand in vertical cliffs, with eroded pinnacles. Such cliffs stand out notably west of Bryman station, north of Victorville.

Victorville, 40 miles from San Bernardino (El. 2,716 feet).

Off to the east from Victorville are the Granite Mountains, and farther still are the Ord Mountains. Gold and copper are reported as occurring in the latter. To the northwest are the vari-colored Calico Mountains, so named because of the vivid green, brown, red, and yellow rocks that are exposed in the eroded cliffs. Silver of a value exceeding one million dollars annually is stated to have been taken from mines in these mountains. At the east end of Calico Mountains, at Borate, northeast of Daggett about eight miles, are deposits from which several million dollars' worth of borax have been obtained. The borax occurs as the mineral colemanite, in a deposit from 5 to 30 feet thick.

Daggett, 85 miles (El. 2,002 feet); Manix, 112 miles; Baker 143 miles (El. 921 feet).

Manix Lake Beds of Earlier Lake

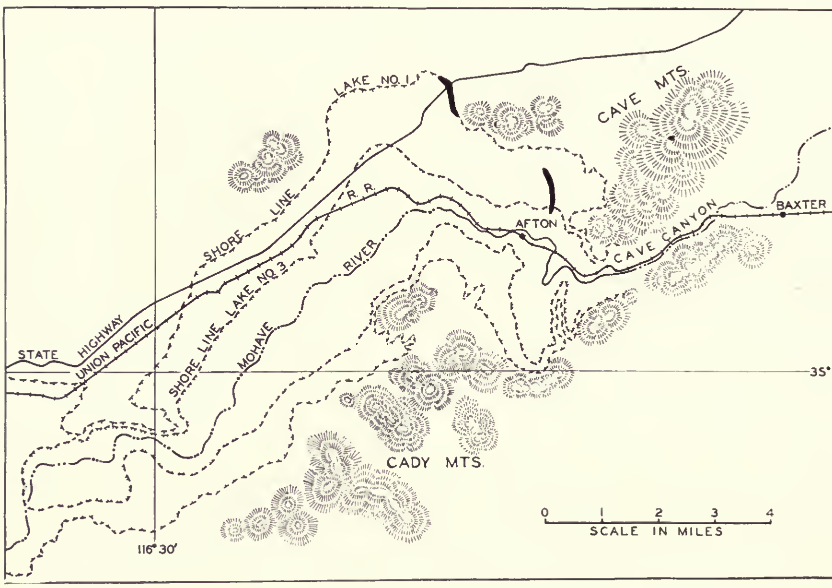
The waters of Mojave River were ponded in a basin about Manix, forming a lake which existed during a period preceding the present, or Recent time (Pleistocene or Quaternary), and covered an area of more than 200 square miles. The precipitation at that time was probably greater than at present, and Mojave River poured its waters into this basin, forming what has been called Manix Lake. In the lake thus formed there was deposited a series of clays and sands, detritus carried down from the surrounding slopes. These deposits are termed the Manix Beds. These beds have been eroded since the disappearance of the lake into vari-colored cliffs, ridges and pinnacles of a bad-land type, with generally smooth slopes. The initial stage in the history of accumulation in the Manix Lake basin was the transportation of large quantities of coarse more or less angular rock waste from the surrounding ranges, deposits to which the term "fanglomerates" is applied. The fanglomerates were deposited on the lower slopes and in the valleys. Overlying these are the horizontally deposited beds of Manix Lake. A fault near Field, east of Manix, where the Mojave River cut a deep canyon, affords a view of both the fanglomerates and the overlying Manix Beds. In the Narrows, south of Field, are greenish beds of Manix Lake deposits. East of Afton red and buff coarse conglomerates are exposed, estimated to be as much as 300 feet. In some places the beds are exposed in almost vertical cliffs, or in high-pinnacled erosion columns. With the vari-colored aspect of the beds these erosion features present a striking stretch of scenery.

River Ceases in Mojave Sink

Near Baxter, at the lower end of Mojave Canyon, called also Cave Canyon, the river has cut through the contorted metamorphic rocks. North of Baxter station the contortions may be clearly seen in a marble quarry. The canyon ends at Baxter, and the river passes into Crucero Valley, dividing its waters (if any) between Crucero and Cronise playas. Mojave River flows through Cave Canyon when there is enough water to cause a stream, and debouches upon the sands of Mojave Sink. In times of flood the river sometimes divides, part going to the wash or sink southeast of Cave Mountains and part going north into Soda Lake playa, where it is lost by evaporation.

Manix Lake Outlet in Granite Rocks

More than 200 square miles of water surface were exposed to evaporation in Manix Lake. Evaporation apparently prevented overflowing of the lake by an outlet, and Manix Lake became the sink of the Mojave River. On the northeast side of the basin are two deep gravel ridges which mark the shore line of the ancient lake. One of these ridges is crossed by the highway. From this ridge gravel was taken in the construction of the highway. A period of desiccation or drying up of the lake



Courtesy Eliot Blackwelder and Journal of Geology

Fig. 103. Sketch map of Afton Basin, an arm of Manix Lake which in Quaternary time was the sink of Mojave River. The two black stripes indicate the positions of the high gravel embankments.

occurred, and the basin became a playa or dry lake. This period of desiccation was apparently followed by a time of greater precipitation, for a lake returned and reached a level 20 feet higher than the former lake. An outlet was formed over the eastern rim of the basin. At the point of outflow east of Afton the river undoubtedly lowered its channel rapidly through the friable fanglomerate deposits. Down-cutting in the more resistant underlying granitic rocks undoubtedly proceeded more slowly. A granite ridge extends south from Cave Mountain. Into this granitic rock in the bottom of the canyon the river has eroded a channel 75 feet. The canyon has a total depth of 200 feet. The terraces observed south of Manix it is thought may be related to the down-cutting of the outlet channel, the terraces or benches representing successive stages in the down-cutting, caused by rock barriers, encountered in the down-cutting, that held back the waters, while the terrace benches were cut by side erosion. Further down-cutting has lowered the bed of the river and enabled it to trench the lake deposits for 25 to 30 miles above the outlet rim. The river is still cutting its narrow vertical-walled gorge through the hard rocks, and while cutting down the hard rocks the river has widened its trench or channel in the soft lacustrine beds to a width of half a mile or more, as at Camp Cady south of Manix.

Rugged Mountains Surround Soda Lake Playa

East of Field, at Midway station, the railroad descends into Cave Canyon. The highway turns away from the railroad and leads through a pass in Cave Mountains, crossing the gravel ridge (beach) before mentioned. The highway runs through the alluvial Cronise Valley between Cave Mountain (south) and Cronise Mountain (north), crossing Soda Lake Mountains, to Baker. Soda station (on the railroad) is on the east shore of Soda Lake (playa) 4 miles east of Beacon station (on the highway). Soda Lake is one of the largest playas in Mojave Desert, having an area of about 60 square miles. Soda Lake and Silver Lake, to the north, occupy a great trough thought to have been caused by faulting. Soda Lake Mountains form a continuous and very rugged range for 20 miles on the west side of the valley, with Turquoise Mountains rising as the east wall. It is thought that faults form the valley walls on either side. Turquoise Mountains, on the east side of the valley, are greatly dissected by canyons extending eastward from Soda

Lake into the granitic mountains. The alluvial slopes east of Soda Lake are very sandy, and because of its desolate character (wind-blown sand) the region is called the Devil's Playground.

Silver Lake, 151 miles (El. 909 feet); Silurian (Riggs) Lake, 172 miles; Ibex Pass, 193 miles (El. 2,250 feet); Death Valley Jc., 225 miles (El. 2,000 feet).

Fault Valley of Soda and Silver Lake
Playas Once Occupied by Lake Mojave

The character of the mountains and other features suggest that the great trough occupied by Soda Lake and Silver Lake, as well as the valley farther north, had its origin in faulting—that is, a segment of the earth's crust that has dropped between blocks on each side. The great trough extends northward a distance of about 50 miles; thence it bends sharply westward about 10 miles and continues northwestward as Death Valley for many miles. Between Soda Lake and Silver Lake a low divide not more than 10 feet high has been cut through by a stream, and in times of flood water flows from Soda Lake to Silver Lake.

There is unmistakable evidence that at some time in the past a large lake covered both Soda and Silver Lakes, submerging the low divide between them and reaching beyond the borders of the present playas. The ancient lake was for a long time the end of the Mojave River drainage system, and it is therefore referred to as Lake Mojave. Evidences of the existence of the lake are wave-cut cliffs and terraces, beach ridges, and an unmistakable outlet channel toward the north. The clearest evidence consists of wave-cut cliffs and terraces on the west side of Silver Lake, opposite the town of that name, and also at the northeast end of the playa. Beach ridges are also well developed at the north end of Silver Lake. A prominent beach ridge which rises nearly 40 feet above the playa extends westward from the railroad to a limestone hill. For a time Lake Mojave had an outlet northward in the great valley that reaches to Death Valley. This outlet was through a low notch cut in the rock hills north of Silver Lake playa. The outlet channel was cut into the bed-rock about eight feet below the top of the beach ridge.

Highway to Amargosa Valley through Riggs Valley and over Mountains

Riggs Valley is a part of the large trough that extends southward from the southeast end of Death Valley, and includes Silver Lake and Soda Lake Valleys. The eastern border of Riggs Valley north of Silver Lake playa is formed by the Silurian and Turquoise Mountains. The western border of the Valley for a large part of its length is formed by the Avawatz Mountains, which rise to a height of more than 6,000 feet, or nearly 5,500 feet above the lowest part of the Valley. The lowest part of Riggs Valley is occupied by a playa, Riggs Dry Lake, formerly known as Silurian Dry Lake. From a low point of 576 feet east of the Avawatz Mountains the highway crosses a low range of mountains, past another Devil's Playground, and descends into the Amargosa Valley, then climbs along the east side of the Ibex Range to Ibex Pass (El. 2,250 feet), then descends again 27 miles to Shoshone, again in the Amargosa Valley, passing Tecopa and Zabriskie, near an old borax works. The valley floor is much dissected for a distance of 10 miles. At Shoshone the valley in narrowed by the encroachment of mountains on either side. North of Shoshone the valley is two to five miles wide and is a comparatively smooth desert floor. Eagle Mountain stands in the middle of the valley five miles south of Death Valley Junction, and causes a playa by ponding the waters of the Amargosa (when there are any!).

Incomparable Death Valley and Good Roads Are Ahead

Death Valley Junction and Amargosa Hotel are near the California-Nevada State line at an elevation of 2,000 feet.

Amargosa Hotel invites the traveler to tarry for rest and refreshment, and after the toilsome journey at least water and gasoline will be needed! To the west is the Amargosa Range, locally designated from north to south as Grapevine, Funeral, and Black Mountains. Turning westward up a mountain canyon, this is not "the highway paved with good intentions" but a well-paved somewhat steep highway to—Death Valley. It is climb out of one fault-walled valley to another, up over the Amargosa Range 6,000 feet above sea level, then down below the level of the waves—but not into the ocean, not yet into the "bottomless pit," but onto the sunken floor of what the geologist calls a "graben" (a sunken valley between fault walls). In this case it is a "graben" which is the catchment floor for the waters of a nearly rainless region, a basin of concentrated salt brine, an almost impassable bottom of salt; this is Death Valley where it has been said the birds fall dead trying to fly across. But be not disturbed. The air is fine, and while the floor of the sunken Valley is said to be almost impassable—and is, off the highway—yet the roads are fine. The scenery is incomparable. If you go to Bad Water, 17 miles south of Furnace Creek Inn (and you certainly will want to) you will be farther below sea level than you have ever been before (unless you have been shipwrecked at sea), 296 feet *minus*. And to get out it will be necessary to climb—and there is no rope ladder! Telescope Peak, up over your head at 11,045 feet above sea level, is at the top of what is said to be the greatest abrupt rise from base to tip in the United States. Here is where you add to find the difference—11,045 feet above sea level plus 296 feet below sea level equals the difference between where you stand and what you look at on the crest of Telescope Peak, horizontally about 12 miles from the floor of the Valley.

Borax Mines, Furnace Creek Camp, and Mount Whitney

After leaving Death Valley Junction it is 30 miles across the

Amargosa Range to Furnace Creek Inn, and it will be convenient to stop. Half way across is the original home and source of 20-mule team borax. Believe it or not, it was from here that the borax that made grocery stores famous was hauled 165 miles to Barstow by the historically famous 20-mule teams. No advice is offered the tourist whether he should or should not go south from Mule Team Canyon (19 miles from Death Valley Junction) to Ryan and ride on the Baby Gauge railroad through the workings of the borax mines; whether he rides through Corkscrew Canyon (do not drive too fast if you do); or go to Dante's View (6,000 feet elevation). These are all very much worth while, and a stop at Furnace Creek Inn (30 miles from Death Valley Junction) will be enjoyed before driving south 17 miles to Bad Water (lowest point in the United States, – 296 feet) over a good road, through the "impassable" salt bottom of Death Valley.

The Amargosa Range reaches an elevation of 6,397 feet at Funeral Peak, a distance of six miles from the – 200 foot contour of Death Valley. The altitude of the range generally is 6,000 to 7,000 feet. That of the Panamint Range averages 7,000 to 9,000 feet. The maximum grade on the west side of the valley from Telescope Peak to the valley floor is 920 feet per mile (9.8°), and on the east side, measured from Funeral Peak, 1,066 feet per mile (11.4°). The canyons leading to the valley do not approximate these grades, except in their upper ends, but the average grade is steep.

Furnace Creek Camp, one mile from Furnace Creek Inn, offers saddle horses and all accommodations for recreation if the engine of your car has become heated, or for any reason it is deemed advisable to take time to enjoy life before going 32 miles to Emigrant Canyon, on top of the Panamint range. The edge of the valley floor is traversed for 18 miles, with the Funeral Mountains rising high on the right (northeast). Chloride Cliff and many other interesting points, including Bullfrog, Nevada, are reached by a highway that turns off north at 11 miles. Having descended the east side of the valley without mishap, Mesquite Flat and some sand dunes lie ahead, and then begins the climb of the Panamint Ranges. Scotty's Castle at the head of Death Valley is about 30 miles north of Sand Dune Junction.

It is not attempted to describe the scenery. It has to be seen. In going 22 miles across the Panamint Range to Panamint Valley, Townes Pass (elevation 6,200 feet) and the western boundary of the Park (Death Valley Monument) will be passed. Panamint Valley extends to the south, and north is Saline Valley. Low mountains are crossed, the Coso Range extending south and the Inyo Range north. Keeler, on the east shore of the old Owens Lake bed, is 30 miles from the point of crossing of the bottom of Panamint Valley, and 13 miles north of Keeler is Lone Pine, at the foot of Mount Whitney. Mount Whitney, 14,501 feet, highest point in the United States, and the culminating point of the Sierra Nevada Range, is about 80 miles in an air line from the lowest point in the United States, Bad Water in Death Valley.

Route C. Los Angeles, via Cahuenga Pass and Mojave Desert to Owens Valley. 218 Miles

Leave Los Angeles by any route, and drive through Hollywood to Cahuenga Boulevard, and north through historic Cahuenga Pass. Cahuenga Pass was on the route of travel of the Mission Fathers between Mexico and San Francisco, the Camino Real. The Pass is a notch in the east end of the Santa Monica Range, and afforded a way across the mountains from Los Angeles Basin to the San Fernando Valley. The Pass is a notch across the summit of the mountain range formed by two streams, one of which flowed south to the Los Angeles Basin and the ocean and the other into the San Fernando Valley. Each stream started high on the mountains and each cut its channel into the soft friable rocks, and pushed its head back till the two met at the summit. The down-cutting of the streams resulted in lowering the divide at the summit, and thus a notch was cut in the mountain crest which made a "pass" possible. The elevation of the Pass is 728 feet.

Cahuenga Peak; Basalt Rock in Pass

Off to the east is Cahuenga Peak, rising to a height of 1,825 feet. Its western face is a fault cliff. To the west of the Pass rises the rough and rugged Santa Monica Range, the core of which is granitic rock. The two streams which have their heads in the divide of Cahuenga Pass are on soft friable rocks (of Pliocene age, Topanga formation). In the Pass will be observed brownish-black rocks overlain by massive lighter colored brown sandstone (Topanga formation). The dark rock is basalt, a volcanic rock that was forced upward in a molten condition under, or between, the sandstone layers. This rock was in a highly heated viscous form, the heat of which baked the sandstones with which it came in contact. Alternating layers of basalt and sandstone are seen, particularly in the southern half of the Pass. Farther north the baked sandstones and basalt disappear, and the formation exposed is the lighter brown and fine-grained shale (Topanga formation). The formations dip toward the north and form the floor of the San Fernando Valley.

San Fernando Valley and Pass

The San Fernando Valley is a great sunken basin, or down-dropped block of the earth's crust, surrounded by mountains, the floor of the basin depressed while the surrounding mountains were uplifted along fault planes. The outlet of the Valley is Los Angeles River, which leaves the basin through the faulted valley at Burbank. Two main thoroughfares lead out of the Valley to the south and east, the Cahuenga Pass and that through which the Los Angeles River flows by Burbank. North of San Fernando the highway crosses folded and crumpled hills, bent and folded by the upheaval by which the San

Fernando Valley was formed. Here is the San Fernando Pass, a "saddle" between the Santa Susana Mountains on the west and the San Gabriel Mountains on the east. A tunnel has been cut through the hills leading to Newhall. Thus a highway has been opened to Saugus and the Santa Clara Valley.

The city of San Fernando (23 miles from Los Angeles, El. 1,066 feet) is at the northern point of San Fernando Valley, on an alluvial fan or "wash" built by Pacoima Creek. The old Mission of San Fernando is two miles southwest of the center of the city. Brand Park is a beautifully green oasis supplied with moisture, as was the Mission of old, by a "cienaga" spring from an alluvial fan that floors a small valley to the north. A mile southwest of the city is a reservoir into which waters from Owens Valley, 250 miles away east of the Sierra Nevada Mountains, are brought by aqueduct to supply the city of Los Angeles.

An anticlinal fold in the rocks along the northern flank of the San Gabriel Mountains, from Newhall Canyon eastward to Sand Canyon, is the location of the Elsmere oil field. The oil is obtained from wells generally not more than 1,000 feet deep, from coarse sandstones and conglomerates of Tertiary age. The first oil refinery in California was built a mile south of Newhall, relics of which are still standing just west of the highway.

Just north of Newhall Placeritas Canyon enters Newhall Valley from the east. It is interesting historically to note that in 1842 gold was discovered in Placeritas Canyon, about four miles east of the highway. Placer gold in not very rich amounts may still be obtained in the canyon, though the district ceased long ago to be actively worked.

Down Newhall Creek the walls of the stream channel are steep. The stream, which is dry much of the year, meanders over a wide gravelly bottom during floods and cuts the banks at the sides. The high terraces which characterize this and other stream valleys entering the Santa Clara, mark stages in the erosion of the region, the high terraces indicating the former valley bottom or floor before the region was uplifted to its present height.

Beyond Saugus, after crossing the bridge over Santa Clara River, the truncated edges of steeply dipping rock formations (of Pleistocene age) are overspread with gravel deposited by meandering side-cutting streams. A few miles east of Saugus Mint Canyon and Soledad Canyon come together. The Southern Pacific Railroad follows the course of Soledad Canyon in its climb over the mountains to Mojave Desert. The Santa Clara River, which flows through Soledad Canyon, has cut its channel deeply, and mostly has eroded through the sedimentary formations into the metamorphic and granitic rocks such as form the main parts of the San Gabriel Mountains.

Through Mint Canyon and Sierra Pelona Valley

The highway follows Mint Canyon. About 13 miles east of Saugus the valley becomes more canyon-like, and changes from a wide flat-bottomed valley in which the stream cuts its banks but does not erode its bottom to a steep-walled V-shaped valley in which down-cutting of the bottom is active. This is the real Mint Canyon. The change is due to the higher gradient of the stream as it descends the slope of the mountain range of Sierra Pelona, which rises to the north. In its upper course Mint Canyon loses much of its canyon-like character and becomes a flat-bottomed valley with steep walls and bordering terraces as it crosses the gently sloping plain of Sierra Pelona Valley with lower gradient. Nineteen miles east of Saugus the highway winds up the side of Mint Canyon and passes through a deep cut to Sierra Pelona Valley.

To the north is the eroded escarpment of Sierra Pelona Mountains, the highest peak of which is Mount McDill, 5,180 feet. Sierra Pelona Mountains were formed by the crumpling and metamorphosing of sedimentary formations. The intrusion of molten granitic magma metamorphosed the shales and sandstones to schists and quartzites. The escarpment of the great ridge stands out boldly because the upheaved rocks are hard and withstand erosion.

Turning south in Sierra Pelona Valley, two or three miles east of Oaks, and going down Agua Dulce Canyon, the famed Vaquez Rocks are at the left. In Escondido Canyon prominent outcrops of red-hued conglomerates and sandstones, with intercalated greenish shales, have been carved by erosion into fantastic forms which give a weird and mysterious aspect to the region.

From Sierra Pelona Valley the highway passes through a gap in the hills, at an elevation of 3,423 feet, into the valley in which Acton is located, and thence up the valley to Vincent, at the summit of the divide between the Santa Clara River and the gulch that leads to the Mojave Desert. At the bottom of this gulch is the zone of crushed, broken and folded rocks which marks the great San Andreas fault, and this in turn marks the southwest boundary of Mojave Desert.

Palmdale, 72 miles from Los Angeles (El. 2,669 feet); Lancaster, 80 miles (El. 2,356 feet); Mojave, 104 miles (El. 2,733 feet).

Crushed and Broken Rock Marks San Andreas Fault

The succession of valleys and ridges or other features that indicate the fault zone can be traced northwestward and northward to San Francisco and beyond, and southeastward through Cajon Pass and San Gorgonio Pass to the Salton Sea Basin. This long zone of faulting is known as the San Andreas rift. Several of these valleys stand out prominently. A notable one is Leonis Valley, in which is Amargosa Creek, west of Palmdale. Harold Reservoir, west of the highway, is in one of these valleys. Water from Little Rock Creek, to the east, is stored in this reservoir for the Palmdale irrigation district. This is the zone of crushing, crumpling, and folding of the rocks of the San Andreas fault, not merely a break in the rocks of the earth's crust. The rift zone, as has been stated, extends for hundreds of miles north and south of this region. A fracture may be represented by an open fissure at the surface, which by erosion may become partially filled with detritus. Sag ponds are a common feature along fault zones, in which the run-off from rains or waters from springs collect to form ponds.

Antelope Valley and Playas

Several playas or dry lakes occur in the Antelope Valley, the largest of which is Rosamond Dry Lake. Antelope Valley is separated by low mountains north of Rosamond and south of Mojave. Fremont Valley extends to the El Paso Range and east to Randsburg and Johannesburg. Ten or 12 miles north of Lancaster, approaching Mojave, is Soledad Mountain (elevation 4,183 feet), an interesting gold mining district. Eleven miles west of Mojave is the Tehachapi Pass (elevation 3,793 feet) through which a highway leads to Bakersfield and the San Joaquin Valley.

Antelope Valley is underlain by a large amount of rock debris, which has been washed down from the surrounding mountains. The rocks weather into fragments that range in size from minute particles to boulders several feet in diameter. If the mountain streams furnish enough water ponds or lakes may be formed in the lower parts of closed basins. The rainfall is so slight, however, and the evaporation is so great a lake is not formed except after heavy rains in the mountains. Such a lake usually contains only a few inches of water, which soon evaporates, leaving a bare smooth flat of clay or silt, locally known as a "dry lake" but by geologists called a playa.

Artesian Wells at Lancaster

The notable water-bearing formation in Antelope Valley is the alluvium that underlies the valley. It is composed of gravel, sand and clay washed down from the surrounding mountains. The water table is highest beneath the upper parts of the principal alluvial fans. In the lower parts of the valley the beds near the surface are composed of clay and silt, and these act as a nearly water-tight cover over the underlying water-bearing beds. These impervious beds extend for some distance up the alluvial slopes, and this provides the conditions necessary for an artesian flow. Many flowing wells have been obtained about Lancaster, and northwest of Rosamond dry lake or playa.

Cantil, 126 miles; Ricardo, 130 miles; Indian Wells, 152 miles.

To the north the highway lies along the edge of the Mojave Desert, with the Sierra Nevada Range rising on the left. Twenty-two miles north of Mojave the highway leaves Mojave Desert and crosses the western end of the El Paso Range into Indian Wells Valley. Seventeen miles north of Mojave the mouth of Jawbone Canyon is passed. Southwest of Jawbone Canyon high mountains rise (Chuckwalla Mountain, 5,006 feet; Cross Mountain, 5,175 feet; and farther southwest Cache Peak, 6,708 feet). The mountains extend many miles westward to the south end of the Sierra Nevada Range.

El Paso Mountains Cut Through by Deep Canyon

The El Paso Mountains extend to the northeast, and have their southwest end at Redrock Canyon, near Cantil. The southeast face of the El Paso Range is straight and very steep, marking the line of the Garlock fault, which continues northeastward for many miles. Twenty miles east is the Randsburg mining district, from which many millions in value of gold, silver, and tungsten have been taken. Five miles east of the highway is Kane Dry Lake or playa. Near the north end of the playa is Saltdale, where pure crystalline rock salt is mined in commercial quantities. Southwest of Cantil to Jawbone Canyon is an area of badlands which extends 5 to 10 miles west to the foot of the Sierra Range. The scenery, particularly from Red Hill at the mouth of Jawbone Canyon through Redrock Canyon, through which the highway leaves Fremont Valley and the Mojave Desert, is picturesque and fascinating.

Redrock Canyon, as also Last Chance Gulch and Goler Gulch farther east, have their heads on the northwest side of the main range of the El Paso Mountains, and cut through the range in a southeasterly direction, and drain large areas on the side of the mountains farthest from the main valley. They are "antecedent" streams. Their courses were established before the mountains were uplifted across their paths. To the east of the highway about three miles, on Last Chance Gulch, are interesting relics of an ancient forest, the remains of a "grove" of petrified trees.

The Southern Pacific Railroad runs eastward, swinging around the El Paso Mountains. The highway leaves the alluvial Fremont Valley of the Mojave Desert through Redrock Canyon to the alluvium covered plain of Indian Wells Valley. The northeast end of the El Paso Mountains is composed of granitic rocks. Farther southwest these rocks are overlain by beds of Tertiary sedimentary and volcanic rocks. In Redrock Canyon, both north and south of Ricardo, rather wide and flat basins have been eroded in the comparatively soft and friable sedimentary rocks. However, upon entering the more resistant plutonic (volcanic) and metamorphic rocks, which Redrock, Last Chance and Goler canyons cut through, the canyons both deepen and steepen very perceptibly, the walls becoming in places almost vertical. Their beds become narrow until in some places they are scarcely wide enough for a wagon to pass between the rock walls. To the north the highway passes upon the alluvium-mantled plain which lies north of the El Paso Range.

Little Lake, 171 miles (El. 3,175 feet); Haiwee Reservoirs, 187 miles (El. 3,764 feet); Olancha, 196 miles (El. 3,649 feet); Lone Pine (Mount Whitney station), 217 miles (El. 3,728 feet).

Rose Valley adjoins the extreme northwest corner of Indian Wells Valley, along the western edge of which the highway has led. Rose Valley is connected with Indian Wells Valley by a canyon south of Little Lake station, through which, during the Pleistocene (glacial) epoch, a river flowed from Owens Lake. Alluvial cones built out from the Sierra Nevada Mountains now block drainage from the north. A small "dry lake" north of Little Lake station is caused by the deposition of alluvial material from the Sierra Nevada.

In or between the Haiwee Reservoirs is the divide between Rose Valley and Owens Valley. Owens Valley is a long open trough-like depression lying immediately east and at the very foot of the highest part of the Sierra Nevada Range. It is a vast basin, about 140 miles long and 20 to 40 miles wide. Owens River, which runs through the valley, is one of the few large perennial streams of the Great Basin region. It ends ingloriously in the briny basin of Owens Lake. Its sparkling comparatively pure water (which is not diverted), derived principally from the rains and snows of the high Sierra Range, is lost under the blazing sun on the flat salt-white bottom of Owens Lake Basin.

Water from Owens River is diverted by means of Tinemaha dam, 43 miles north of Owens Lake, and an aqueduct intake five miles south of the dam, and conveyed 250 miles to Los Angeles. That part of the water of Owens River which is not diverted enters Owens Lake. Owens Lake is a saturated salt-brine. Haiwee Reservoir, 10 miles south of Owens Lake, is supplied from the river above the lake by an aqueduct around the salt basin.

All land waters contain some mineral impurities. While the water of Owens River is essentially pure (339 parts per million total salts), coming from the heights of the snow-capped mountains, yet when the waters of Owens Lake fell by evaporation below the level of overflow over the divide to the south the waters of the lake became increasingly, though very slowly, more highly charged with salts derived from the rocks over and through which the water passed.

Owens Valley is a depressed floor between high mountain ranges, formed by the faulting of the rocks on either side and the elevation of the mountains. It is a structural valley and not a valley of erosion. Owens River flows across the flat bottom of the valley from far north in the mountains. The valley offers a highway for the passage of the waters from the mountains. In Pleistocene time the waters of Owens Lake overflowed southward over the low divide at Haiwee Reservoir.

Owens Lake at one time stood at a much higher level than now. This is shown by beach ridges and shore marks around the flat basin. Beach lines on the east slope of the Alabama Hills are 220 feet above the present lake level. Distinct gravel-covered beach remnants may be observed just northeast of Swansea, three miles north of Keeler. Old shore lines show also along the valley margin between Swansea and Keeler. The lake was lowered about 30 feet by erosion of its outlet. The water stood at 190 feet above the present lake level when discharge by the outlet ceased. Since this time the surface of the water has been lowered by evaporation alone. The area of the lake at this time was about 240 square miles (the present area of the lake is approximately 97 square miles). The period of desiccation since the lake ceased to overflow, during which time the concentration of salts to the present brine has been going on, is estimated to have been in the neighborhood of 4,000 years. Salt in commercial quantities is taken from the desiccated ancient bottom of the lake at Keeler.

Mount Whitney, 10 miles west of the highway at Lone Pine, rises 14,501 feet above sea level (highest point in the United States). At one time in the recent geologic past waters from the crest of the Sierra Nevada, in the vicinity of Mount Whitney, moved through Owens Valley to Searles Lake and Panamint Lake—and probably to Death Valley, the lowest point in the United States.

The highway continues north. For 200 miles, from Walker Pass (reached by a highway through Freeman Canyon, five miles south of Indian Wells) north to Tioga Pass, west of Mono Lake, there is no pass across the Sierra Nevada Range. A highway leads southeast from Lone Pine to Death Valley and the central Mojave Desert.

Route D. Los Angeles, via Coast Line to San Francisco. 471 Miles

Los Angeles River Above the City

The route lies along the Los Angeles River for 10 miles. Los Angeles River flows out of the San Fernando Valley, and crosses through a sag in an anticlinal ridge which connects the Santa Monica Mountains with the Repetto and Puente Hills. The rocks along the west side of the river in Elysian Park are shales and sandstones of Miocene (Tertiary) age. To the west are the Santa Monica Mountains; to the north the San Gabriel Range. The Verdugo Mountains and the San Rafael Hills on the right are geologically part of the San Gabriel Range, cut off by faults. The fault scarp, which forms the southwest wall of the Verdugo Mountains and the San Rafael Hills, stands boldly in a nearly straight line from Pasadena to Pacoima. A stream cuts across from La Canada Valley to Los Angeles River, separating the Verdugo Mountains from the San Rafael Hills. The stream is what is called an "antecedent" stream; that is, it was there before the disturbance by which the mountains were uplifted, and kept on its way during the slow uplifting. The city of Glendale is built on an alluvial fan built by this stream. The city of Burbank stands upon waste detritus from the fault scarp which forms the mountain side north.

Burbank, 11 miles (El. 555 feet); San Fernando, 22 miles (El. 1,076 feet); Santa Susana Pass, 34 miles (El. 1,604 feet); Moorpark, 50 miles (El. 511 feet); Santa Paula, 68 miles (El. 288 feet); Ojai, 85 miles (El. 743 feet); Ventura, 98 miles (El. 13 feet); Santa Barbara, 126 miles (El. 37 feet).

San Fernando Valley and Pass

The San Fernando Valley is a deep basin of Tertiary and Quaternary deposits, cut off at its eastern end by a fault which marks the boundary of the Verdugo Mountains and San Rafael Hills. The northwest end of the Verdugo Mountains is covered with Miocene (Tertiary) sandstones and conglomerates. A short distance east of Pacoima an isolated hill, geologically a part of the Verdugo Mountains, stands above the alluvium. The south side of this hill consists of granite. To the east, between Pacoima and San Fernando, the San Gabriel Mountains may be seen, rising in the western part of the range to an altitude of more than 5,000 feet above sea level. The main mass and higher parts of the mountains are formed by a huge block of granitic and metamorphic rocks which have been pushed upward. It is bounded on all sides by faults.

Northwest of San Fernando is San Fernando Pass, which marks the junction of the crystalline mass of the San Gabriel Mountains with the sedimentary rocks of the Santa Susana Mountains. The Santa Susana Mountains are formed by an uplifted block with a large thrust fault along its south side. The San Fernando Mission, one of the old California missions, is passed in going westward from San Fernando. From Devonshire Street, in the vicinity of the junction with Reseda Avenue, a good view can be obtained of the south side of the Santa Susana Mountains. The main mountain mass has been overthrust by faulting from the north toward the south. Along the Santa Susana fault, which is the uppermost of three faults, older (Miocene) beds are thrust over younger deposits (of Pliocene or Pleistocene age). The south edge of a terrace of sand and gravel hangs about 500 feet above the level of the valley floor, the terrace tilted northward toward the Santa Susana fault. The Santa Susana fault is well marked north of Chatsworth, where Brown Canyon has cut a steep cirque-like face in the mountain wall.

Simi Hills and Tapo Canyon Oil Field

Near the west end of San Fernando Valley the Cretaceous strata forming the Simi Hills rise abruptly from the alluvium in bold cliffs. The sandstone appears as though piled in huge blocks. Winding up the side of one of the small canyons ascent is made to Susana Pass. From the summit Simi Valley can be seen lying between the Simi Hills on the south and Oak Ridge, the western extension of the Santa Susana Mountains, on the north. The Simi Hills form an uplifted mass, faulted (probably) on the south and east sides.

Simi Valley is a synclinal depression, Cretaceous strata being gently folded into a syncline and overlain by Eocene strata. One of the thickest and most fossiliferous Eocene sections in California is to be found in the hills bordering Simi Valley. Over 5,000 feet of sandstone, conglomerate and clay are exposed on the north side of the valley in the road cuts between Simi and Moorpark.

Directly north of Santa Susana lies the Simi or Tapo Canyon oil field. It is the only field in southern California yielding oil in commercial quantities from the Eocene. The field is situated on an anticline extending from Tapo Canyon along the north side of the valley.

At the summit of Oak Ridge the view northward overlooks the valley of Santa Clara River, another synclinal depression. Directly northward is a complexly folded series of sandstones, clays, and siliceous shales which forms the grass and brush covered mountains for about five miles east of Sespe Creek. West of Sespe Creek the high and rugged Santa Paula Ridge is composed of Eocene strata. The contact between the Eocene and Pliocene is marked by a major thrust fault known as the San Cayetana fault. It is plainly visible following the foot of the steep south slope of Santa Paula Ridge. Oak Ridge is an anticline having a thrust fault along its north base.

The Bardsdale oil field, west of the mouth of Grimes Canyon, is one of a series of fields lying along the north side of Oak

Ridge. From east to west these fields are the Torry Canyon, Shiells Canyon (Montebello), Bardsdale, and South Mountain. The fields are localized on domes along the general Oak Ridge anticline.

Bardsdale and Other Oil Fields

At Bardsdale the route turns westward along the south side of Santa Clara River, allowing an excellent view of the mountains (Santa Paula Peak, 4,959 feet; San Cayetano Mountain, 4,122 feet) on the opposite side. The trace of the San Cayetano fault can be easily followed as the line between the grass-covered lower hills of soft Pliocene and Miocene strata and the brown, hard, well-bedded Eocene section above. A fine example of an alluvial fan is to be seen at the mouth of Timber Canyon. This canyon, one of the largest cut into the Pliocene on the north side of Santa Clara River, has been completely filled with detrital material carried down from the fault face of the San Cayetano thrust.

Six miles west of Bardsdale is the South Mountain oil field. This field is one of the most picturesque in California, owing to the exceedingly rugged badland type of erosion which the area has undergone. A number of the locations for derricks are so inaccessible that all materials for drilling were transported to them by inclined railways. Excellent views of this anticlinal fold are obtained as the Santa Clara fault is approached along the river. (Figs. 80, 81, 82.)

Sulphur Mountain; Santa Clara and Upper Ojai Valleys

To the west of Santa Paula Creek is Sulphur Mountain, an upthrust block of Miocene formations lying between two faults. Beyond Sulphur Mountain are the Topatopa Mountains, the east end of the Santa Ynez Range, lying directly back of Ojai Valley. From South Mountain a good idea can be obtained of the structure of the Santa Clara Valley, which is a huge synclinal trough composed of Tertiary and Quaternary strata. The Pliocene section alone is nearly 20,000 feet thick, and can be seen in its entirety between Santa Paula and the San Cayetano fault. This section has been squeezed together between two major thrust faults on the sides. On the Oak Ridge fault the movement has been about 8,000 feet toward the north, whereas on the San Cayetano fault the Eocene rocks have moved over two miles southward.

The floor of Upper Ojai Valley is reached after a gentle climb to an altitude of 1,500 feet above sea level. The valley is structurally a "graben" (a depressed area between two faults) lying between the Santa Ynez Range and Sulphur Mountain. At the west end of Upper Ojai Valley the road crosses the axis of a large anticline known as Black Mountain. One of the faults of the San Cayetano fault zone lies at the foot of the grade that leads down from the Upper to Lower Ojai Valley and extends westward along the north side of Black Mountain. Movement on this fault has caused the difference in altitude between the Upper and Lower Ojai Valleys.

From San Antonio Creek the road follows the Ventura River through a narrow canyon at the west end of Sulphur Mountain and the east end of Red Mountain. Red Mountain rises high above the west bank of Ventura River, and structurally is a large dome-like anticline. Red Mountain is almost entirely circumscribed by faults. The Ventura Avenue anticline (folded Pliocene rocks) extends westward from the valley of Santa Clara River north of Saticoy to Punta Gorda, on the coast 12 miles north of Ventura, a distance of 18 miles. The Ventura Avenue oil field, one of the largest in California, is located on this anticline, and is cut through the center at right angles by the Ventura River, where the arch of the fold can be plainly seen on each side.

Ventura Oil Field and Channel Islands

At the mouth of Ventura River, at the city of Ventura, the route turns northwestward along the ocean shore for a distance of 28 miles, to Santa Barbara. For a distance of 11 miles, from Ventura to Punta Gorda station, the formation exposed in the steep cliffs is mainly of upper Pliocene age (Pico formation). It is a part of the south flank of the Ventura anticline, the crest of which finally passes into the ocean at Seacliff. The Rincon oil field is located on this fold and is partly on shore and partly in the sea. In 1930, after a geological survey of the outcrops on the floor of the ocean, a long pier was built and wells drilled under the water. The depth of the water here is not more than about 35 feet.

Unless fog interferes it is usually possible to see Santa Cruz Island from the Ventura County coast, and to the south the smaller Anacapa Island, which belong to the group of Channel Islands. They are structurally a part of the Santa Monica Mountains and form the south side of the Ventura basin. The rocks of these islands are mainly sedimentary, though on Santa Cruz Island both schist and granite are exposed.

After crossing the bridge over Rincon Creek the road leads up a deep cut to the Carpinteria terrace or mesa. From Carpinteria terrace, on the west side of Rincon Creek, to Santa Barbara and northwestward to Point Concepcion, the high Santa Ynez Mountains rise abruptly from the terrace and low foothills. A prominent line of foothills extends westward from Rincon Creek, back of which lies one of the large faults of this district, the Arroyo Parido fault. It continues beyond Summerland through Montecito and Santa Barbara. From Summerland to Santa Barbara the road passes over the low sea terrace cut into the Pleistocene gravel deposits, some of which are tilted, as shown in the cut near the Montecito Inn.

Santa Barbara and Marine Terraces

The city of Santa Barbara is situated in a "graben" between the Arroyo Parido fault on the north and a fault along the north side of the hills on the southwest. This graben extends northwestward to Goleta, and is a major structural feature of this part of the coast. Other large faults exist also in this district, and it is probably along one of these numerous faults that the Santa Barbara earthquake originated.

Gaviota, 157 miles (El. 94 feet); Buellton, 163 miles (El. 490 feet); Los Alamos, 177 miles (El. 560 feet); Santa Maria, 194 miles (El. 204 feet).

Photo by J. W. Collinge. Courtesy Santa Barbara Chamber of Commerce
FIG. 104. Court house, Santa Barbara. A masterpiece of architecture.

Santa Barbara is located in a broad valley between the Santa Ynez Mountains on the northeast and a group of hills on the southwest, the latter rising in gently sloping terraces from the ocean. The terraces are remnants of what was the ocean beach, now uplifted far above the waves. Terraces 250 to 500 feet above the sea extend far along the coast. Southeast of Santa

Barbara a lagoon indicates that the sea has sunken again so that the sea has crept inshore thus far. Sunken basins and elevated terraces far along the California coast show that the land has been elevated many feet and again depressed somewhat. Southeast of Santa Barbara the valley opens toward the Santa Barbara Channel, in which the water is shallow, and beyond which are

Photo by J. W. Collinge. Courtesy Santa Barbara Chamber of Commerce

Fig. 105. Old Mission, Santa Barbara. Founded by the Franciscan Fathers in 1786.

the Channel Islands. The submerged bottom of the channel and the islands really belong to the continent rather than to the ocean. The hills just north of Santa Barbara are remnants of old marine terraces. The highway for a distance of 30 miles, to Gaviota, runs on a well-defined terrace but little above sea level. The terrace is strikingly sculptured into vertical cliffs east of Goleta. West of Goleta to Gaviota beautiful views of ravines, cut in the terrace, and views of the sea, may be enjoyed from the car seat. Just west of Goleta a large lagoon indicates coastal sinking.

Santa Maria and San Luis Structural Valleys

At Gaviota the highway turns away from the coast up a canyon through Gaviota Pass, across the Santa Ynez Mountains eight miles to Buellton on Santa Ynez River, thence through and over the rolling Purisima Hills to Los Alamos, and through Solomon Canyon 10 miles to Santa Maria Valley and Santa Maria. The route is through the Santa Maria oil district. This district is one of long sinuous folds or anticlines, and it is on the axes of these folds that the productive wells are located. The shales of the Monterey group are the probable source of the oil. A large refinery is located at Gaviota, to which much of the oil is conveyed by pipe lines.

Dune sand rises high on the mountains, and encroaches on the fertile farm lands of the broad alluvial Santa Maria Valley. Santa Maria Valley is a "structural" valley. A clearly defined terrace follows the north bank of the river, and the valley is deeply filled with Pleistocene and alluvial deposits. Arroyo Grande is at the mouth of a stream of that name which opens out upon the alluvial plain of Santa Maria Valley. Four miles west is Pismo Beach, once again at the ocean shore. Following the beach five miles, Sycamore Springs is reached, at the mouth of San Luis Creek. After a visit to the hot springs turn north up San Luis Creek (an "antecedent" stream) which cuts through the San Luis Range to the San Luis Valley. This valley extends 20 miles northwest to the ocean, but has no stream flowing lengthwise through it. It is drained mostly by Pismo and San Luis creeks, which cut through the San Luis Range to the sea. The valley is a structural valley lying between the Santa Lucia Range on the northeast and the San Luis Range on the southwest.

San Luis Obispo, 228 miles (El. 243 feet) ; Santa Margarita, 240 miles (El. 998 feet); Atascadero, 248 miles (El. 834 feet); Paso Robles, 259 miles (El. 740 feet).

Old Volcanoes; Tunnels through Santa Lucia Mountains

San Luis Obispo (Bishop of St. Louis) is one of the old Spanish towns of California. The Mission building founded in 1772 by Father Junipera Serra is still standing. A most striking geologic feature in the vicinity of San Luis Obispo is a row of eight hills, four northwest and four southeast of the city, which are the cores of volcanoes which broke through the sedimentary (Franciscan) rocks which occur in the region.

The railroad elevation of San Luis Obispo is 240 feet. At the summit of the Santa Lucia Range, where the railroad passes through a tunnel 3,616 feet in length, the elevation is 1,570 feet, a climb of 1,338 feet in a distance in a straight line of six miles, the railroad winding a circuitous way about double the distance through six tunnels. The long tunnel (Cuesta Pass) is through the divide of Santa Lucia Range between San Luis Obispo Creek and Salinas Valley, nearly 600 feet below.

Upper Salinas Valley a Structural Basin

Upper Salinas Valley (as distinguished from the lower and main Salinas Valley) is a basin nearly 20 miles in length, a long narrow trough through which Salinas River flows for most of its length, but the valley does not reach the ocean. It is a structural valley, bent down into a syncline, with hard granitic rocks on the northeast side and the Santa Lucia Range on the southwest. Tertiary sediments were deposited in the trough. During the long processes of erosion the valley floor was lowered. The Salinas River had become established in a course through the soft friable Tertiary deposits. As the valley floor was lowered the channel of Salinas River reached the underlying granite. Its course having been established it could not leave its channel. Thus the river for several miles flows through hard granite rocks instead of following the floor of the valley. This is what geologists call a "superimposed" river—one let down from above upon the lower hard rocks. After flowing five or six miles through the hard granite the river returns to the flat valley floor about three miles northeast of Santa Margarita.

Paso Robles Canyon between Upper and Lower Salinas Valleys

At Templeton the highway turns north, following the course of Salinas River as it crosses a range of hills through Paso Robles Canyon to the lower or main Salinas Valley. Paso Robles (Pass of the Oaks) is on the old highway (Camino Real) which was the route of the Church Fathers to the missions between Mexico and San Francisco. The canyon cut by the river is through the sandstones and conglomerates of the Paso Robles (Tertiary) formation. Hot sulphur springs and mud springs having a temperature of 95° to 140° occur at Paso Robles, probably related to faults in the rock formations.

The head of the main Salinas Valley is near San Miguel. The valley extends northwest for nearly 100 miles, to Monterey Bay. It is an outstanding example of a "structural valley" (one formed by faulting of the earth's crust and down-throw of the valley floor). The slope northeast from the vicinity of San Miguel suggests that it is a tilted block with a fault along its northeast side. That a large fault occurs along the west side of Salinas Valley is indicated by a line of springs, many of them hot.

San Miguel, 268 miles (El. 622 feet); Soledad, 331 miles (El. 180 feet); Salinas, 357 miles (El. 41 feet); Watsonville, 375 miles (El. 21 feet); Coyote, 412 miles (El. 248 feet); San Jose, 424 miles (El. 85 feet).

The Santa Lucia Range bounds Salinas Valley on the southwest. The range culminates in Santa Lucia Peak and Vaquero Peak, west of San Lucas. On the northeast side of the valley the Gabilan Range rises, becoming more rugged, with granite and some schist and crystalline limestone. To the south and east, in Stone Canyon, in the Gabilan Range, coal occurs in the Vaqueros sandstone (Tertiary), said to be the best in California. The beds of coal are in places 16 feet thick.

Soledad, Salinas, and Watsonville on Broad River Terrace

Soledad (meaning Solitude) is beautifully located on the broad terrace plain such as occurs all along the Salinas Valley from Templeton northward, and which becomes broader toward the mouth of the river at Monterey Bay. Paraiso Hot Springs are eight miles southwest in the Santa Lucia Range. Fourteen miles northeast of Soledad is The Pinnacles State Park, picturesque masses that have been sculptured by erosion from the rocks. Six or seven miles east of Soledad are Chalone Peaks, composed of marble and other crystalline rocks that are thought to be older than any others in the Coast Range.

Salinas, world-renowned for its production of lettuce, and Watsonville, famous for garden seeds, fruits and vegetables, are on the broad terrace plain of Salinas River. Pajaro and Salinas rivers both enter Monterey Bay from the broad terrace plain. The highway turns east through Elkhorn Slough, and beyond Aromas passes through Pajaro Gap, a small valley cut by Pajaro River where a fault in the Santa Cruz Mountains enabled the river to cut a channel across the range. Crushed igneous rocks (diorite) appear in the hillsides on the right. Traces of the San Andreas fault are visible just beyond Chittenden in the scarred hillsides to the northwest.

Santa Clara Valley and Sargent Oil Field

After crossing Pajaro River the country opens suddenly into the Santa Clara Valley. Here the shales, sandstones and conglomerates of the Monterey formation are bent into anticlines and synclines, the source of the oil in the Sargent oil field. West of Sargent, beyond the oil field, Franciscan rocks (mostly granitic) form the higher portion of the Santa Cruz Range. The Diablo Range, on the northeast, separates the Santa Clara Valley from San Joaquin Valley. The Santa Clara Valley extends from San Francisco Bay southeast for a distance of nearly 100 miles (Chap. V), one of the most productive fruit-growing regions in the world.

Low Divide in Santa Clara Valley

About two miles north of Madrone where the Santa Clara Valley narrows is the divide between Pajaro River and Coyote River, the former draining to Monterey Bay and the latter to San Francisco Bay. The divide will scarcely be noticed in the flat alluvial plain (if driving 70 miles an hour). Close observation reveals the conical form of an alluvial cone or fan. This deposit was made by Coyote River (probably in Glacial time) when the land was higher than now, and the river probably shifted its course over the fan from south (Monterey Bay) to north to San Francisco Bay.

Six miles southwest of Coyote, in the hills composed of ancient Franciscan rocks, is a quicksilver mine which is said to have produced more of this metal than any other mine in the United States.

San Jose on Broad Plain of Santa Clara Valley

San Jose is on the broad fertile plain of the lower Santa Clara Valley, 11 miles southeast of the head of San Francisco Bay. Well-kept orchards of fruit trees and vineyards surround. Lick Observatory, elevation 4,209 feet, may be seen from the highway three miles west of Coyote, or may be reached from San Jose.

Palo Alto, 441 miles (El. 58 feet); Belmont, 449 miles (El. 30 feet); San Mateo, 452 miles (El. 19 feet); Millbrae, 457 miles (El. 8 feet); San Francisco, 461 miles (El. 11 feet).

Long Straight Valley Marks San Andreas Fault

At Palo Alto (Spanish for tall tree) to the west of the highway is Stanford University. The buildings are of buff sandstone taken from a quarry 10 miles south of San Jose, of Miocene (Monterey) age. The San Andreas fault, movement along which caused the earthquake of 1906, which greatly damaged the buildings of the University, is four miles west. Between Redwood and San Carlos, five or six miles west of Palo Alto, the even-crested forest-covered Cahill Ridge may be seen west of the highway. Between this ridge and the foothills near the highway is a long narrow nearly straight valley which marks the San Andreas fault. Two lakes, San Andreas and Crystal Springs lakes, have been formed by damming, and these supply much of the water used by the city of San Francisco.

Fresh Water from Below Salt Marshes

A little beyond Belmont, to the right (east), may be seen the salt marshes and the white salt fields where salt is obtained by solar evaporation of water from the bay. Along this portion of the salt marsh which borders the bay fresh water is obtained from wells of various depths up to 400 feet. This fresh water evidently comes from formations that lie below the salt water. At high tide when the flats are covered by salt water some of the fresh-water wells flow over the surface from the hydrostatic pressure of the heavier salt water.

At San Mateo a creek of the same name is crossed, which carries water from Crystal Springs Lake in the San Andreas rift valley to San Francisco Bay. The lake is one of those formed by dams in the creek. At San Mateo an alternate route may be taken into the city by turning on Crystal Springs road to Skyline Boulevard, which runs along the San Andreas rift, and returns to the highway at Colma.

East of Millbrae, in the bay, are oyster beds where young oysters, or "spat," brought from the Atlantic seaboard are planted and matured.

San Francisco Peninsula Made up of Fault Blocks

The San Francisco Peninsula, on the northern end of which the city of San Francisco is located, is divided into two parts by the northwestwardly trending Merced Valley. Millbrae and San Bruno are at the southeast end of this valley where it merges into the salt marshes of San Francisco Bay. Each part of the Peninsula is a block of the earth's crust with a fault along its southwest side, upheaved and tilted so that it has a gentle slope to northeast. Both blocks have been worn by erosion so that they have lost much of their original block-like appearance. The block east of the Merced Valley is known as the San Bruno block, and that to the west as the Montara block. The fault at the west side of the San Bruno block is concealed by the alluvium of the valley. North of San Bruno Mountain (or block), between it and the Golden Gate is a group of hills, partly sand dunes and partly hard granitic rocks, on and between which the city of San Francisco is built.

ROUTE E. SAN FRANCISCO, VIA THE GREAT VALLEY TO EL PORTAL AND YOSEMITE NATIONAL PARK. 199 MILES

Oakland, four miles from San Francisco; Haywards, 13 miles; Tracy, 59 miles.

San Francisco to Oakland, via High Bridge or ferry, four miles. The route out of San Francisco basin is across the alluvial plain to Haywards. Cross San Leandro Creek at San Leandro. This creek meanders across the flat plain after descending from the foothills of the Diablo Range to the northeast. Haywards is located in a bottle-neck or gap in a ridge of igneous and metamorphic rocks which flank the Diablo Range. East of Haywards is Castro Valley, through which San Lorenzo Creek flows, swinging south and west through the gap at Haywards. Eastward from Haywards is the broad alluvial Livermore Valley. The route leads across the Diablo Range, the easternmost range of the Coast Range system.

Diablo Range Broken by Many Faults

The rocks of the Diablo Range are metamorphic sedimentary and igneous rocks of the Franciscan formation, overlain in places by Cretaceous and Tertiary shales, sandstones, and conglomerates. East of Haywards is a fault or break in the crust of the earth. East of the fault Chico (Upper Cretaceous) rocks are exposed, and immediately west of the fault the Knoxville (Lower Cretaceous) rocks are at the surface, covered and obscured by the surface soil. Southeast of Haywards other faults occur, which show the stresses and strains by which the Diablo Range has been shattered and uplifted.

Axis of Great Central Valley but Little above Sea Level

Rolling hills of the Diablo Range are crossed to Tracy, on the flat bottom of the Great Central Valley of California. From Tracy to Manteca the route is across Tom Paine Slough, Paradise Cut, and San Joaquin River. Here is the low axis of the Great Central Valley, through which meanders San Joaquin River. The valley floor is made up of alluvium washed into the valley by streams on either side. The great Valley trough is a sunken basin into which in Cretaceous and Tertiary and later time deposits of sand, silt, and gravel have been borne. The San Joaquin River, only about 20 feet above sea level, meanders sluggishly over the nearly level floor. North of Tracy are old abandoned river channels or sloughs, and canals have been cut to salvage the land from overflow of flood waters. The soils are sands, sandy loams, and loams. The Great Valley of central California is one of the world's great agricultural districts. A great variety of agricultural crops—grains, forage crops, orchard and garden fruits, and vineyard products—make this a region of tremendous possibilities.

Approach to Yosemite National Park through Canyon of Merced River

Stanislaus River is crossed seven miles beyond Manteca, at Ripon, and 16 miles farther is Modesto and Tuolumne River. From Modesto it is possible to select another route to Yosemite National Park, but the classic and most desirable route is across the flat valley floor to Turlock and Merced (133 miles). From Merced the all-year highway up the canyon of Merced River offers an unparalleled approach to Yosemite entrance at El Portal (199 miles). This is the approach par excellence to Yosemite National Park.

Old Roof Rocks of Granitic Batholith Exposed in Merced Canyon

After leaving Merced the rocks making up the foothills as far west as Bagley belong to the Mariposa formation (of Jurassic age). Beyond Bagley to El Portal is a belt of older rocks, the Calaveras formation. These are the ancient formations that once extended far over the Sierra slope, but since the upheaval of that great range have been largely eroded and worn away. These are the remnants of the roof rocks which were uplifted when the great granitic batholith which is the core and body of the Sierra Range was forced up as a hot molten mass under them. The rocks are highly metamorphosed, upturned, bent and folded. The two formations extend far along the lower western slope of the Sierra Nevada.

Calaveras Formation Crossed between Bagley and El Portal

The rocks of the Calaveras formation form a belt along the lower Sierra slope. Across this belt the Merced River has cut its canyon. The highway follows the course of Merced Canyon. From the vicinity of Bagley to El Portal, a distance of about 30 miles, the highly metamorphosed and contorted rocks of the Calaveras formation are on either side of the canyon. The rocks are composed mostly of upturned beds of slate, quartzite, and marble, originally shales, sandstones and limestones, which were deposited on sea bottoms as mud, sand, and lime. The rocks have been metamorphosed by heat and pressure, and the beds folded and squeezed together, the remnants of compressed folds or wrinkles of an ancient mountain range that was upheaved and in turn worn down, and later uplifted as a roof over the injected batholith of the Sierra Range. It is in this series of rocks, and those of the younger Mariposa formation which lie to the west, far to the northwest along the Sierra slope, that the group of gold-bearing quartz veins, the famous Mother Lode, occurs.

In Merced Canyon, a little above the mouth of Ned Gulch, about 7 miles before reaching El Portal, the river cuts across a series of chert and shale beds (metamorphosed sea-bottom ooze) that are compressed into intricate wrinkles and folds. Polished and scoured in the river gorge these bent and contorted wrinkles in the hard rocks show with astonishing clearness.

Alternate Route via Big Oak Flat Road

And now, here is El Portal, the Gateway, entrance to Yosemite National Park, one of the most marvelous regions of natural scenic grandeur in the world. (Read Chapter XVI, and spend as much time as possible in the Park.) Returning, an alternative route may be chosen. Big Oak Flat road leaves the Valley at El Capitan bridge. It is necessary to check out before departing as the road is a one-way thoroughfare. It has been built at great expense through incomparable rocks, and winds up a well-nigh impossible rock wall, the wall of the Incomparable Yosemite Valley.

Route F. San Francisco, via the Gold Belt to the Crest of the Sierras. 243 Miles

Alternate Routes to Sacramento

Leaving San Francisco via the High Bridge or ferry to Oakland, it is possible to reach Sacramento by different routes.

The route described follows the waterway to Carquinez Strait. An alternate route, slightly farther, is by the tunnel road to Walnut Creek and the Stockton highway to Sacramento, or turn off the highway east of Pinole (about 25 miles from San Francisco) after crossing Pinole Creek, through Franklin Canyon to Martinez, thence by ferry to Benicia.

Oakland, 8 miles (El. 12 feet); Berkeley, 10 miles (El. 8 feet); Benicia, 33 miles (El. 6 feet); Suisun, 49 miles (El. 15 feet); Davis, 76 miles (El. 42 feet); Sacramento, 97 miles (El. 30 feet).

Shell Mound and California State College

Driving out of Oakland north Shell Mound Park is passed on the left. The mound is composed of soil mixed with an immense number of shells of clams, oysters, abalones, and other shellfish left by a prehistoric people who evidently made this an eating-place long before white men established sea-food eating stations on the shores of San Francisco Bay. Many such mounds have been located in the vicinity of the bay.

Adjoining Oakland on the north is the city of Berkeley, where is located the University of California, one of the largest State Universities in America. The University and the city are on high ground overlooking San Francisco Bay. The residence portion of the city is on the slope of the Berkeley Hills, formerly known as the Contra Costa Hills, to the east. Beyond Richmond and San Pablo rocks of the Franciscan group outcrop. To the east (right) Grizzly Peak and Bald Peak rise to 1,759 and 1,930 feet, respectively. To the west of San Pablo are hills of Franciscan sandstone, called Protrero San Pablo (San Pablo pastures) by the early Mexicans whose horses were pastured on these dry uplands before fences were thought of.

Many Formations Exposed on Shore of Carquinez Strait

Approaching Vallejo Junction and Carquinez bridge, on the right in a high cliff a fault appears in which buff-colored Monterey sandstones and shales (Miocene) rest with marked unconformity upon black Eocene shales. East of Vallejo Junction is Carquinez Strait, through which the waters of the Sacramento and San Joaquin rivers pass to San Francisco Bay and through the Golden Gate to the ocean. Along the south shore of Carquinez Strait the steep bluffs show many good exposures of folded sedimentary rocks (Chico formation, of Upper Cretaceous age). From an elevated point Mount Diablo may be seen, about 15 miles south and east. If the route via Walnut Creek is followed, turn east to reach the mountain, then continue north. It will be necessary to ferry across the strait from Martinez or Port Costa to Benicia.

State Agricultural College on Plain but Little above Sea Level

North and east of Benicia rocky headlands crowd in upon Carquinez Strait, and fine exposures of Cretaceous and Tertiary sandstones and shale occur in the cliffs and road cuts. Suisun Bay lies close at the right and Suisun Flats, a swampy district but little above tidewater, extends for 16 miles to the towns of Suisun and Fairchild. The foothills of the Coast Range are passed through to Elmira. Then a broad alluvial plain ensues to Davis, where is located the State Agricultural College and U. S. Experiment Station. The land about Davis is a smooth plain but little above tide-level, but high enough to be drained and used for agricultural purposes. Between Davis and Sacramento marshy tule-lands extend for many miles. Sacramento River is crossed just below the mouth of American River to the city of Sacramento.

Levees Protect Floodplain of Lower Sacramento River

The lower courses of the main streams in the Sacramento Valley have built their floodplains above the level of the adjacent land, and levees have been built to protect the farm lands. Many channels, dry most of the year, particularly those from the Coast Range on the west, lead into the valley. The flood waters from these channels cannot reach the main river at all, and therefore spread out over the lowlands on either side, and eventually disappear chiefly by evaporation.

Rocklin, 11 miles (El. 249 feet); Auburn, 125 miles (El. 1,360 feet); Colfax, 143 miles (El. 2,422 feet); Gold Run, 154 miles (El. 3,224 feet); Emigrant Gap, 172 miles (El. 5,225 feet); Donner Pass (Summit), 193 miles (El. 7,135 feet); R. R. Summit (El. 7,012 feet); Truckee, 208 miles (El. 5,820 feet); Reno, Nev., 243 miles (El. 4,497 feet).

Cross American River to Gold Dredging Fields

Crossing American River, which joins the Sacramento just north of the city, do not fail to visit old Sutter's Fort. The flat plain of the Great Valley continues 18 miles, to Roseville, where begins the Sierra slope. At the west base of the Sierra slope brown Upper Cretaceous and Tertiary sandstones and clays are exposed. These formations are younger than the rocks forming the mass of the Sierra Range. These formations have not been squeezed, folded or altered by metamorphism. Remnants of the lavas that were poured down the Sierra slope during Tertiary time cap some of the foothills.

Great gold-dredging fields lie along the Sierra slope where it merges into the valley plain. Near Folsom, a few miles south and east of Rocklin, where American River emerges upon the plain of the Great Valley, huge electrically operated dredges scoop up the gold-bearing earth, which is mechanically washed and the gold recovered. The gold was brought down the Sierra slope and deposited in the river gravels in recent geologic time.

Granite Quarries; Granite Soils Produce Fruits

Rocklin, named for the granite rock which is quarried there, is the principal granite producing district in California, with many quarries in operation. The stone for the State Capitol, at Sacramento, and for many buildings in San Francisco, came from Rocklin quarries. The rock is a normal granite—composed of quartz, feldspar and mica. A short distance from Rocklin the country rock grades into granodiorite, which is the predominant rock in the Sierra Range. Granodiorite differs from granite in that it contains little or no quartz.

At Loomis there is a large granite quarry, but its most important industry is fruit-growing. The soil is decomposed granite. Granite ledges outcrop on the soil-covered plain. The district is favorable for oranges, which are said to ripen early, and that injurious frosts are almost or quite unknown. Penryn and Newcastle are fruit-growing districts. Pears, peaches and prunes, and also oranges and lemons, abound, and fig trees and palms are also seen.

Auburn, Former Mining Town, Produces Fruits

Auburn in the early days was a mining town, built in the valley of a small stream known as Auburn Ravine. In later years the surrounding hills have been settled and fruit-growing has largely taken the place of mining. Two miles west of Auburn is a mining district where gold and silver occur in veins in the granitic rock (granodiorite). Remnants of lava beds are passed through about Auburn, beds which originally covered the granite rocks.

Gold-Bearing Quartz Veins at Colfax

Approaching Colfax yellow soil derived from Jurassic (Mariposa) slates is crossed. Beyond Colfax is a deep ravine up which runs a narrow-gauge railroad to Grass Valley and Nevada City. The ravine opens into the valley of North Fork of American River, cut in Mariposa (Jurassic) slate. In this formation are some of the principal gold-bearing quartz veins of California, including the Mother Lode. Beyond Colfax and across the ravine is a high ridge, the south end of which is known as Cape Horn. At the south end of the ridge is a precipice 1,500 feet above the North Fork of American River from which a splendid view may be had of the canyon. To avoid a dangerous curve around the Horn a tunnel has been bored through the ridge through which the railroad now passes. On a clear day from a high vantage point near Cape Horn placer pits may be seen far to the southeast across the canyon at Iowa Hill and Michigan Bluff, once busy mining centers.

Grass Valley and Nevada City
Historically Interesting

It may be of interest to turn up a highway that traverses the ravine through which runs the narrow-gauge railway to Grass Valley and Nevada City. These are historically interesting places, and from a gold-producing standpoint they are still important. It is said that probably nowhere else in the State has there been so great a concentration of gold in a small area. The North Star mine is said to be the most productive gold mine in the State. At Grass Valley a monument marks the spot where it is claimed gold quartz was first discovered, from which sprang the great quartz-gold mining industry of California. The Empire mine, with 200 miles of underground workings, has been in continuous operation for nearly a hundred years. The city is honeycombed with tunnels. The crooked streets and weather-beaten brick buildings with stout iron doors and iron-shuttered windows tell of the days of '49. Nevada City originally had only placer mines. Even the streets were "washed" for gold. Ancient houses, 3 or 4 stories high, with steep roofs, cling to the precipitous canyon walls, and point to a history that runs back to early days. The Ott Assay office, established in 1853, is still in operation. The old reconstructed Joss House, now a museum, contains relics that tell of the old-time days.

Hydraulic Pits at Gold Run and Dutch Flat

Approaching Gold Run a north-south belt of slate of Carboniferous age (Calaveras formation), cut by dikes of dark igneous rock, is crossed. Patches of Tertiary lavas, remnants of the lava-flow which covered the plateau in Tertiary time, cap the highest hills along the summit of the ridge in this region. Nearing Dutch Flat Tertiary gold-bearing gravels are crossed. The gravels that rest under the railroad tracks, if they could be "washed" for gold, it is said would be worth $8.00 per cubic yard, while gravels elsewhere that yield $1.00 to $2.00 per yard are worked profitably. The town of Dutch Flat is almost surrounded by great pits made by hydraulic washing for gold. Here is a region that was prominent in the early mining days of California for its yield of placer gold. The gold came chiefly from the high bench gravels which were deposited in Tertiary time, and now high above the present streams. The gravels were formerly washed by jets of water driven under great pressure, but this method is now forbidden by law because of the damage to agricultural lands below from the silt and sand washed down the streams.

In passing it is interesting to note that from a side-track on the railroad near Alta round white quartz boulders, obtained from the old gold washings, are shipped to Sacramento for use in the furnaces of the railroad shops. The pure white cobbles are left behind as the finer materials are washed away, and surprisingly there are none of the common red granite boulders.

Deep Gorge of American River near Midas

A little south of Midas appears a nearly sheer drop of 2,000 feet into the gorge of the North Fork of American River. Near Gorge station on the railroad is Giant Gap or Lover's Leap. This is a narrowing of the canyon caused by the fact of the river here crossing a belt of igneous rock that is harder than the slate which forms the higher walls of the gorge. The depth to which the river canyons have been cut in this Sierra slope indicates the amount of erosion that has occurred since the range was uplifted. These canyons are topographically what the geologist calls young features of the landscape. When they have become "old" the ridges between them will have been worn down to low rounded divides, and the streams, instead of rushing through steep rock canyons, will roll leisurely in meandering channels through broad green meadows.

Old Emigrant Trail in Notch in Lava-Capped Ridge

Blue Canyon (station) is near the crest of one of the flat-topped lava-capped ridges which are characteristic of this part of the mid-Sierra slope. The deep canyon of Blue Creek joins American River near by. Emigrant Gap is a grass-covered notch in the slates and schists of the Calaveras formation, through which a branch of the old California emigant trail led down into the valley of Bear Creek. It is said wagon-wheel marks of the old trail are still visible.

Here the character of the surface soil changes as the crest of the Sierra Range is approached. High on the crest the soil has been largely removed by the ice of glaciers, and the surface of the rocks in many places has been scoured and smoothed by the moving glacier ice. Nearing the summit the rocks are principally granite (technically granodiorite) and lavas. Volcanic rocks generally cap the ridges, the lava rocks being hard and resistant to erosion. The canyons have been generally cut through into granite or into the sedimentary rocks which were invaded in the upheaval of the granite. Most of the sedimentary formations are of the Calaveras formation (Carboniferous) and the Mariposa slate (of Jurassic age).

South Fork Yuba River Scoured by Glacier Ice

Near Cisco north (left) of the valley of the south fork of

Yuba River is a high ridge known as Signal Peak. This ridge is composed of metamorphic slates of Triassic age. On the peak a fire look-out station is maintained. The brown talus from these slates is in marked contrast with the white granite which outcrops over much of the summit region. Below Soda Springs the valley of the south fork of Yuba River has been scoured by glacier ice, its broad and smoothly rounded bottom worn into the bare granite. Morainic material is scattered along the sides of the valley in the form of boulders, irregular shaped stone fragments, and gravel.

Crossing Sierra Summit, Above 7,000 Feet

For about two miles, nearing the summit, an upland glacially-formed meadow is in a valley in the lower part of which is Lake Van Norden. And here is the summit of the Sierra Nevada Range. In a distance of less than 200 miles from the ocean, and in about 100 miles from the edge of the Great Central Valley of California, an elevation of more than 7,000 feet has been reached. The achievement of building a railroad through a rough mountainous country from sea level to such an elevation was a marvel of engineering construction. To traverse this vast slope now, through the same land that was crossed by the pioneer '49-ers with such danger and difficulty, over hard-surfaced well paved highways, is another of the marvels of modern times.

The highway crosses the summit of the great range at an elevation of 7,135 feet. The railroad cuts under the crest of the range through a long tunnel at a level 123 feet lower. Here is Donner Lake and Donner Pass, memorable for the terrible tragedy of 1846. The highway is north of Donner Lake. Donner Lake State Monument, where is recorded the date and the facts of the suffering and tragic fate of the emigrant party, is south of the lake.

Donner Lake in Granite Basin, Water Held by Glacial Debris

Donner Lake lies in a basin in the granite rock. The basin was evidently once filled with ice of a glacier. Bare granite cliffs form the walls of the upper basin. Below, at the east end of the lake, a moraine deposited by the ancient glacier holds back the waters of the lake. The lake is drained by Donner Creek, which has cut a channel through glacial debris and lava rocks (basalt), and discharges into Truckee River. The valley of Donner Creek is broad and U-shaped, scoured by glacial ice. Moraines are numerous. Large boulders of granite, relics of the ice of the Glacial Period, strew the surface on all sides.

Eastern Sierra Slope Marked by Moraines

The eastern Sierra slope down to an elevation of 5,000 feet was long buried under ice. The grinding of this mass of moving ice had the effect of widening the valley bottoms and steepening the sides, tending to change the cross-sections of the valleys from V-shaped to U-shaped. Moraines composed of rough and angular boulders of all sizes, and gravel and sand, were deposited by the melting ice at the lower ends of ice tongues and along the sides of the valleys. Truckee is at the foot of the eastern (ice covered) slope. The higher part of the city is built upon deposits made by glacial ice. The canyon of Truckee River, between Truckee and Lake Tahoe, has evidently never been glaciated.

Due to the relatively great precipitation on the Sierra crest (officially reported from 58 to 74 inches annually) Lake Tahoe overflows. The lowest point of the rim of its basin is at Tahoe City on the northwest shore of the lake. From here water escapes through Truckee Canyon—and finally disappears by evaporation from Pyramid Lake in the desert of northwestern Nevada.

Lake Tahoe on Sunken Floor between Faulted Mountains

Lake Tahoe is an exceedingly interesting lake. A trip may be made by narrow-gauge railroad (about 15 miles) from Truckee through the canyon, or by automobile over a good highway, to Tahoe City, and from here a steamer trip may be made around the lake. In making the trip from Truckee Tinker Knob is passed on the west, one of the culminating peaks of the Sierra Range. Lake Tahoe lies in a structural depression—a block of the earth's crust that was dropped down between two mountain ranges. The Sierra Range is here a double range of almost parallel north-south ridges, and Lake Tahoe lies on the depressed floor between the two. This is a case where the bottom fell out between two mountain ranges. Mount Rose, in the Carson Range on the east, rises to a height of 10,800 feet. The crest of the range to the west forms the watershed between the waters that flow to the Pacific and those that pass out upon and disappear in the Great Basin.

During late Tertiary and early Pleistocene time the waters of Lake Tahoe basin stood at a much higher level than now. This is shown by distinct old beaches or terraces that stand at levels 35 to 40 feet, and up to 100 feet, above the present lake. Such terraces or beaches marking earlier levels of the lake may be observed almost all the way around the lake. The lake is 21 miles long by 12 miles wide at the widest point. The climate is most balmy in the hottest summers, and accommodations for tourists and visitors are abundant.

Fishing Fine in Truckee River

Returning to the highway at Truckee, it is claimed that the fishing is fine down Truckee River to Boca and beyond, and camps and hotels offer stopping-places to suit the convenience of guests. This is near the State line and Reno is but a short way ahead. It is said that families are sometimes separated there, so it will perhaps be well to stop on the river and fish!

Columnar Basaltic Lava in Walls of Truckee Valley

Beach gravel terraces, formed by the larger (Pleistocene) Lake Tahoe, are all along Truckee River. Near Boca terraces that were overflowed by basaltic lava show the columnar joint structure in the walls of basalt. This columnar jointed structure is very characteristic of basaltic lavas. The jointing results from shrinkage during the slow cooling of the lava. Ledges of volcanic rock are exposed in many bluffs along Truckee Canyon. The exposures are of many shades of color, light gray, rusty, purplish, and dull green. The canyon is in places very narrow and deep. Iceland is a small place that gets its name from the industry which predominates at numerous places along the canyon, viz., ice cutting. No natural ice is obtained at lower levels in California, consequently on extensive business has been built up in the production of ice in reservoirs formed by dams in the canyon.

Time to Return!

Calvada is 229 miles from San Francisco, on the State line of Nevada, at an elevation of 5,041 feet, and 14 miles farther on is Reno. In the interest of domestic tranquillity it may be well that we stop right here!

Route G. Sacramento, via Marysville to Lassen Volcanic Peak and Mount Shasta. 256 Miles

Roseville, 18 miles (El. 162 feet); Marysville, 52 miles (El. 72 feet); Chico, 95 miles (El. 193 feet); Tehama, 123 miles (El. 223 feet); Redding, 213 miles (El. 557 feet); Mount Shasta, 247 miles (El. 3,553 feet); Yreka, 291 miles (El. 2,624 feet).

The Sacramento Valley extends from Carquinez Strait, through which the Sacramento and San Joaquin rivers reach the ocean, north 160 miles to Redding. It embraces the vast area between the Coast Range on the west and the Sierra

Nevada on the east. It embraces the north half of the Great Central Valley of California, of which the San Joaquin Valley is the south half. Into the Sacramento Valley from both east and west enter streams which have carried detritus to the valley, forming the alluvial floor of the nearly flat plain. In the flatter parts of the valley overflow from the incoming rivers is practically a yearly occurrence. The overflow lands on a large area have been protected by dikes. Overflowed lands which support a luxurious swamp vegetation are among the most fertile in the valley when reclaimed by levees.

Rainfall is seasonable. The months October to March constitute the rainy season. The rest of the year is practically rainless. Cattle-raising is an important industry. Lands that are overflowed yearly (tule-lands) are grazed during the dry summers, and with the coming of the fall rains cattle and sheep are moved to grazing lands in the mountains. Cereal grains are sown in the fall and harvested in the early summer. All deciduous fruits bear abundantly, and are rarely damaged by frost. Many fruits and nuts are grown, and there are large areas of vineyards.

The gently undulating, nearly flat, plain of Sacramento Valley, which is crossed en route to Roseville, merges into the broadly eroded depression of the valley of American River. This broad valley, east of Roseville and about Folsom, has been formed by the erosion of the comparatively soft and erodable granodiorite which is the body rock of the Sierra Nevada. Off to the north and east Lincoln looks like a great table-land. This is known as the Auburn Ridge. It is a hard volcanic rock (technically andesite) of Tertiary age. The rock is hard, and the softer formations surrounding are eroded away leaving the flat-topped table-land. The foothills which lie along the edge of the valley at the base of the Sierra Range are the disturbed, folded and wrinkled metamorphic sedimentary rocks of the Mariposa (Jurassic) formation, intermixed with lavas, together with later deposits of nearly horizontal beds of sandstone, conglomerates, shale and clays, of late Tertiary and Pleistocene age.

At Lincoln is a deposit of white sand and clay (Ione, late Tertiary formation) and lava (andesite). The flat plain to the west comprises a deep alluvium varying from black adobe clay to sand, generally very fertile. The soil along the edge of the valley is commonly a reddish sandy and gravelly loam. In the foothills there is little alluvium, the soils being derived from the long continued distintegration of the rocks. Soils derived from lava rocks generally are rich in plant food, and therefore adapted to fruit-growing. Areas of andesite lava, a rock which disintegrates very slowly because of its hardness, are commonly covered with boulders and but little soil.

The elevation of the valley floor in the vicinity of Wheatland is about 50 feet. To the northeast the foothills lie in parallel ridges. Brown's Valley Ridge rises conspicuously from the flat plain, with successively higher ridges beyond.

At Marysville the Yuba and the Feather rivers come together, both coming from high on the Sierra Range. These rivers pursue winding courses on low ridges built up by sediments deposited during high water. Tributary streams are turned aside before reaching the main streams and become stagnant pools or sloughs, and large areas are overflowed during the wet seasons. Extensive tracts are protected by levees. Minor swamps and sloughs occur on both sides of Feather River.

Marysville Buttes an Extinct Volcano

In marked contrast to the flat plain, there rises between the Feather and Sacramento rivers a circular group of mountains, the Marysville Buttes. This group of mountains has a diameter of 10 miles, the central peaks of which have an elevation of 2,000 feet. This high isolated mountain group rises with serrate and fantastic outline from the flat and monotonous plain of Sacramento Valley. The Marysville Buttes constitute an extinct volcano. A view from a distance shows gentle slopes made up of beds of mud-lava poured out from the vents of the volcano, and within the periphery of the great crater basin abrupt jagged peaks and domes rise, of which South Butte and North Butte are the most prominent, rising to 2,128 and 1,827 feet respectively. It is thought when the volcano was in active eruption it formed one great cone. The central mass of the buttes consists principally of massive volcanic rocks. Between the peripheral mud-flows and the massive volcanic core occurs a series of sandstones, clays and gravels. These beds are very much disturbed, and dip away from the central core near by, standing at high angles, sometimes vertical. The force of the ascending lavas during eruption was so great that the surrounding sediments were uplifted more than 1,000 feet, and bent upwards on all sides.

Fertile Soils; Gold Washing in Foothills

After crossing Feather River at Marysville the flat plain of the Sacramento Valley continues for 47 miles to Chico. This is a vast agricultural region, and stock-raising, grain growing, and the production of fruits are important industries. Gold washing in the stream courses from the mountains on the east has been common. Southeast of Chico in the valley of Butte Creek for several miles "tailings" or re-washed soil from placer gold mining fills the valley. By irrigation water is brought to higher and dryer lands. Levees hold back water on low lands. Not enough water and too much water are problems of agriculture. A U. S. Plant Introduction Field Station is located southeast of Chico. A variety of soils are crossed, ranging from clay and silt loams to sandy and gravelly loams, with boulder-covered rough slopes extending down the foothills on the east. A large sugar-beet factory west of Chico testifies to the richness of the river bottom lands. No less than 39 soil types have been determined in the Chico area by the U. S. Department of Agriculture.

In the foothills along the east side of the valley are lava flows, sandstones, shales, and clays of Tertiary age, also sandstones, shales and limestones of Jurassic age. Metamorphosed sedimentary and igneous rocks in the foothills underlie the auriferous (gold-bearing) gravels.

Red Bluff at Northern End of Citrus Belt

Red Bluff gets its name from the river bluff about 50 feet high in which is exposed sands and gravels of Tertiary age. These are the older alluvial sediments deposited in the bay that filled the valley in late Cretaceous and Tertiary time, as distinguished from the later alluvium which has been deposited during late Pleistocene time and down to the present, and which comprises the present alluvial floor of the valley. Red Bluff is at the northern end of the citrus belt. Oranges, lemons, almonds, and figs are raised here, though fruit orchards, peaches, pears, and prunes, occupy more extensive areas.

Hot Springs; Volcanic Craters; Sandstone Dikes

Northeast of Red Bluff are the Tuscan Buttes, made up of volcanic tuffs, gravel, sand and clay. Tuscan Springs, a health resort, is nine miles northeast of Red Bluff. The springs, which are hot, emerge from shale surrounded by volcanic tuff thrown out from volcanoes in the Lassen Peak region. Directly east of Anderson is Shingletown Butte, a perfect little extinct volcanic cone. Inskip Hill, a group of recent craters, lies to the south of Shingletown Butte. A view of Lassen Peak may be had from this section.

Cottonwood Creek is crossed 17 miles north of Red Bluff. It is of interest to note that 14 miles west on this creek are sandstone dikes, a not common geologic occurrence. Cracks in the rocks that were formed by an ancient earthquake have been filled with sand and the sand filling hardened into rock so that the dikes resemble true igneous dikes.

Redding at Northern End of Sacramento Valley. Canyons and Gorges North

East of Cottonwood the Sacramento meanders over the alluvial floodplain, with islands and sloughs common. Eighteen miles north is Redding, which is at the north end of the Sacramento Valley. Beyond Redding the Sacramento for 75 miles runs between the rocky walls of canyons and gorges cut by the river in hard lava and other rocks.

If time will permit it will be of interest to visit Lassen Volcanic National Park. Going north the trip may be made from Red Bluff, returning to the highway at Redding, or going south, turn east from Redding, returning to the highway at Red Bluff. The distance between Red Bluff and Redding is 35 miles. The side trip through the Park is 130 miles.

Side Trip to Lassen Peak

From Red Bluff a highway runs east to Mineral, 43 miles, headquarters for Lassen Volcanic National Park. Here a permit for an automobile may be obtained for one dollar. From Mineral to the Park boundary is eight miles. Brokeoff Mountain and Lookout are three miles by trail from the highway. Passing Tophet Springs and Diamond Peak (elevation 7,969 feet), Soda Springs is 13 miles from Mineral. Pilot Pinnacle (elevation 8,886 feet) and Mount Diller (elevation 9,086 feet) are at the left (west). Emerald Lake and Lake Helen are about 14 miles from Mineral. Do not say any bad words, for Bumpass Hell is only one and one-half miles (by trail) from the highway! Within a depression 500 feet by 1,400 feet in size are concentrated a vast number of fumaroles, sulphur cauldrons, boiling fountains, and hot springs. Lassen Peak (elevation 10,453 feet) is two and one-half miles by trail from the highway at Summit. The Devastated Area is reached 27 miles from Mineral. Memorial Museum and Manzanita Lake are 35 miles from Mineral. The northwest boundary of the park is 36 miles from Mineral, and from the boundary to Redding via Viola is 50 miles.

Canyons of Sacramento; Important Mines

Proceeding north from Redding the Sacramento River has cut a canyon 200 feet deep in hard ancient lava rock. A little above Redding the valley opens out into the wider valley that forms the north end of what is known as Sacramento Valley.

Middle Creek, which enters the Sacramento three miles north of Redding, was at one time rich in placer gold, which was recovered from river gravels brought down from the mountains on the west.

Northwest of Keswick five miles is the Iron Mountain mine, which has produced many millions in value in copper. The ore is conveyed from the mine by a crooked narrow-gauge railroad, and is smelted near Martinez, on San Francisco Bay. Gold-bearing quartz veins are worked east of the river at Central Mine, and the ore is brought to the railroad by a bucket tramway. From Keswick north for 10 miles the region is one of desolation. Fumes from the copper smelters at Keswick, Coram, and Kennett have killed all the vegetation and left bare slopes which resemble the colorful sunbaked hills of the desert. Copper occurs principally in the hills to the west. On the east are ancient lavas in which are gold-quartz veins.

About three miles northwest of Kennett is the Mammoth copper mine. The ore occurs in large bodies of irregular shape, in quartz-porphyry (a granitic rock composed chiefly of quartz crystals with feldspar). This is an igneous rock which was injected into andesite lava, a lava which was poured out in early Palaeozoic time. The intrusion of the quartz-porphyry into the lava occurred in Jurassic time. Almost the only rocks visible from Redding north to Kennett are quartz-porphyry and andesite lava.

Pit River Joins the Sacramento

Pit River enters the Sacramento a few miles north of Kennett. Pit River comes from Goose Lake, in the northeastern corner of California, about 200 miles distant across the Cascade Range of mountains (the northern continuation of the Sierra Nevada Range). This might have been called the Sacramento, as it is a much larger stream than the comparatively small Sacramento, which has its source southwest of Mount Shasta, 60 miles north. This would have made the Sacramento River—from Goose Lake to the Strait of Carquinez and the Golden Gate—a river nearly 700 miles long, the longest river in California.

The scenery along the Sacramento Canyon from above Redding to the foot of Mount Shasta is wild and interesting. Slopes 200 feet high crowd upon the river in places, and occasional wider places in the valley afford locations for farms. Wherever there is land not too steep or rocky, and soil has gathered there, somebody finds a home and attempts to develop a farm. The Sacramento, here a turbulent mountain stream wrestling with boulders and rock obstructions, is a stream that invites the fisherman.

Lava from Mount Shasta in Sacramento Valley

From near Elmore north to the foot of Mount Shasta, a distance of approximately 50 miles, the valley of the Sacramento is occupied by lava, which was poured from the vent of volcanic Mount Shasta and flowed down the valley. Sacramento River persists in flowing down this valley. At Lamoine lava terraces are on either side of the valley overlying slate rock. The river has cut down through the lava and excavated a canyon in the slate below. As Delta is approached, on the left (southwest), a bluff of slate is overlain by 10 feet of gold-bearing gravel which was deposited by the river when it flowed at a level a good deal higher than now. The gravel is capped or covered by lava which flowed down the valley. The river has cut through the lava and through the gravel and has eroded a canyon 60 feet into the slate rock.

The long narrow strip of lava which flowed as a long tongue down the Sacramento Valley forms the bed of the river at Castella, and lava terraces are on either side. Where the river has yet to cut down through the lava the floor or bottom of the river is the lava rock.

Columnar Basaltic Lava near Dunsmuir

Near Dunsmuir on the left (west) a good example may be seen of the columnar jointing (shrinkage joints formed in the cooling lava) such as is seen in many places in basaltic lava beds. (The Devil's Post Pile, south of Yosemite National Park, is a monumental example). South of Dunsmuir, on the left (west), are the rugged pinnacles of Castle Rock. Here are effervescent (carbonic acid) springs, and water is commercially bottled at the mouth of appropriately named Soda Creek. This was a noted station on the old Oregon-California stage line. Fine summer resorts are here now. Whether the effervescent soda water was the chief means of entertainment in the old days is not recorded. There are well kept hotels now—and everything!

Shasta Springs, town and hotel, are on a terrace 300 feet above the contact of the horizontal lava beds with the rocks below. The springs issue forth at the juncture of the lava with the rocks below. A short distance below Shasta Springs the lava which once filled the valley forms walls on both sides of the canyon cut by the river.

Great Engineering Feat in Deep Lava Canyon

To construct a highway or build a railroad through a gorge that falls more than 1,000 feet in 10 miles is a feat calling for engineering skill beyond that of common mortal understanding. The hairpin turning and doubling on itself of the railroad has long been one of the fascinating features of the drop down to the bottom or climb up to the top of the lava canyon, whence the Sacramento River enters upon its task of overcoming the lava which flowed from Shasta down its original valley. Here may be seen a section of more than 300 feet of lava and tuffs (fragmentary lava dust).

Timberline Camp at Summit of Mount Shasta

From Sisson a good trail leads to Timberline Camp, 6 miles. If a day can be spared, and *if* the tourist has good lungs, heart and muscles, the climb to the summit of Mount Shasta, 6,000 feet higher, may be undertaken. (Note the *if* in the above sentence!). The summit is 14,380 feet, not quite as high as Mount Whitney. The view from the summit is said to be unsurpassed by that from any peak in the Cascade Range. A sulphurous fumerole (a vent from which hot gases are emitted) is at the summit, and another on the northern slope. During an eruption of the volcano lava poured down the south side and flowed for 50 miles down the valley in which the Sacramento River now struggles to keep its "right-of-way."

Lava Fragments Pushed Down Mountain Side by Glacier

Along the west foot of the mountain, from Sisson to Weed, fragments of lava which have been brought down the mountain side by a glacier that has now disappeared, are piled in hummocky hills, between and among which are ponds and swamps such as occur commonly in moraines formed by glaciers. On the right (east) near Summit (elevation 3,905 feet) is a lava cone known as Sugar Loaf. It is made up of solid andesite lava. When emitted it was in the form of a thick pasty lava which bulged up over the volcanic vent without explosion, and cooled forming the conical peak. It rises to a height of 6,250 feet.

Near Sisson is a large spring which is spoken of as the source of Sacramento River. Small streams in the foothills of the

Klamath Mountains are the headwaters of Sacramento River, and the waters from this spring doubtless contribute a small share to the river.

Broad Shasta Valley Marked by Volcanic Hummocks

North of the divide between the south flowing Sacramento and the Shasta River, which latter flows north to Klamath River and thence through the Klamath Mountains (locally called the Siskiyou Range) and the Coast Range to the Pacific Ocean, is the broad Shasta Valley. Scattered over this valley are many knolls of lava representing local volcanic eruptions. In this valley many cattle are grazed, and from Gazelle station on the railroad many hundreds of car loads of livestock are shipped annually.

West of Gazelle, along the hills of the eastern slope of the Klamath Range (locally called Trinity Mountains), the line of the Yreka ditch, completed in 1856 to carry water for the placer mines near Yreka, may be seen. The ditch is now used for irrigation purposes.

Yreka at North End of Bee-Line

And now Yreka is reached, once a thriving mining town, now an active progressive community devoted more largely to the pursuits of agriculture. Oregon lies beyond. If the patient reader has read Chapter IV—El Centro to Yreka—then let him realize that here is the other end of the Bee-Line of the 850 miles from El Centro, and all the time in the great State of California. Oregon and Washington bid you continue north. Good highways, magnificent scenery, and generous people are all the way to Portland (the Rose City), 292 miles farther, and 578 miles farther is the great city of Seattle, Washington. Or, go a little farther north to Medford and Grant's Pass, Oregon, and cross over to the westward and return through the far-famed Redwood Empire and the northwest coast region of California.

Route H. San Francisco, Through the Redwood Empire to the Northwest Coast. 378 Miles

Redwood Empire along Fog-Ridden Northwest Coast

The Redwood Empire is a unique part of California. It is delimited by climatic and soil conditions which make the Redwood forests possible. The Redwood (*Sequoia sempervirens*) has survived the vicissitudes of geologic ages. Redwood forests were once widespread over many parts of North America, parts of Asia, and across Europe and the Arctic Islands. The tree is now confined to a limited area, a belt 15 to 35 miles in width, a little inland from the coast, along the fog-ridden northwest coast of California and southwestern Oregon.

The southern limit of what is designated as the Redwood Empire is San Francisco Bay, though there are two important groves south of the bay, in Santa Cruz and Monterey counties. The Empire proper begins with Lane's Redwood Flat, 192 miles north of San Francisco, a few miles south of the north line of Mendocino County, and extends north to the Oregon State line and beyond to Grant's Pass.

Redwoods and Big Trees Two Distinct Species

The Redwood (*Sequoia sempervirens*) should be clearly distinguished from its near relative, *Sequoia gigantea,* or Big Tree. It is the Redwood that is confined to the fog-ridden coast. *Sequoia gigantea,* the Big Tree, thrives under quite different physical conditions. The great groves of *Sequoia gigantea* are on the western slope of the Sierra Newada Range, in the heavily forested belt ranging from 3,000 to 6,000 feet altitude. The Big Trees are bigger; the Redwoods are the taller. The two cousins are the noblest trees of earth. It is fortunate that the State of California and the United States government have preserved fine groves of both species for the enjoyment of the people for all time. The State of California, included among

70 State parks, has provided safe anchorage and protection for many fine groves of Redwoods (*sempervirens*), and the federal government has provided for the preservation of magnificent groves of Big Trees (*gigantea*) in Sequoia, and General Grant National Parks. Three groves also are included within Yosemite National Park, the Mariposa Grove, the Tuolumne and the Merced groves.

Several Redwood Groves Near San Francisco

The official Redwood highway starts from San Francisco and traverses successive groves of Giant Redwoods northward, a few miles from the coast, to the Oregon State line and some miles into that State. Muir Woods, a national monument, is but a few miles from the Golden Gate. This is a small but magnificent grove, embracing 424 acres. Armstrong Grove is farther north, 18 miles west of Santa Rosa. This grove, embracing 400 acres, is one of the most magnificent in the State, though not the largest trees. It is well worth a side trip to see. It is four miles from Jenner-by-theSea, and may be reached from Redwood highway from Santa Rosa.

Especial attention is called to Muir Woods and Armstrong Grove, and the two groves south of San Francisco. If it is not possible or practicable to traverse the Redwood highway throughout, at least visit Muir Woods and Armstrong Grove, and indeed if practicable to do so visit Big Basin Grove in Santa Cruz County (California Redwood Park), and Pfeifer Redwoods at Big Sur, in Monterey County.

Alternates Routes Leading to Redwood Empire

Any desired route may be followed from San Francisco north to northern Mendocino County, and the visiting tourist may be assured that the route chosen will lead through interesting and prosperous valleys, with much to be seen that will be worth while. The official Redwood highway is north from the Golden Gate bridge and Sausalito to San Rafael, Petaluma and Santa Rosa, 47 miles, thence north 25 miles to Geyserville (and the geysers 15 miles east of the highway); up Russian River to Hopland and Ukiah, to Willits (134 miles north of Sausalito), and Richardson Grove (201 miles from Sausalito).

If desired leave San Francisco via the Oakland Bay bridge to Oakland and Berkeley, crossing Carquinez Strait to Vallejo,

Photo by Redwood Empire Association

FIG. 106. Historic Bale Mill, near St. Helena. Erected in 1846. The wheel is forty feet in diameter.

thence through Napa Valley, famed for its fine wines, vineyards and wine cellars, passing Napa, St. Helena and Calistoga (here are the geysers, and the petrified forest is near), thence over Mt. St. Helena and Cobb Mountain to Lower Lake. From Lower Lake proceed around Clear Lake, east shore, or west shore over Mount Konocti and Glass Mountain (Glass Mountain is composed of obsidian or volcanic glass) to Upper Lake, to Ukiah and Willits.

Fossil Redwood trees which lived long ago may be seen in a number of places. The most spectacular of these is the Petrified Forest of Sonoma County, 15 miles east of Santa Rosa. If the Napa Valley route is followed the Petrified Forest is six miles southwest of Calistoga, on the road to Santa Rosa.

Shore-Line Highway San Rafael to Rockport

If it is preferred to follow the Shore-Line highway north this may be done by turning west at San Rafael and driving northwest to Jenner-by-the-sea. Following the Redwood Highway, turn west at Santa Rosa. From the Napa Valley turn west at Calistoga and pass the Petrified Forest to Santa Rosa, thence to Jenner-by-the-Sea. (Armstrong Grove is at Guerneville.) The Shore-Line highway follows the coast 135 miles to Rockport, thence 16 miles to the Redwood highway near Lane's Redwood Flat and the Pie Shop. This is not a highway for the crazy driver. The highway follows the shore, with many hairpin curves, and narrow bridges over small streams that enter the ocean.

The drive is a beautifully scenic one. Fort Ross (State Park) and the old Russian chapel (dating back to 1812) is 13 miles from Jenner-by-the-Sea. Near Fort Ross is a sea cliff and boulder beach with terraces sloping toward the sea. Below the cliff are wave-cut terraces ranging in height above the sea to 1,400 feet, and successively lower terraces at 1,180, 760, 440, 350, and 280 feet. The terraces mark stages in the uplifting of the land, and were cut by the waves as the elevation of the land progressed. Two and one-half miles from Fort Ross is a still higher terrace, 1,520 feet. At Plantation a school house has been built on a beautiful beach.

Fine terraces occur all along the coast through Sonoma and Mendocino counties. The rock formations along the shore are much folded and crumpled, and the edges of the outcropping strata have been beveled by the waves. Point Arena (town) is on a fine terrace. Point Arena Lighthouse is on the high promontory that projects into the sea. At historic Fort Bragg a crooked little railroad (the California Western) winds through the hills of the Coast Range from Willits, which is on the official Redwood highway. It is possible to cross from Noyo, near Fort Bragg, to Willits, 35 miles. The (official)

Courtesy Redwood Empire Association

FIG. 107. Old chapel at Fort Ross. On coast north of Jenner-by-the-sea and the mouth of Russian River. Russian explorers constructed a fort in 1811 and raised the Russian flag. Old fort buildings still standing. Now a state monument.

Shore-Line highway ends three miles north of Rockport. A few miles farther north wave-worn pebbles strew an ancient terrace beach 1,200 feet above the sea. Turn right (east) three miles north of Rockport, and after 16 miles here is the official Redwood highway and the beginning of the Redwood groves.

The first grove of Redwoods to be passed on the highway going north is Lane's Redwood Flat, 187 miles north of Sausalito; 53 miles north of Willits. It may be of interest to note that Mrs. McCush keeps a home-made pie shop a little north of Lane's (at Piercy)! Richardson Grove is the first unit of Humboldt State Redwood Park, 14 miles north of Lane's; 201 miles north of Sausalito. There are over-night cabins and camping facilities at Richardson Grove. Garberville is eight miles farther north. There are hotels at Garberville and at Benbow.

Educational Exhibit at Richardson Grove

Richardson Grove is a magnificent stand of virgin Redwoods. An educational exhibit including the stump of a fallen Redwood more than 1,200 years old has been prepared by Professor Emanual Friz, of the University of California. The tree measured 12 feet in diameter at breast height, and was 320 feet high. There is also an interesting exhibit of wild flowers. Richardson Grove, the first unit of Humboldt State Redwood Park, is about 25 miles south of the Park proper.

Famous Tree House Near Entrance to Humboldt State Park

At Lilley's Redwood Park, 18 miles south of Garberville; 55 miles north of Willits, is the famous Tree House. This tree measures 101½ feet in circumference at the ground, 92 feet circumference breast high, and 250 feet high. In years past it was burned at the base in a forest fire leaving the tree standing on four corner "legs" or roots. A "room" was burned out 21 by 27 feet. The tree is said to have been used as a bunk-house by workmen during the early construction of the Redwood highway.

Fourteen Redwood State Parks

California has 70 State parks. Of these 14 are Redwoods, embracing an area of more than 41,000 acres. Of the 14 Redwood State parks nine are in Humboldt County, two in Del Norte County, and one each in Sonoma, Santa Cruz, and Monterey counties. Of the nine designated State parks in Humboldt County eight are included in what is known as Humboldt State Redwood Park, and in these eight units are embraced 35 individual groves. The town of Dyerville is near the northern limits of the park, about 25 miles north of Garberville, which is a little south of the south park boundary. There is a store at Dyerville but no hotel accommodations. Camping and picnicking facilities are available at Stephens' Grove, Williams and Gould Grove, North Dyerville Flat, and Upper Bull Creek. Meals may be had at the little town of Weott, about two miles before reaching Dyerville Flats and Bull Creek Flat.

Founders' Tree in Dyerville Flat Forest

The forests of the Dyerville Flats are considered among the finest. In the North Dyerville Flat forest is the giant Redwood designated Founders' Tree, 364 feet high, thought to be the world's tallest known tree. Circumference at ground 47 feet, diameter, breast high, 11 feet. This tree stands 300 yards east of Redwood highway on the county road leading east to South Fork station. Turn east at the south approach to Dyerville bridge over South Fork of Eel River. The Bull Creek Flat grove, considered by many to be the world's finest forest, is less than two miles off the main highway on the county road leading west from Dyerville. "Big Tree" and "Flatiron Tree" are on Upper Bull Creek, four milest west, turning left at north end of Dyerville bridge. Big Tree measurements on Bull Creek Flat are: circumference 72 feet; diameter, breast high, 16½ feet; height of tree 346 feet.

Half a mile north of Dyerville is a privately owned tract regarded as one of the most majestic of all the Redwood forests. It is called the "Avenue of the Giants." It is hoped that this fine forest may be acquired by the State and preserved, and efforts to this end are being made.

Photo by Redwood Empire Association

FIG. 108. Giant redwood trees (*Sequoia sempervirens*). Tallest and oldest living trees in the world. Tallest known tree 364 feet.

Avenue of the Giants and Eel River Valley

From the vicinity of Dyerville the Redwood highway runs down Eel River Valley for 40 miles. Beyond the Avenue of the Giants there are few Redwoods. Eel River winds over the bottom of a vast mountain trough. The drive through this valley is fascinating. The slopes on either side of the valley are broken by many rock outcroppings. Fishing, wild game and wild flowers all have their appeal, to each according to his several tastes and inclinations. The river spreads out over a flat plain of alluvium as it nears the ocean.

Most Western Points of the United States

Cape Mendocino, the westernmost point of land in the United States, is west of the main Redwood Forest, a rocky promontory at the western extremity of Mount Blank, a plateau 2,100 feet above the sea, on the point of which stands Cape Mendocino Lighthouse. North of the mouth of Eel River for 60 miles the Redwood highway skirts the Pacific Ocean. North of the mouth of Eel River the highway runs along the shore of Humboldt Bay for 25 miles. Here is Eureka, which lays claim to being the westernmost city in the United States, "an enterprising up-to-date city, the metropolis of northwestern California." Here are hotels, auto camps and cottages, with sea coast, mountains, and primeval Redwood forests within easy reach, also the United States Coast Guard station overlooking a broad expanse of the Pacific Ocean, and the entrance to Humboldt Bay. North eight miles is Arcata, at the northern end of Humboldt Bay, seat of Humboldt State College, also lumber manufacturing industries. North of Arcata for 20 miles the highway hugs the ocean shore, crossing a flat-topped plateau 1,600 feet above the sea, with an uplifted wave-cut wall 1,000 feet above the sea forming the plateau front.

Historic Trinidad and Lighthouse

On the route north is old historic Trinidad. This is an historic town in very fact, with a lofty lighthouse on the headland high above the breakers. It was at Trinidad that the first landing was made by early Spanish explorers, on Trinity Sunday, 1775, an event commemorated by a granite cross. On the route northward from Trinidad what is pronounced to be some of the grandest coast scenery in America is viewed.

Patrick Point a Wild Flower Reserve

Twenty-two miles north of Arcata, on the main Redwood highway, is Patrick's Point State Park. This Park contains no Redwoods, but here are bold outcroppings of rocks and a rugged shore line. It is a wild flower reserve. Probably nowhere is there a greater variety of flowers. In May and early June the Rhododendrons and Azaleas brighten the region. During the fall the woodland glows with color, and around the Christmas holiday season California holly berries are at their brightest and best.

A few miles north, Big Lagoon, the first of a series of coastal lagoons, is crossed by the highway. A few miles farther on is Stone Lagoon, and farther still is Freshwater Lagoon. These three lagoons, shut off from the ocean by wave-built bars of sand, are interesting features of this northwest country. With heavily wooded shores and sandy beaches the lagoons are the habitat of many water fowl, especially pelicans and cranes.

Mendocino County Streams Offer Fine Fishing

Mendocino County offers 100 miles of picturesque and rugged shore line. If interested in fishing, numerous rivers and small streams offer all that the most enthusiastic Waltonian could desire. Beside the larger rivers, interspersed between them are numerous smaller strams that teem with fish. With 800 miles of perennial streams, Humboldt County offers good sport for fishermen. During the summer and fall fishing in Eel River is unexcelled. Trout and king salmon and steelhead abound in these waters. The steelhead range in size from 1 to

15 pounds, pronounced by some enthusiastic anglers to be the gamiest fish in America. Steelhead are found in practically all the coast streams and lagoons.

King salmon and other kinds of salmon abound in the larger streams. They are caught in both salt and fresh waters. Commencing in May vast schools of salmon appear off the coast, and run far up the rivers and many smaller streams to spawn. King salmon weighing as high as 60 pounds have been taken by trollers at the mouth of Redwood Creek.

And, while speaking of fishing, one of the few places where razorback clams can be taken in season is Clam Beach, near the mouth of Little River, crossed by the highway south of Trinidad. Several species of mud clams can be taken, by shovel or clam hook, at various points in the bay.

And now, to stop fishing and clam-digging, it may be interesting to stop and hunt for agates on Agate Beach, then move on to Orick, gateway to Prairie Creek State Park. Hotel accommodations (Orick Inn) and cottages offer hospitality.

North of Orick about five miles begins Prairie Creek State Park, at the southern boundary of which is Elk Prairie (called also Bowes Prairie), where is what is said to be the last remaining herd of Roosevelt Elk. The highway runs through the Park to near the boundary line of Humboldt and Del Norte counties. It embraces about 6,000 acres, and includes the Russ Grove of 186 acres, one of the finest groves. This is a beautiful area, combining splendid Redwoods, fine Spruce and Fir, and beautiful ferns and oxalis.

Henry S. Graves Redwood Grove in Del Norte County

About six miles north of the Del Norte County line Klamath River is crossed at Klamath, and about four miles farther north is Del Norte Coast Park, of about 2,500 acres. The highway passes through this park. One main unit of this park is the 287-acre Henry S. Graves Redwood Grove. The entrance to this grove is by a trail a few feet north of the

Graves Grove Monument. This trail winds down through the giant Redwoods, Ferns, Rhododendrons, Huckleberry, and Salmonberry, about two miles to the shore of the Pacific Ocean. Splendid Redwoods with fine views of the ocean make it well worth while to follow this trail to the shore.

Frank S. Stout Memorial and Hiouchi State Parks Near Crescent City

Northeast of Crescent City, eight miles off the main highway to the right (east) on a side road (Howland Grade), at the confluence of Mill Creek and Smith River, is one of the finest of all the Redwood groves, the Frank D. Stout Memorial Redwood Park, on Mill Creek Flat, a tract of 44 acres. Splendid Redwood forests in the vicinity of the Stout Grove, to be known as the Mill Creek Redwood Forest, are in process of acquisition by the Save-the-Redwoods League. It is devoutly hoped that this will be realized.

Nine miles from Crescent City, on the main Redwood highway, is Hiouchi State Park, the farthest north State Redwood Park in California.

Oregon Caves and Grant's Pass at End of Route

Fifty miles farther, by the main Redwood highway, a side road leads to the Oregon Caves, and 39 miles still farther is Grant's Pass, Oregon, 444 miles from San Francisco, and 277 miles from Portland. The caves have been made a national monument, and were referred to by Joaquin Miller, the author, as "The Marble Halls of Oregon." The monument covers an area of 480 acres. Regular guide service is available, and a trip through the galleries, which are embraced on four floors of the cave, occupies two hours.

From Grant's Pass the tourist may continue north to Portland, 277 miles, or turn south via Mount Shasta and Lassen Peak to Sacramento and San Francisco, 466 miles.

THE END

GLOSSARY

Acidic—A descriptive term applied to those igneous rocks that contain more than 65% of silica.

Alkali—The opposite of acid; forming salts with acids. Alkalies have the property of corroding organic substances. The term is applied to the hydroxides of potassium, sodium, and ammonium. Vegetable matter corroded leaves the carbon, hence the term "black alkali."

Alluvial fan—The outspread sloping deposit of boulders, gravel, and sand left by a stream where it spreads from a gorge upon a plain or open valley bottom.

Andesite—A volcanic rock of porphyritic or felsitic texture, whose crystallized minerals are (plagioclase) feldspar and one or more of biotite (mica), horneblende, or augite.

Antecedent (river)—A river that holds its early course in spite of crustal movement of uplift across its course.

Anticline—A fold or arch of rock strata, dipping in opposite directions from the axis.

Arkose—Material derived from the disintegration of granite. A sandstone rich in feldspar fragments, as distinguished from the more common richly quartzose varieties.

Basalt—The term is used to include all dark, basic, volcanic rocks. When poured forth upon the surface it spreads in thin sheets. In cooling basalt tends to take on a columnar structure. The leading minerals are (plagioclase) feldspar and horneblende (pyroxene). Basalt is classed as basic (low in silica).

Base-level—The level below which a land surface cannot be reduced by running water.

Basic—A descriptive term for those igneous rocks that are comparatively low (less than 50%) in silica.

Batholith—Huge irregular masses of plutonic rocks that have been forced up from the interior of the earth in molten condition, and have cooled and crystallized under a depth of overlying rocks, and have only been exposed by erosion.

Beach—The wave-washed shore of a sea or lake.

Bed-rock—Called also basement complex. The series of slates, schists, and associated igneous rocks, including the auriferous slate series, comprising all the sedimentary formations from pre-Cambrian through Palaeozoic and Jura-Trias.

Boulder—A fragment of rock, usually large and rounded in shape, generally but not always brought from a distance by natural means.

Breccia—A rock composed of angular fragments. Distinguished from conglomerate as not water-worn.

Canyon—A valley, usually precipitous; a gorge.

Chert—A compact, siliceous rock formed of chalcedonic or opaline silica, one or both, and of organic or precipitated origin. Flint is a variety of chert.

Cirque—A steep-walled, amphitheatre-like recess in a mountain side, the starting-place of a glacier.

Clay—Principally decomposed feldspar, aluminum silicate. The most abundant of the materials derived from the decomposition of igneous rocks. Clay and silt differ in fineness of particles largely, those of clay being microscopically small. Many so-called clays are chiefly siliceous silt.

Conglomerate—An aggregate of rounded and water-worn pebbles and boulders cemented together into a coherent rock.

Consequent (river)—A river having a course determined by the form and slope of the surface of the land.

Coulée—A deep gulch or water channel, usually dry.

Dacite—An igneous rock (generally volcanic) containing essential (plagioclase) feldspar and quartz, with or without horneblende and biotite; quartz-andesite.

Delta—An alluvial deposit at the mouth of a river.

Diabase—A basic igneous rock usually occurring in dikes or intrusive sheets, composed essentially of (plagioclase) feldspar and augite, with small amounts of other minerals.

Diatom—A minute plant (of microscopic size) which is provided with a siliceous envelope. Diatomaceous earth may be composed of nearly pure silica from the frustules of the microscopic plants called diatoms.

Dike—A thin body of igneous rock forced in molten condition into a fissure in older rocks, and there solidified (cooled). May vary in thickness from an inch or two to 300 feet.

Diorite—An intimate mixture of crystals of horneblende and (plagioclase) feldspar, with biotite (mica) or augite. A granitic rock. If considerable quartz is present it is called quartz-diorite.

Drift—Earth materials, as boulders, gravel, sand and clay, transported by a glacier and deposited from the melting ice.

Epoch—Division of a period. The time during which a formation or group of strata was deposited.

Era—The largest division of geologic time. The geologic eras are: Archaean or Proterozoic, Palaeozoic, Mesozoic, and Caenozoic.

Fault—A break in the rock body with movement on one side or the other, so that parts of one continuous stratum are now separated.

Feldspar—A general name for a group of rock-forming minerals of wide extent, silicates of the metals calcium, aluminum, sodium, potassium, as orthoclase, plagioclase, etc. Feldspar is found in practically all igneous rocks. It is quite commonly flesh-colored, but varies in color.

Felsitic—Almost or wholly crystalline, but made up of crystals too small to be readily distinguished by the unaided eye; said of the texture of some igneous rocks.

Ferromagnesian—Containing iron and magnesium. Applied to dark silicate minerals, as amphibole, pyroxene, biotite (mica) and olivine, and to igneous rocks containing them.

Fissure—An extensive crack, break, or fracture in the rocks.

Floodplain—The flat ground along a stream, covered by water at the flood stage. The plain is generally made up of muds, sands, and gravel.

Foraminifera—Minute one-celled animals that secrete a calcareous (lime) shell. In myriad numbers on shallower ocean bottoms these microscopic shells form globigerina ooze.

Formation—Any assemblage of rocks which have some character in common. Sometimes applied to the groups of related strata that were formed in a geologic period.

Fossil—Remains or impression of a plant or animal of past geologic ages preserved in the rocks.

Gabbro—A finely to coarsely crystalline igneous rock, composed mainly of lime-soda feldspar (labradorite or anorthite), pyroxene and frequently olivine.

Geomorphogeny—That part of geomorphology which treats of the origin and development of the earth's surface features.

Granite—A granular igneous rock composed essentially of quartz, feldspar, and mica, often with horneblende.

Granite family—The group of crystalline, homogeneous or non-foliated igneous rocks resembling granite, as syenite, quartz-monzonite, granodiorite, diorite, monzonite, and all varieties of granite itself.

Granitic—Characteristic of, composed of, or resembling granite.

Granodiorite—A term employed for the intermediate rocks between granites and quartz-diorites. The term is a contraction of granite-diorite. Called also granite.

Hardhead—A large, smooth, hard, rounded stone, generally a glacial boulder, occurring in coarse gravels and morainal deposits.

Horneblende—An important rock-forming mineral, a silicate of calcium and magnesium, usually with iron. Color ranges between black and white, through green, dark brown, yellow, pink, and rose-red.

Igneous—(From ignis, meaning fire). Formed by solidification from a molten state. One of the two great classes into which all rocks are divided. Contrasted with sedimentary. Also called plutonic; includes volcanic rocks.

Joint—A crack or fissure, one of an approximately parallel set of fissures, from a few inches to many feet apart.

Latite—A broad family name including the effusive (extrusive) monzonites. Plagioclase and orthoclase (feldspars) both present, with ferromagnesian minerals in varying amounts. Texture may be glassy, felsitic, or porphyritic.

Lava—A general name for the molten outpourings of volcanoes. Fluid rock, as that which issues from a volcano or a fissure in the earth's crust; also the same material solidified by cooling. Commonly regarded as molten rock, but more exactly it is mineral matter dissolved in mineral matter, the solution taking place only at high temperatures.

Limestone—The general name for sedimentary rocks composed essentially of calcium carbonate.

Loam—A term applied to soils. A mixture of clay and sand. Varies toward clay loam on one hand and sandy loam on the other.

Lode—A fissure in the country rock filled with mineral; usually applied to metalliferous veins or lodes.

Magma—Liquid molten rock; the molten material from which igneous rocks are formed by solidification.

Massive—Homogeneous, without stratification. In mineralogy, without definite crystalline structure.

Metamorphism—Change in the texture or composition of a rock, produced (principally) by heat, moisture, and pressure, involved in earth deformation.

Mica—A hydrous silicate having a very fine basal cleavage that renders it capable of being split into thin, tough, transparent plates. The common varieties are muscovite (silicate of potash), and biotite (silicate of magnesium and iron).

Mineral—Inorganic material having a definite chemical composition.

Monadnock—A rock, hill, or plateau standing above a peneplain, not yet worn away by erosion.

Monzonite—Feldspars, with biotite (mica) and horneblende.

Moraine—A French term meaning "a heap of stones." An accumulation of earth materials, as stones, clay, etc., carried and finally deposited by a glacier.

Névé—The mass of granular snow forming the upper part of a glacier.

Obsidian—Dense volcanic glass, having a conchoidal fracture.

Oxidize—To unite with oxygen. Many minerals and most metals oxidize when exposed to air or water.

Peneplain—A land surface of slight relief and gentle slopes, worn down by erosion almost to base-level.

Period—A unit of geologic time, division of an era. Example: Silurian period, Devonian period, are units of the Palaeozoic era.

Petrified wood—Formed by replacement of wood by silica. Wood, shells, bones, etc., embedded in sediments become converted into stone by the gradual replacement of their tissues with infiltrated mineral material.

Placer—A mass of gravel, sand, or other loose material, resulting from the crumbling and erosion of solid rocks, and containing particles or nuggets of gold, platinum, tin, or other valuable minerals, that have been derived from rocks or veins.

Plateau—An upland, table-land, or elevated plain having a fairly smooth surface and bounded on at least one side by an escarpment separating it from lower country.

Pleistocene—The earlier of two epochs of the Quaternary period, also called the glacial epoch. Also applied to series of sediments deposited during that epoch.

Plutonic—Of igneous origin. Applied to those rocks that have crystallized in the depths of the earth and have therefore assumed, as a rule, the texture of granite. Formed under the influence of high heat and pressure.

Porphyritic—A term applied to those rocks which have larger crystals (phenocrysts), as feldspar, quartz, or augite, set in a finer ground-mass. The latter may be crystalline or glassy or both.

Pre-Cambrian—All that part of geologic time represented by rocks older than Cambrian; thought to be 3 times as long as all time since the earliest Cambrian rocks were deposited. Also applied to all rocks earlier than Cambrian.

Quartz—Crystallized oxide of silicon, SiO_2. (See Silica.)

Quartzite—Metamorphosed quartz sandstone, formed by deposition of secondary silica between the grains. Called also granular quartz.

Quartz-monzonite—An igneous rock of granular texture containing quartz with feldspars (orthoclase and plagioclase in about equal proportions), and with these may be mica and horneblende. Often classed as granite.

Radiolarian ooze—Formed by microscopic animals known as Radiolaria, which fashion their beautifully ornate shells from silica.

Rejuvenated landscape—A previously worn-down region uplifted so as to renew erosive activity.

Rhyolite—A lava, usually of light color, corresponding in chemical composition to granite. The same molten liquid that at great depth within the earth solidifies as granite would, if it flowed out upon the surface, cool more quickly and crystallize less completely as rhyolite.

Rock—Any naturally formed aggregate or mass of mineral matter, coherent or not, forming part of the earth's crust.

Sandstone—A sedimentary rock formed of coherent or cemented sand.

Schist—A crystalline rock that can be readily split or cleaved because of foliated structure; generally developed by shearing and re-crystallization under pressure.

Sedimentary—Rocks formed by the accumulation of sediment, from water (mostly) and from the air. Sediment may consist of rock fragments; of the remains of animals or plants; of the product of chemical action or evaporation (as salt, gypsum); of fragments blown from volcanoes (tuffs), or mixtures of these. Sandstone, shale, limestone, coal, are examples of sedimentary formations. Sedimentary deposits are generally in flat beds or strata.

Shale—A fine-grained, fissile, argillaceous sedimentary rock, characterized by fragile laminae or thin layers. Sometimes incorrectly called slate by miners, well-drillers, etc.

Silica—An oxide of silicon (a rare non-metallic mineral known only to the chemist), SiO_2; occurs as quartz, chalcedony, chert, flint, opal, diatomaceous earth, and sandstone. The most abundant constituent of the earth's crust.

Silt—The muddy bottoms of bays and harbors. Rock particles are intermediate in size between the finest sand and clay. Rocks pulverized by glacial ice are often spoken of as silt or rock-flour. Silt tends to crumble when wet whereas clay when wet is plastic.

Stratum, plural strata—A bed or layer of rock.

Stone—A small (or larger) piece of rock. A fragment broken from a ledge (of rock) is a stone. Large natural masses of stones are generally called rocks; small quarried masses or small fragments are called stones.

Striae—Glacial markings. Straight, regular scratches, commonly parallel in sets, on smooth glaciated rock surfaces.

Structural valley—A relatively long narrow depression produced by movements of the surface, as a synclinal trough. The floor of a structural valley may be depressed between fault planes, on one or both sides of the valley.

Superjacent series—The nearly horizontal westward dipping strata, of late

Cretaceous and Tertiary age, together with the auriferous gravels and later lavas.

Syncline—A fold in rocks in which the strata dip inward from both sides toward the axis. The opposite of anticline.

Terraces—Floodplain terraces (the most common) are bench-like flats rising from a river like flights of stairs, formed by a stream whose velocity has been increased (generally by upward warping of the land).

Till—Material deposited from melting ice; generally, but not always, unstratified; a heterogeneous mixture of clay, sand, gravel, and boulders. Also called boulder-clay.

Unconformity—The surface of contact between unconformable strata above and the rocks beneath them. Discordance or break due to a lapse in deposition, representing a "lost interval" during which the rocks beneath were deformed or partly eroded away, or both.

Vein—A crack in rocks filled with mineral matter deposited from solution by underground waters. When metalliferous it is called by miners a *lode;* when filled by eruptive material it is called a *dike.*

Volcanic neck or plug—The vent or pipe of a former volcano filled with solidified lava.

Volcano—A vent in the earth's crust from which are emitted molten rock or lava, fragmental solid material, hot water, mud, steam and various gases.

BIBLIOGRAPHY

The bibliography of California Geology and Mineralogy is very extensive. More than 15,000 books and articles are listed in the official State bibliography. Those listed below will be of interest to students, and to those general readers who may wish to pursue any phases of the subject further.

Alluvial Fans of the Cucamonga District. R. Eckis. Jour. Geol., Vol. 36.

Annual Reports, State Mineralogist. Ferry Bldg., San Francisco.

Berkeley Hills, Coast Range Geology. A. C. Lawson and Charles Palache. Univ. of Calif., Dept. Geol. Bull., Vol. 2, No. 12.

Big Trees, Most Northern. Waldemar Lindgren. U. S. G. S. Folio, No. 66.

Big Trees Quadrangle. H. W. Turner and F. L. Ransome. U. S. G. S. Folio, No. 51.

Blackhawk Canyon, San Bernardino Mountains. Woodford and Harris, Univ. of Calif., Dept. Geol. Bull., Vol. 17.

Borate Minerals, Kramer District, Mojave Desert. W. T. Schaller. U. S. G. S. Prof. Paper 158.

Borax Deposits of Death Valley and Mojave Desert. M. R. Campbell. U. S. G. S. Bull. 200.

Cambrian Rocks of the Mojave Desert. Hazzard and Crickmay. Univ. of Calif., Dept. Geol. Bull., Vol. 23, No. 2.

Cambrian Rocks in Southeastern California. N. H. Darton. Jour. Geol., Vol. 15.

Coast Ranges, Geology of. H. W. Fairbanks. Geol. Soc. Am., Vol. 6.

Coast Ranges, Geology of. A. C. Lawson. Am. Geologist, Vol. 15.

Colorado Desert, The. W. C. Mendenhall. Nat. Geog. Mag., 1909.

Colorado River, Changes of. D. T. MacDougal. Nat. Geog. Soc. Mag., Vol. 19.

Crystalline Rocks of the San Gabriel Mountains. Ralph Arnold and A. M. Strong. Geol. Soc. Am., Vol. 16.

Crystalline Rocks of Middle Southern San Gabriel Mountains. William J. Miller. Geol. Soc. Am. Bull. 37.

Deep Spring Valley, Geology of. William J. Miller. Jour. Geol., Vol. 36.

Delta of the Colorado, The. D. T. MacDougal. Am. Geog. Soc. Bull. 38.

Desert Basins of the Colorado Delta. D. T. MacDougal. Am. Geog. Soc. Bull. 39.

Desert Watering Places, Southeastern California. W. C. Mendenhall. U. S. G. S. W-S Paper No. 224.

Diatoms, Organic Shales, Southern San Joaquin Valley. E. G. Gaylord and G. D. Hanna. Bull. A. A P. G., Vol. 9.

Diatoms, Monterey Shale, Malaga Cove. G. D. Hanna. A. A. P. G. Bull. 12.

Earthquake of April, 1906. J. C. Branner, A. C. Lawson, G. K. Gilbert, H. F. Reid and Others. Carnegie Inst. Washington Pub. 87.

Fault Map of California, the Coast Ranges. B. Willis. Geol. Soc. Am. Bull., Vol. 34.

Geochemistry, Data of (Fifth edition). F. W. Clarke. U. S. G. S. Bull. 770.

Geologic Atlas, Folios 3, 5, 11, 15, 17, 18, 29, 37, 41, 43. U. S. G. S. Washington, D. C.

Geological Journeys in Southern California. Alfred Livingston, Jr. Los Angeles City College, Los Angeles.

Geology of the San Francisco Peninsula, Sketch of. A. C. Lawson. U. S. G. S. An. Rep. 15.

Geology and Oil Resources, Coalinga District. Ralph Arnold and R. Anderson. U. S. G. S. Bull. 398.

Geology and Oil Resources, Los Angeles and Ventura Counties. W. S. W. Kew. U. S. G. S. Bull. 753.

Geology and Oil Resources, Puente Hills Region. W. A. English. U. S. G. S. Bull. 768.

Geomorphogeny of the Coast of Northern California, The. A. C. Lawson. Univ. of Calif., Dept. Geol. Bull. 1.

Geomorphogeny of the Upper Kern Basin, The. A. C. Lawson. Univ. of Calif., Dept. Geol. Bull. 3.

Gold-bearing Tertiary Channels. O. P. Jenkins and W. Q. Wright. Eng. and Min. Jour. 135 (1934).

Gold-quartz Veins, Nevada City and Grass Valley. Waldemar Lindgren. U. S. G. S. Seventeenth An. Rep., Pt. 2.

Granite Boulders in San Joaquin Valley. R. W. Pack. U. S. G. S. Prof. Paper 116.

Ground Waters, Indio Region. W. C. Mendenhall. U. S. G. S. W-S Paper 225.

Ground Water in San Joaquin Valley. W. C. Mendenhall. U. S. G. S. W-S Paper 398.

Guide Book, Western U. S., Pt. B, Overland Route. Lee, Stone, Gale and others. U. S. G. S. Bull. 612.

Guide Book, Western U. S., Pt. C, Santa Fe Route. N. H. Darton. U. S. G. S. Bull. 613.

Guide Book, Western U. S., Pt. D, Shasta Route. J. S. Diller. U. S. G. S. Bull. 614.

Igneous, Metamorphic, and Sedimentary Rocks of the Coast Ranges. H. W. Turner. Jour. Geol., Vol. 6.

International Congress Geologists. Guide Books 15 and 16, 1933.

Inyo Range and Eastern Slope of the Sierra Nevada. Adolph Knopf and Edwin Kirk. U. S. G. S. Prof. Paper 110.

Lassen Peak Volcanic National Park, Geology of. Howel Williams. Univ. of Calif., Dept. Geol., Vol. 21, No. 8.

LaJolla Quadrangle, Geology of. M. A. Hanna. Univ. of Calif., Dept. Geol., Vol. 16.

McKittrick-Sunset Oil Region, The. Ralph Arnold and H. R. Johnson. U. S. G. S. Bull. 406.

Mojave Desert Region. David G. Thompson. U. S. G. S. W-S Paper 578.

Mojave River, Ancient Lake Basin on. E. E. Free. Carnegie Inst. Washington Year Book 15.

Mother Lode District, The. F. L. Ransome. U. S. G. S. Geol. Atlas, Folio 63.

Mother Lode District (South), Mines of. C. E. Julihn and F. W. Horton. U. S. Dept. Interior, Bureau of Mines, Bull. 424, Parts I and II.

Mother Lode Region, The. W. H. Storms. Calif. State Mining Bureau. Bull. 18.

Mother Lode System, The, of California. Adolph Knopf. U. S. G. S. Prof. Paper No. 157.

Mount Diablo, Geology of. J. A. Taff. Geol. Soc. Am. Bull. 46.

Mount Diablo, Geology of. H. W. Turner. Geol. Soc. Am. Bull., Vol. 2.

Oil Districts, Santa Clara, Puente Hills, and Los Angeles. Ralph Arnold and G. H. Eldridge. U. S. G. S. Bull. 309.

Peninsular Range, Geologic Section Across the. William J. Miller. Calif. Dept. Nat. Res., Div. Mines, Rep. 31.

Peninsular Range, Geomorphology of. William J. Miller. Geol. Soc. Am. Bull. 46.

Redding Quadrangle, Geology of. J. S. Diller. U. S. G. S. Geologic Atlas, Folio 138.

Physiography and Structure of the Western El Paso Range. C. H. Baker. Univ. of Calif., Dept. Geol. Bull., Vol. 7, No. 6.

Pleistocene Lakes of the Afton Basin. Blackwelder and Ellsworth. Am. Jour. Sci., Vol. XXXI.

Post-Pliocene Diastrophism, Southern California Coast. A. C. Lawson. Univ. of Calif., Dept. Geol. Bull., Vol. 1, No. 4.

Post-Tertiary Elevation of the Sierra Nevada. H. W. Turner. Geol. Soc. Am. Bull. 13.

Pre-Cretaceous Rocks of the Coast Ranges. H. W. Fairbanks. Am. Geologist, Vol. 1.

Rifts of Southern California. W. M. Davis. Am. Jour. Sci., Vol. 13.

Salines in Owens, Searles, and Panamint Basins. Hoyt S. Gale. U. S. G. S. Bull. 580.

Salton Sea, The. D. T. MacDougal. Carnegie Inst. Washington Pub. 193 (1914).

San Andreas Fault, and Other Active Faults in Desert Region. L. F. Noble. Seis. Soc. of America Bull., Vol. 17.

San Andreas Rift and Other Active Faults in Southeastern California. L. F. Noble. Carnegie Inst. Washington Year Book 25.

San Bernardino Mountains, Geology of. F. E. Vaughan. Univ. of Calif., Dept. Geol. Bull., Vol. 13.

San Bernardino Valley, Hydrology of. Walter C. Mendenhall. U. S. G. S. W-S Paper 142.

San Diego and Imperial Counties, Geology of. F. J. H. Merrill. State Min. Bureau, Rep. 14.

San Diego and Portions of Orange and San Bernardino Counties. H. W. Fairbanks. State Min. Bureau, Rep. 11.

San Francisco Region, Geology of. Andrew C. Lawson. U. S. G. S. Geol. Atlas, Folio 193.

San Francisco Peninsula, Geology of. H. W. Fairbanks. Jour. Geol., Vol. 5.

San Gabriel Mountains North of Los Angeles, Structure of. M. L. Hill. Univ. of Calif., Dept. Geol. Bull., Vol. 19.

San Gabriel Mountains, Western, Geology of. William J. Miller. Univ. of Calif. at Los Angeles, Vol. 1. No. 1 (1934).

San Gabriel Mountains, Rocks of the Southwestern. William J. Miller. Bull. Geol. Soc. Am., Vol. 41.

San Gabriel Mountains, Geomorphology of Southwestern. William J. Miller. Univ. of Calif., Dept. Geol. Bull., Vol. 20, No. 9.

San Jacinto Quadrangle, Geology of. D. M. Fraser. Mining in Calif., 27th Rep. State Mineralogist.

San Luis Quadrangle, Geology of. H. W. Fairbanks. U. S. G. S. Geol. Atlas, Folio 101.

Santa Ana Canyon, Geology of. E. K. Soper. State of Calif. Dept. Pub. Works, Bull. 19.

Santa Ana Investigations, Flood Control. W. S. Post. Dept. Pub. Works, Div. Eng. and Irr., Sacramento.

Santa Cruz Quadrangle, Geology of. J. C. Branner, J. F. Newsom, and Ralph Arnold. U. S. G. S. Geol. Atlas, Folio 163.

Santa Monica Mountains, Eastern, Geology of. H. W. Hoots. U. S. G. S. Prof. Paper 165-C.

Seventeenth Rep. State Mineralogist, 1920, Mining in California.

Sierra Nevada Crest Region. Waldemar Lindgren. U. S. G. S. Geol. Atlas, Folio 31.

Sierra Nevada Crest Region. Waldemar Lindgren. U. S. G. S. Geol. Atlas, Folio 39.

Sierra Nevada, Geologic Sections Across Southern. William J. Miller. Univ. of Calif., Dept. Geol. Bull., 20, No. 9.

Stratigraphy of the Coast Ranges. H. W. Fairbanks. Jour. Geol., Vol. 3.

Stratigraphy of North America. W. C. Mendenhall. U. S. G. S. Prof. Paper 71.

Structural Evolution of Southern California. Reed and Hollister. Am. Ass. Pet. Geol.

Sunset-Midway Oil Field. R. W. Pack and G. S. Rogers. U. S. G. S. Prof. Paper 116.

Tectonics of the Coast Ranges. B. L. Clark. Geol. Soc. Am. Bull. 38.

Tertiary Gravels of the Sierra Nevada. Waldemar Lindgren. U. S. G. S. Prof. Paper 73.

Yosemite National Park, Geologic History of. François E. Matthes. U. S. G. S. Prof. Paper 160.

INDEX

THE MICROBE'S CHALLENGE

By
FREDERICK EBERSON, Ph.D., M.D.

This is a story of vital interest to every individual. For the scientist and physician it presents a permanent record of the progress made during very recent years in preventive medicine. For the student, it illustrates how by perseverance, accurate procedure, and meticulous observation, the great discoveries of science are made. For the general reader, it provides a cultural education that touches nearly every phase of daily living.

Of very great interest is the account of the work now being done by contemporary scientists and the important problems that are on the verge of being solved. We like to know of these benefactors of humanity living and working in our day.

It behooves every true student to read Dr. Eberson's inspiring book, to live once again the tense moments of epoch-making discoveries, and to be reminded that many fertile seeds still lie dormant with the floodlight of today's amazing progress playing upon them, awaiting only the "seeing eye" of a searcher for the truth.

334 pages $3.50

•

THE
JAQUES CATTELL
PRESS
LANCASTER, PA.

Adv... In ...

[T]HE story of California geology is the history of the earth since Jurassic time. Unique among all the states, great in area and with markedly outstanding geological features, no other region offers a more fertile field for the study of the many and varied problems of geology. In language the general reader can understand, Dr. Willard presents a fascinating pictu[re] of the State; the marvellous scenery; the meaning of the varied land forms; the remarkable coast line; the mountains, valleys, deserts and fertile lands, and the eccentrically varied climate. Based upon extensive personal observations and studies in the field, and supplemented by valuable facts gleaned from the vast literature of the subject, the book describes the important regions from a new angle, a fresh and human interest point of view. The studies are so arranged that the reader will be able to carry them beyond the State as his interest may suggest. What is true of California is also true of adjacent regions. In the geological story lies the explanation of what may be seen, the key to the best development of our natural resources.

California has been, and still is, an important source of gold. It is one of the leading States in the production of oil. Its climate ranges from that of perennial snow to that of perennial balmy summer. It has an inexhaustible potential wealth of soil. Agriculture is the greatest of the State's varied industries. The great Sierra Nevada mountain range dominates the State. The Coast Ranges determine the varied features of the ocean shore. Regional topographic conditions determine the great Mojave and Colorado deserts, and the fertile valleys. Mount Shasta and Lassen Volcanic Peak have added a finishing touch to vast areas by their outpourings of molten lava. Great rivers have serrated the landscape and deposited their burden of erosional detritus over extensive plains which, in turn, have become broad reaches of fertile agricultural lands. In pursuing their endless task of erosion, and simultaneously with and following tremendous mountain upheavals, the marvellous scenic features of the State have been developed.

After discussing the geologic features and history of the processes involved, the author gives a vivid description of what may be seen by the traveler as he motors over the long highways to every accessible and some almost inaccessible regions.

438 pages - - - - - - - - - $3.75