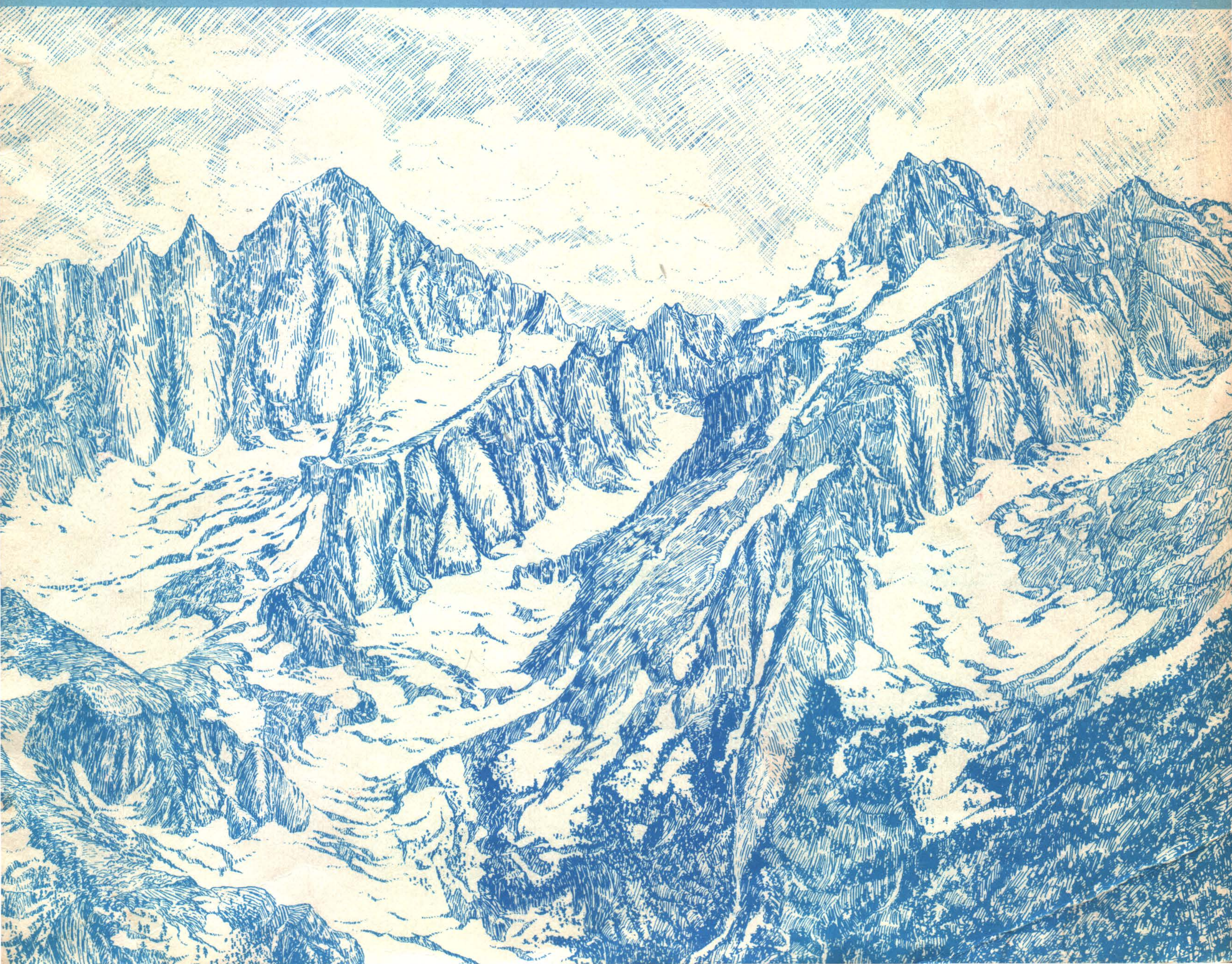
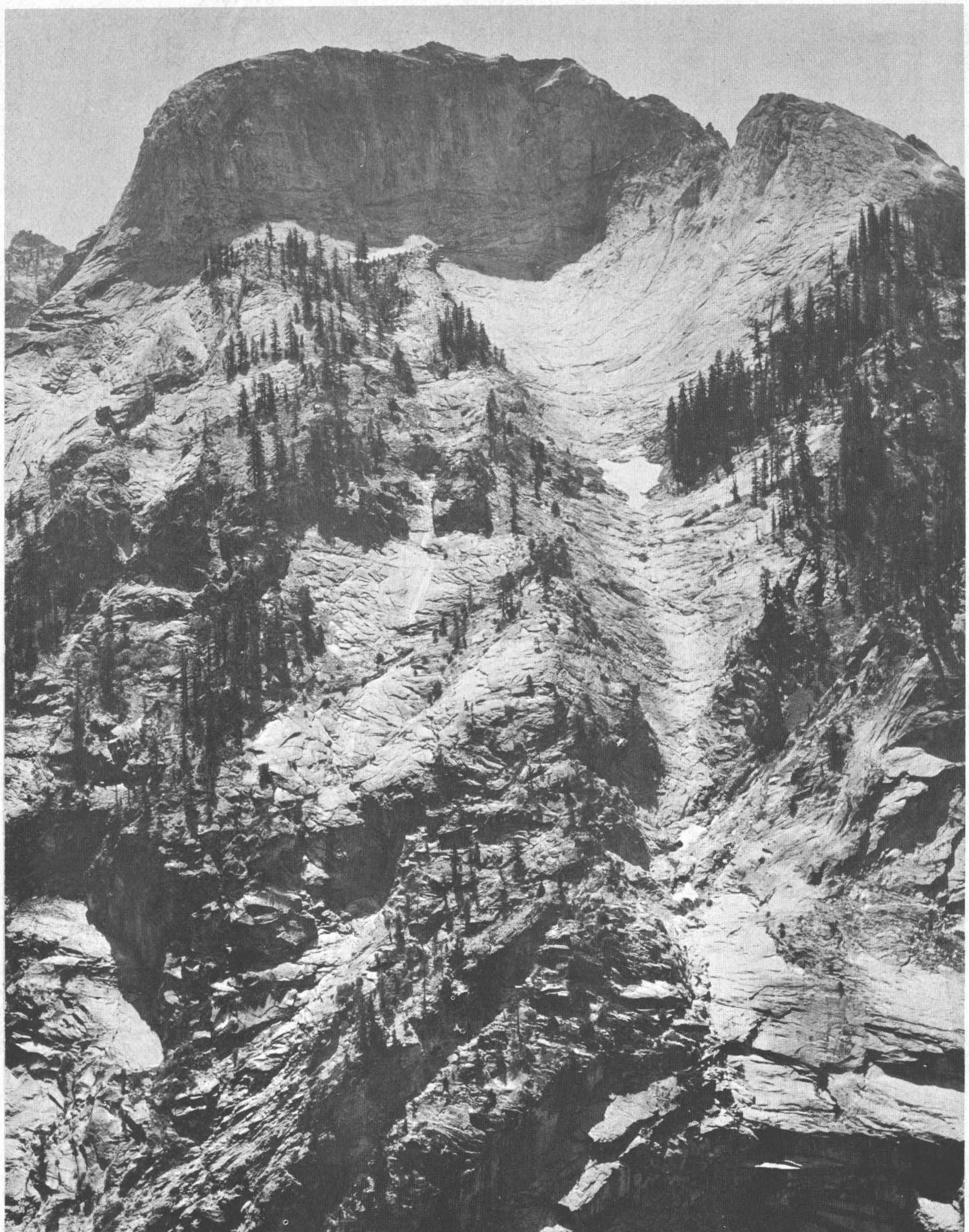
GEOLOGICAL SURVEY PROFESSIONAL PAPER 504-A

GLACIAL RECONNAISSANCE OF SEQUOIA NATIONAL PARK CALIFORNIA



GLACIAL RECONNAISSANCE OF
SEQUOIA NATIONAL PARK



The largest and most perfectly formed avalanche chute in Sequoia National Park, viewed from the High Sierra Trail east of camp in Bearpaw Meadow. Like its smaller companion, this chute is carved in massive exfoliating granite and terminates at the brink of the glacial U-shaped canyon below. The downward narrowing of the chute is explained by the protection given to the lower part of the chute by a snow cone on the surface of the glacier which lay in the canyon.

Glacial Reconnaissance of Sequoia National Park California

By FRANÇOIS E. MATTHES

Prepared posthumously by FRITIOF FRYXELL *from Matthes' notes and other sources*

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 504-A

Characteristics and distribution of the ancient glaciers in the most southerly national park of the Sierra Nevada

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, ***Director***

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

FOREWORD

In 1905, the U.S. Geological Survey assigned François E. Matthes to make a large-scale (1:24,000) map of Yosemite Valley. The classic Yosemite Special map which resulted enhanced Matthes' well-established reputation as a master topographer, but paradoxically it contributed to his decision to discontinue topographic surveying. His sojourn among the sublime but imperfectly understood features of the "Incomparable Valley" had confirmed a conviction that his deepest interest lay in studying the genesis of landforms rather than in depicting them on topographic maps. Matthes' decision in favor of geology was not the result of any sudden impulse. He had long been a serious student of glacial geomorphology and geology, he had published papers in these fields, and he had spent a year at Harvard University taking advanced courses under William Morris Davis, the "father of geomorphology." The opportunity to engage in geologic work on a full-time basis came in 1913, in which year Matthes was officially transferred from the Topographic Branch of the Survey to the Geologic Branch.

The Yosemite mapping project had other far-reaching consequences. Quite logically, the first geologic assignment given Matthes was to return to Yosemite to investigate the origin of this celebrated valley, a subject which had been a matter of controversy ever since the Whitney surveys in the 1860's. Matthes' painstaking research eventually produced USGS Professional Paper 160, "The Geologic History of Yosemite Valley," a monograph of great and enduring significance.

As his Yosemite investigations progressed, Matthes felt the need for testing his tentative conclusions by comparative study of other valleys in the Sierra Nevada that, presumably, had had much the same history. Therefore he extended his field studies into several major drainage basins of the west slope. These studies, besides serving their immediate purpose, opened up many new geological vistas, some of which involved fundamental questions pertaining to the Sierra Nevada as a whole.

After the Yosemite report was published, Matthes gave renewed attention to these broader problems and during the 1930's he made a succession of geological reconnaissances, particularly in the central and southern Sierra Nevada. On these explorations he employed whatever means were practicable. For the most part, he depended on pack trips, a mode of transportation at which he had become expert from many years of topographic surveying. "Packing in" enabled him to establish camps in remote regions otherwise inaccessible because they were far from railroads, roads, and even trails. Areas surrounding his base camps were explored on horseback or on foot. In the later years, when better roads were available, he got about also by car. On one occasion, in 1936, he employed a chartered plane to make an aerial survey of the High Sierra in the Mount Whitney region. (His companion on this trip was Conrad Wirth, later Director of the National Park Service.)

The difficulties of the Sierra terrain make Matthes' accomplishments in covering the territory all the more impressive. There were few parts of the Sierra Nevada, especially throughout the middle and upper reaches of the broad west slope, which he did not come to know firsthand. The times demanded much such reconnaissance work, and a number of geologists became highly proficient at it. Matthes was outstandingly successful in making geological surveys in mountainous regions.

The results of Matthes' Sierra studies were summarized in several general papers. However, he earnestly desired to report more fully on certain specific areas. This hope was never realized. Though he worked on several longer papers whenever he could do so, the opportunities were infrequent, for other assignments of more immediate urgency if not greater importance generally took precedence. Thus he came to regard the completion of these reports as something that would have to wait until after his retirement. On June 30, 1947, he did retire, and he moved to California; but the following year, before he was fairly started with his writing, he suffered a brief and fatal illness.

Matthes had entered into negotiations with the University of California Press for the writing of two books intended for the general public. In 1949, at the request of the publisher and Mrs. Matthes, I endeavored to carry out these plans; and consequently, in 1950, two works were published (Matthes, 1950a, b) in connection with observance of the Centennial Year of California. In the Geological Survey and in the Sierra Club, interest was also manifested in posthumous works which might embody the substance of Matthes' studies, even though they could not attain the exact form or completeness that he would have given them. The Geological Survey assigned me to look into these possibilities. Review of the Matthes' papers indicated that some of the materials left by Matthes might best serve for reference use, in connection with future glacial and geomorphological studies, but that two significant reports might be prepared for publication.

There resulted, as a first product of this undertaking, USGS Professional Paper 329, "Reconnaissance of the Geomorphology and Glacial Geology of the San Joaquin Basin, Sierra Nevada, California," published in 1960. The paper herewith published is the second of the two reports planned. In a sense these are companion works. However, since Matthes' geomorphological studies in Sequoia National Park have previously been published (Matthes, 1937, 1938, 1950a) and little new information could be added, the emphasis in this paper is on glacial geology, and only brief incidental attention is given to such subjects as erosional history, exfoliation, and avalanche sculpture.

The glacial terminology that Matthes used is retained in this report, although it departs from the current Geological Survey usage as outlined in the Code of Stratigraphic Nomenclature prepared by the American Commission on Stratigraphic Nomenclature (1961). For example, Matthes used the term "stage" for glacial episodes such as El Portal, Glacier Point, and Tahoe, whereas the code (p. 660, art. 40) specifies the term "glaciation" for these episodes. Similarly, Matthes used the term "substage" for subdivisions of a glaciation, whereas current usage employs the term "stade."

A rather detailed description of the topography of Sequoia National Park ("Geographic Sketch"), which Matthes had almost completed, is included in full because of the valuable picture is gives of the park area.

As a preliminary to the preparation of this report, I spent the period from July 22 to August 27, 1952, in Sequoia National Park working from camps in Giant Forest, Bearpaw Meadow, Mineral King, and the Kern Canyon. This fieldwork refreshed my memory of features already familiar and acquainted me with others not previously seen. Subsequently, a procedure was followed that was, in the main, similar to that adopted for preparation of Professional Paper 329. The attempt was made to prepare a unified account that would be as complete as possible from the materials at hand, and that would set forth Matthes' observations and conclusions, and retain, wherever feasible, his own words. This procedure involved the synthesis of information from many different sources, particularly field notes and maps, sections of text written in longhand with various degrees of finish, annotated photographs, and published papers. The project further necessitated both the transfer of information from field maps to an unfinished office map and the completion of three topograhic profiles. No outline for a report was found, but the source materials at hand, as well as those used for the San Joaquin report, provided working guides for the organization of material and filling in of gaps in the report. The photographs proved particularly useful. In taking these, Matthes had kept in mind the needs of the interpretative program of Sequoia National Park and had made a special effort to secure a comprehensive, illustrative series. Many of these he had annotated fully for use in his so-called "Sequoia Albums" (Matthes, 1950a).

It is hoped that this publication will in some measure fulfill Matthes' intent to provide an overall picture of the geography and glacial geology of Sequoia National Park, and also, that it may prove useful not only to geographers and geologists, but to others, such as the staff of the park and to visitors. The reader must bear in mind that this work is, as its name emphasizes, the report of a reconnaissance survey. Matthes clearly regarded his work as tentative, and he recognized the need for future detailed studies to clarify some of the complex glacial relationships in the area and to make possible more exact correlations with the records of other areas. The report will have served one of its main purposes if it encourages other geologists to undertake such studies and suggests to them specific localities where research may be pursued profitably and with minimum expenditure of time and effort.

FRITIOF FRYXELL

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

748-960 O—65——2

GLACIAL RECONNAISSANCE OF SEQUOIA NATIONAL PARK, CALIFORNIA

By François E. Matthes

ABSTRACT

Sequoia National Park, like Yosemite and Kings Canyon National Parks to the north, is on the broad west slope of the Sierra Nevada. It extends from an elevation of about 1,400 feet in the western foothills to 14,495 feet at Mount Whitney, the culminating summit on the main crest of the range at the east. Thus its altitudinal range, about 13,100 feet, is greater than that of any other national park in the United States, south of Alaska. The park embraces the most southerly portion of the High Sierra, the scenic higher part of the range.

The main crest of the Sierra Nevada, at the east border of the park, bears many high peaks, no less than seven of which have altitudes exceeding 14,000 feet. Traversing the central part of the park from north to south is a secondary crest, the Great Western Divide, which is likewise an impressive range with peaks 11,000 feet to over 13,000 feet in altitude. This crest divides the park into two approximately even but dissimilar halves. The western half is occupied by the basin of the Kaweah River, most southerly of the southwestward-flowing master streams of the Sierra Nevada. The Kaweah Basin is an intricately dissected, rugged area of high relief. The eastern half is occupied by the upper basin of the Kern River. The Kern is unique among the master streams in that it flows directly southward, nearly parallel to the main crest of the range. Distinctive features of the upper Kern Basin, in addition to the high bordering mountain crests, are the impressive U-shaped Kern Canyon and the broad benches (ancient erosion surfaces) that border this canyon and its branches.

In the Pleistocene Epoch both the Kaweah Basin and the upper Kern Basin were occupied by glacier systems. These were the most southerly of the major glacier systems of the Cascades-Sierra Nevada chain. Being less favorably situated than those to the north, they were of smaller volume; nevertheless, glaciers of considerable size formed in both basins, especially the Kern, during each of the three glacial stages—the Glacier Point Stage, the El Portal Stage, and the Wisconsin Stage. Information concerning the characteristics and distribution of the glaciers was sought by distinguishing and mapping the morainal deposits of each of the stages.

In the Kaweah Basin, the development of glaciers was limited by the fact that this basin heads not along the lofty main crest of the Sierra Nevada but on the Great Western Divide and on other secondary crests that are only part way up the Sierra west slope. Evidence is present in this basin for the earliest stage, the Glacier Point, but is extremely meager. For the next stage, El Portal, and the most recent stage, the Wisconsin, the records are far better. They indicate that during both of these stages the converging canyons of the Kaweah Basin became pathways for cascading ice streams. Even the larger of these streams, however, attained a length of only 10 miles. The ice streams therefore fell short of uniting to form a major trunk glacier corresponding to the ones in the main drainage basins to the north and in the Kern Basin to the east. There formed, instead, relatively small separate glacier systems, one or more in the headwater areas of each of the main branches of the Kaweah. Only locally, in their upper reaches, did these glaciers oversweep the divides; for the most part the glaciers were confined to the canyons, and these they filled only in part. The lowest altitude reached by ice in El Portal Stage was about 4,550 feet; in the Wisconsin Stage, about 5,200 feet.

The Kern glacier system, by contrast, was a great, many-branched ice body fed from ranks of cirques along the high bordering ranges. Since the Kern Canyon extends in a nearly straight line through the middle of the upper Kern Basin, and the tributary canyons branch from it like the ribs in an oak leaf, the Kern glacier system had much the same leaflike pattern.

The maximum extent reached by the Kern glacier system in the Glacier Point Stage cannot be determined with certainty, but the evidence would seem to warrant the inference that the glacier advanced approximately as far as its successor of El Portal Stage.

Records of El Portal Stage, though incomplete, can be interpreted with more assurance. The volume of ice was then greater in some places than the canyons could hold; the ice locally spread across intervening divides and over benchlands on either side of the main canyon to a total breadth of 4 to 6 miles, thus producing a central ice sheet about 30 square miles in extent. The overall length of the Kern glacier system was 32 miles; the terminus of the trunk glacier lay at an altitude of 5,700 feet in the bend of the canyon to the north of Hockett Peak (at lat 36°14′, which may represent the southern limit reached by glacial ice in the Sierra Nevada).

Records of the Wisconsin Stage are for the most part very well preserved. They indicate that during this stage the Kern glacier system had less volume than during El Portal Stage and remained a sprawling ice body whose trunk and branches lay confined within their respective canyons as distinct ice streams, separated from one another by mountain spurs or low divides. The tributary glaciers were as much as 15 miles long. The overall length of the Kern glacier system was 25 miles. The farthest point reached by the terminus of the trunk glacier coincides with the south boundary of the park; the boundary posts stand at an altitude of 6,350 feet on the curving outer moraine that marks the extreme limits of the Wisconsin glaciation.

The time available for this reconnaissance did not permit subdividing the Wisconsin Stage into substages. However,

morainal complexes were noted that may throw light on this subject as detailed investigations are undertaken in the future.

The more significant postglacial changes in the park include those which have served to modify the form of the Kern Canyon. The present U-shaped form of that canyon is not precisely the one that resulted from repeated glacial erosion. The walls, once smooth, are now furrowed by gullies, and talus slopes at their base define the curves of a new U-shaped form superimposed on the glacially eroded one. The low gradient of the canyon over a stretch of several miles suggests that the glaciated rock floor may have been excavated into a chain of lake basins that are now filled with sediments.

INTRODUCTION

The field data upon which this report is based were gathered in the course of three field seasons devoted wholly or in part to a reconnaissance of Sequoia National Park for the U.S. Geological Survey. The initial fieldwork was done in 1925 between June 9 and July 15. For the next decade the author's research was diverted to other sections of the Sierra Nevada, but in 1935 he resumed work on Sequoia National Park—this time at the request of the National Park Service and with the effective cooperation of that agency—with a view to completing a systematic reconnaissance. In that year he spent the period from July 8 to December 18 in the field, and in 1936, during the interval from May 27 to July 15, he concluded the project.

Lawson (1904) was the first to give a comprehensive sketch of the geomorphology and glacial geology of Sequoia National Park, and his classic report provided an excellent insight into the mode of development of the major landforms of that region through successive cycles of erosion and through glaciation. Some details on the glaciation of the Mineral King region were provided by Knopf and Thelan (1905). But the need for more complete information on the genesis of the landscape of the entire park—for the scenic features of this park are so exceptional as to be secondary only to the "Big Trees" which give it name—led to the joint sponsorship of the reconnaissance reported in this and previous papers (Matthes, 1937, 1938, 1947, 1950a).

Necessarily, because of the mountainous character of the tract, the physical difficulties which it offers to travel—especially through its wilder parts—and, also, because of the shortness of the working season in the High Sierra portion, much of which is above the timberline, the survey could be only of a preliminary nature. It will readily be understood that the interpretations which resulted are in part tentative and in need of verification by future, more intensive studies. Nor did the reconnaissance cover all the different aspects of the geology with equal thoroughness. Particular attention was given to the evolution of the landforms, and relatively little time was devoted to the examination of the different types of rock that occur within the area. There are so many different formations, and these are so complexly related to one another, that to map them individually and study the petrologic character of each of them would alone have required several field seasons. Some of the results of the reconnaissance have already been published, particularly those pertaining to the geomorphological features. In the present report, additional results are set forth, especially with reference to the character and distribution of the ancient glaciers which occupied Sequoia National Park during the various stages of the Pleistocene Epoch.

The author wishes to thank officials of the National Park Service for the support they gave this survey and for their warm interest in it. While the fieldwork was in progress, staff members of Sequoia National Park were generous with their time and assistance on many occasions and in many ways. Thanks are in order to several individuals who provided illustrations which appear in this report (all photographs not taken by the author have been credited to those who furnished them). The University of California Press freely gave permission to quote extensively from its publication, "Sequoia National Park: a Geological Album" (Matthes, 1950a). Finally, grateful appreciation is expressed to Clyde A. Wahrhaftig for critical reading of the manuscript and for the constructive suggestions that served to improve its effectiveness.

GEOGRAPHIC SKETCH

Sequoia National Park (fig. 1) comprises an irregular tract 604 square miles in extent on the west slope of the Sierra Nevada between lat. 36°18′ N. and 36°42′ N. and between long. 118°14′ W. and 119°00′ W. (pl. 1). It embraces chiefly the scenic upper part of the range, including the main crestline, and in that respect it is situated much like Kings Canyon National Park, which adjoins it directly on the north, and Yosemite National Park, which lies a hundred miles farther to the northwest (figs. 2, 3). But Sequoia National Park has the distinction of including the culminating stretch of the crestline, bearing Mount Whitney (14,495 ft) and six more of the eleven 14,000-foot peaks of the Sierra Nevada; the park has the additional distinction of being traversed from north to south by a secondary crest that is but little lower than the main crest—the Great Western Divide. Noteworthy also is the fact that Sequoia National Park has the greatest range of altitude of any national park or national monument in the United States, south of Alaska. Its lowest point, in the canyon of the Kaweah River near the entrance below Ash Mountain Park Headquarters, is only about 1,400 feet

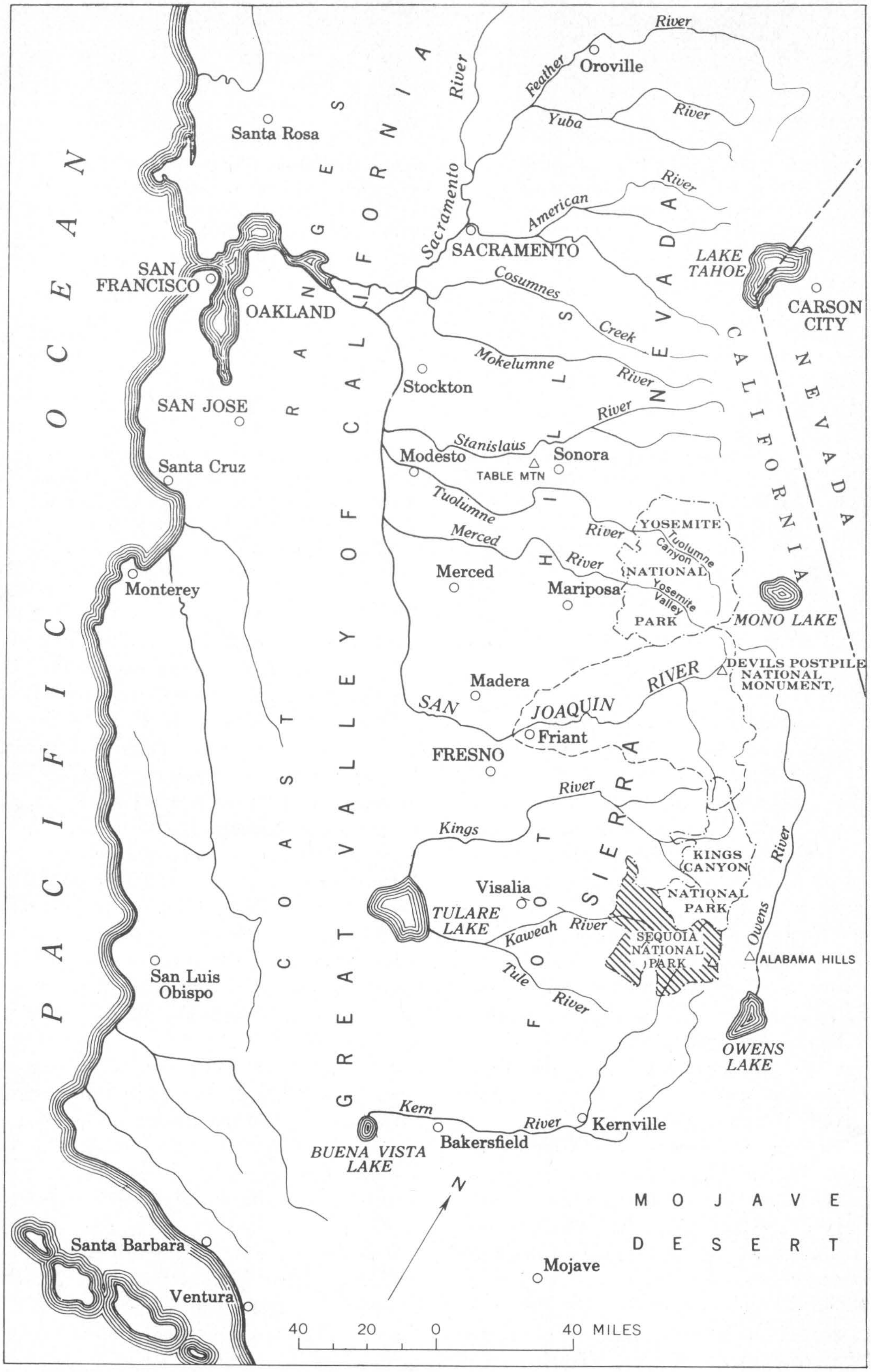


FIGURE 1.—Index map showing location of Sequoia National Park.

FIGURE 2.—Idealized section across the Sierra Nevada representing the simple "textbook conception" of its tilted-block structure. That conception fits approximately the facts as they are known in the central part of the range, in the latitude of Yosemite Valley. Both northward and southward, however, the structure becomes more complex.

FIGURE 3.—Idealized section across the Sierra Nevada in the latitude of Sequoia National Park. Step faults exist at the western margin of the range as well as at the eastern margin, and the west slope consequently breaks off rather abruptly in the foothills belt. Some distance from the foothills, the tops of peaks on the down-faulted buried fault block emerge as isolated rocky hills above the sediments that fill the San Joaquin Valley. From Matthes (1950a, p. 3).

above sea level. Thence to the top of Mount Whitney, therefore, the change in altitude amounts, in round numbers, to 13,100 feet.

All of the three national parks in the Sierra Nevada include parts of that scenic upper region near the main crestline which Californians aptly call the "High Sierra." This region is a mountain land of truly alpine character, whose jagged snow-flecked peaks rise high above the timberline and whose strongly glaciated valleys are dotted with hundreds of picturesque lakes and lakelets. Of this alpine upper country, Sequoia National Park embraces the southernmost part. Its southern boundary, indeed, coincides approximately with the line where the High Sierra comes to an end; thence southward the range assumes a more subdued aspect, none of its summits rising above timberline.

In one other respect Sequoia National Park differs markedly from its two sister parks. Both Yosemite and Kings Canyon National Parks are traversed by southwestward-trending rivers—that is, by rivers that flow directly down the west slope of the range, roughly parallel to the rank and file of the master streams. The drainage net of Sequoia National Park, on the other hand, is complicated by the secondary mountain crest previously mentioned, the Great Western Divide. To the west of that divide is the drainage basin of the Kaweah River, the southernmost of the great series of southwestward-flowing master streams. To the east of the divide, on the other hand, is the headwaters basin of the Kern River; this river flows directly southward in a nearly straight line, parallel to the main crestline, and maintains that unusual course for 75 miles before turning in a southwesterly direction toward the Great Valley of California. The Kern River, moreover, heads against the South Fork of the Kings River, to the north, and as a consequence the Kaweah River does not reach up to the main crestline.

The Great Western Divide is far more than a mere ridge or crest; it is a mountain range in itself (fig. 4). Surmounted by a row of sharp-profiled peaks from 11,000 to more than 13,000 feet in altitude, and unbroken by any profound gaps,[1] it constitutes in effect a formidable barrier that trends from north to south across the park and divides it into two approximately even but very dissimilar halves. The divide stands 2,000 to 3,000 feet above the valleys at its eastern base and 4,000 to 6,000 feet above the canyons at its western base. Viewed from points in the western half of the park—as from Moro Rock, on the edge of the Giant Forest—the Great Western Divide has the appearance of a spectacular alpine range, and as a consequence it is commonly mistaken by sightseers for the main crest of the Sierra Nevada. The main crest actually lies behind the Great Divide, completely hidden from view.

Finally, a word about the country between Sequoia National Park and the western foothills of the Sierra Nevada. In an airline, that country measures 12 to 15

[1] The only trail-passes over the Great Western Divide are Kaweah Gap (10,700 ft.), Black Rock Pass (11,500 ft.), Franklin Pass (11,300 ft.), Shotgun Pass (11,300 ft.), and Coyote Pass (10,034 ft.).

FIGURE 4.—View eastward toward headwaters of Middle Fork, Kaweah River. The snow-clad peaks on the skyline are on the Great Western Divide. In the left foreground is Moro Rock, an imperfect dome that owes its rounded form to long-continued exfoliation of the massive granite. At the lower right is the canyon of the Middle Fork. Aerial photograph by Frank Webb.

miles in width. From the point where the Kaweah River leaves the park to the embayment in which it debouches upon the plain of the San Joaquin Valley, the airline distance is only 11 miles. Looking down the Kaweah River canyon from the top of Alta Peak or from the rim of the Giant Forest platform, one is impressed by the multiplicity of rugged ranges and spurs advancing toward the canyon from either side, one behind another, at successively lower heights, parallel to the border of the distant plain. The name that has been given to one of the viewpoints on the Generals Highway—Eleven Range Point—well expresses the effect which the landscape makes upon the spectator.

Between those successive ranges and ridges are deep-cut canyons and gulches tributary to the Kaweah. The majority of these canyons trend at right angles to the southwesterly course of the master stream, but an inspection of the topographic maps shows that this trend is by no means universal and that, taken as a whole, the drainage pattern is extremely varied and irregular. Nor is the alinement of the ridges with the foot of the range as parallel and as persistent as their appearance in the distant view would seem to indicate. The map shows, furthermore, that not all are sharp crested; a considerable proportion have broad undulating summit areas.

There is no complete gradation of summit levels all the way down to the San Joaquin Valley. That fact is evident at once to the traveler who approaches the mountain range from the west, by way of either Lemon Cove or Woodlake. Even the first outlying hills which he passes rise abruptly 500 to 1,000 feet above the level of the plain, and the first continuous ridges of the mountain mass rise 1,500 to 2,000 feet above the plain. These ridges form an irregular, steep mountain front that resembles an escarpment.

KAWEAH BASIN

The western half of the park is profoundly dissected by the converging branch canyons of the Kaweah River system (fig. 5). Though none of its peaks rise to great altitude, it is an extremely rugged piece of country, difficult to traverse save on manmade roads or trails. The main canyon of the Kaweah River at Ash Mountain Park Headquarters is 3,000 to more than 4,000 feet deep. Ash Peak (5,621 ft), on the northwest side, stands 4,100 feet above the river, and Milk Ranch Peak (6,305 ft), on the southeast side, 4,800 feet. The canyons of the

FIGURE 5.—Panoramic view from Alta Peak of the broad west slope of the Sierra Nevada. The Kaweah River canyon, left of center, is one of the many deep trenches cut by southwestward-flowing rivers. The foothills are 27 miles away. Beyond them is the level San Joaquin Valley, deeply filled with silt, sand, and gravel washed down from the bordering ranges. On the horizon, barely discernible because of the haze, are the Coast Ranges, more than a hundred miles distant. Photograph by L. Moe.

North, Middle, East, and South Forks are even deeper. Paradise Peak (9,370 ft) stands 5,400 feet above the East Fork and 6,400 feet above the Middle Fork. Homers Nose (9,005 ft) stands 5,200 feet above Clough Cave, on the South Fork, and 5,500 feet above the East Fork. The Castle Rocks (9,150 ft) rise 6,150 feet above the Middle Fork, and Alta Peak (11,211 ft) rises 6,910 feet above it.

Some parts of the Kaweah Basin, however, are not deeply dissected by canyons but consist of undulating plateaulike uplands traversed by shallow valleys. Of these upland areas—which are clearly surfaces recording successive stages in the erosional history and rise of the Sierra Nevada (Matthes, 1930, 1933, 1937, 1950a, 1960)—the most extensive is in the headwaters of the Marble Fork. The platform on which the Giant Forest stands (figs. 6, 7), at altitudes ranging from 6,500 to 7,000 feet, is a characteristic part of this upland; Lodge-

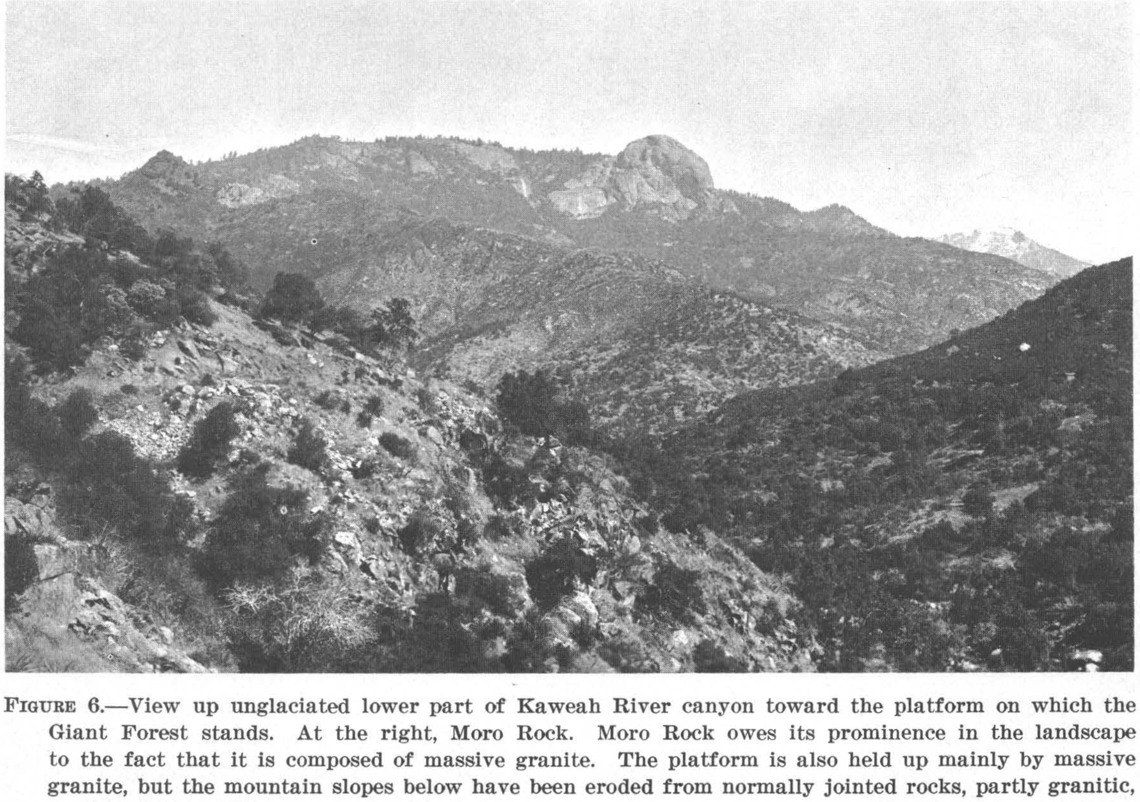


FIGURE 6.—View up unglaciated lower part of Kaweah River canyon toward the platform on which the Giant Forest stands. At the right, Moro Rock. Moro Rock owes its prominence in the landscape to the fact that it is composed of massive granite. The platform is also held up mainly by massive granite, but the mountain slopes below have been eroded from normally jointed rocks, partly granitic, partly metamorphic.

FIGURE 7.—View westward from Moro Rock along the cliffs bordering the platform on which the Giant Forest stands. Part of the Giant Forest is seen at the right. The cliffs are of sparsely jointed granite that is exfoliating very slowly and rather irregularly. Similar massive granite outcrops elsewhere on the platform indicate that the whole platform is made up largely of this durable material; it is no doubt to this circumstance that the platform, a remnant of an ancient erosion surface, owes its preservation.

pole and Tokopah Valleys, in the middle course of the Marble Fork, also form part of it. High above the Giant Forest, however, on the summit of Panther Peak (9,044 ft) is another much smaller platform or flat; 2,000 feet above that, again, is a third flat on the top of Alta Peak (11,211 ft). Thus the landscape appears to rise by successive stories, each being marked by a level of gently undulating surface that contrasts with the steep mountain slopes between.

UPPER KERN BASIN

The upper Kern Basin, which forms approximately the eastern half of the park, contrasts strikingly with the Kaweah Basin, both in general configuration and in arrangement of drainage lines (pl. 2). Instead of being intricately dissected by a maze of branching canyons and gulches, the Kern Basin has a broadly open, spacious aspect. This spaciousness is due not merely to the fact that the neighboring mountain ranges—the Great Western Divide on the west and the main crest of the Sierra Nevada on the east—stand 13 to 18 miles apart but also to the presence of extensive terracelike benchlands that flank the central canyon and give the basin what appears, at least from a distance, to be a broad and nearly level floor. These benchlands, like those in the Kaweah Basin, are ancient erosion surfaces, better preserved here, perhaps, than in any other section of the Sierra Nevada. From these benchlands and from the even older erosion surfaces recognizable in the tabular summits of certain of the peaks may be read the record of the rise of the Sierra Nevada. Their characteristics and significance were set forth in the pioneer study of Lawson (1904) and in the later studies of Webb (1946) and of the author (Matthes, 1930, 1933, 1937, 1950a, 1960). (See fig. 8.)

At its head the Kern Basin is encircled by the Kings-Kern Divide and the Great Western Divide, which form one continuous jagged mountain range. The Great Western Divide is strongly bowed toward the west, but the main crest of the range is locally bowed towards the east; the basin as a whole is therefore spoon shaped in outline. Even more apt, in view of the simple drainage pattern, is its likeness to a foliage leaf, as suggested by Lawson (1904). The straight Kern River traverses the basin axially like the midrib of the leaf, and the tributary streams branch from it at intervals, like veins. This simple pattern, it should be observed, is limited strictly to the upper basin, which lies within the limits of the park. Farther south, the drainage net becomes more complex, some of the tributary streams running parallel to the southflowing Kern River for considerable distances. Examples are the Little Kern River,

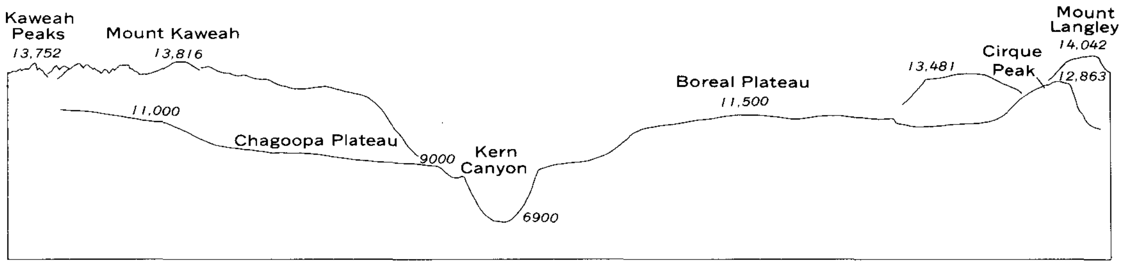


FIGURE 8.—Simplified profile across the Upper Kern Basin, showing remnants of four ancient landscapes (erosion surfaces) at different levels above the Kern Canyon. The gently sloping summit of Mount Langley, like that of Mount Whitney, is a remnant of a hill in the lowland (Whitney erosion surface) that existed before the first major uplift of the Sierra region took place. The rounding summit of Cirque Peak is representative of a more mountainous landscape (Cirque Peak erosion surface) formed during the long interval between the second uplift and the third. The Boreal Plateau is a large remnant of an undulating landscape (Boreal Plateau erosion surface) that was also produced during the interval between the second uplift and the third. Chagoopa Plateau and the corresponding benches on the east side of Kern Canyon are remnants of a broad valley (Chagoopa erosion surface) that was evolved during the interval between the third uplift and the fourth. The Kern Canyon has been cut since the fourth and latest uplift, which took place at about the beginning of the glacial epoch. It is a product of alternate stream erosion and glacial erosion and is still in the process of being cut deeper. From Matthes (1950 a, p. 12, 13). Vertical exaggeration × 2.

which flows southward for a distance of 16 miles between the southern portion of the Great Western Divide and the Hockett Meadows Plateau, and the South Fork of the Kern, which pursues an irregular but, in the main, southerly course for some 50 miles (air-line distance) through the eastern part of the Sierra Nevada before turning southwestward to join the master stream.

The upper Kern Basin, further, is much less deeply trenched than is the Kaweah Basin. Throughout most of its length the Kern Canyon is only 2,000 to 2,500 feet deep. Whereas the Kaweah River has cut its canyon down to an altitude of 1,400 feet at the point where it leaves the park, the Kern River has an altitude of 6,400 feet where it crosses the southern park boundary. It follows that the upper Kern Basin, as a whole, is a region of relatively great altitude. The broad benchlands flanking the Kern Canyon range from an altitude of about 8,000 feet at the southern boundary of the park to more than 11,000 feet at the head of the basin.

The benchlands vary greatly in width—from a few yards to several miles—owing to the presence of bold spurs and mountain groups that project here and there from the enclosing ranges. At intervals, moreover, these benchlands are cut across by tributary canyons: yet, as is evident at once in any comprehensive view, they are remarkably persistent throughout the length of the basin. Though by no means level—from the flanking mountain ranges they slope down to brinks of the Kern Canyon at rates of 500 feet and more to the mile, and, in addition, are interrupted by low ridges and vales—the benchlands together form a distinct story in the landscape that contrasts with the towering mountains above and the steep-sided canyon below. They form a story not unlike that of the Giant Forest platform or of the Hockett Meadows Plateau in the Kaweah Basin but far more extensive and more clean-cut than either of these.

Particularly broad and typically developed is that section of benchland which is known as the Chagoopa Plateau (fig. 9). It is on the west side of the Kern Canyon immediately above the junction of the great side canyon called the Big Arroyo. This plateau extends 3 miles back from the canyon rim and in that distance rises from about 8,500 feet to more than 10,500 feet in altitude. Immediately above it loom Mount Kaweah (13,816 ft) and the great Red Spur (13,186 ft) which, together with the Red Kaweah (13,754 ft) and the Black Kaweah (13,752 ft), form one of the most imposing mountain groups that are attached to the Great Western Divide. To the tourist public the Chagoopa Plateau is well known, for it is traversed by the High Sierra Trail, the main horse trail leading from the Giant Forest to Mount Whitney.

The Chagoopa Plateau and the benchlands of corresponding altitude on the opposite side of the Kern Canyon are not, however, the only story in the landscape of the upper Kern Basin. As in the Kaweah Basin, so here there are several plateaulike flats or benches at different levels one above another (pl. 2). A prominent example is the Boreal Plateau, a gently undulating upland bench averaging more than 11,000 feet in altitude and stretching for a distance of 7 miles along the southeastern boundary of the park. Above

FIGURE 9.—View westward across the Kern Canyon to the Chagoopa Plateau; Kaweah Peaks Ridge in the background. The timbered plateau on both sides of the canyon is a remnant of an erosion surface; that forming the Chagoopa Plateau is particularly striking. In the foreground, at the lower right, is a small hanging valley.

it, again, is the broadly convex summit of Cirque Peak, which ranges from 12,200 to 12,863 feet in altitude (pl. 2). And high above that peak rises the summit platform of Mount Langley, which ranges from 13,800 to 14,042 feet in altitude. Even Mount Whitney, the highest peak of the Sierra Nevada, has a broad, gently sloping summit platform (figs. 8, 10). The platform, which is closely analogous to the one on Mount Langley, rises from 14,000 to 14,495 feet in altitude. Indeed, so very similar in general form are the two peaks that in 1871 Clarence King (1872), one of the early explorers of the Sierra Nevada, mistook Mount Langley for Mount Whitney and climbed it thinking that he was ascending the culminating peak of the range.

It is not to be inferred from the foregoing that flat plateaulike summits are the rule or even are prevalent on the main crest of the Sierra Nevada. The summits of Mount Whitney and Mount Langley, and the lower one on Cirque Peak, are the only ones on that part of the main crest that flanks the Kern Basin. Farther north in the range, a few flat summits occur at long intervals—for example, on Mount Darwin (13,841 ft and 13,701 ft) and on Mount Wallace (13,328 ft) at the head of the upper San Joaquin Basin (Matthes, 1960, p. 38, 41) and on a continuous platform (12,500 to 13,000 ft) 3½ miles long in Yosemite National Park (Matthes, 1937, p. 8–9)—but most of the peaks are sharp profiled, as are those on the Great Western Divide. Only one of the peaks on the Great Western Divide, Table Mountain (13,646 ft), has a clean-cut tabular summit platform (fig. 11), although a few others have ill-defined sloping summit areas.

The Great Western Divide and the main crest of the range are much alike in general character, indeed, are much like the majority of the serrate mountain crests that traverse the High Sierra for more than a hundred miles northward. Each consists essentially of a single chain of lofty angular peaks connected with each other by narrow, sharp crested, often splintered or pinnacled ridges (fig. 12). Their sprawling spurs likewise are for the most part narrow and sharp crested, whereas the intermediate canyons as a rule are broadly U-shaped and head in steep-walled amphitheaterlike bowls. These ranges accordingly possess predominantly attenuated, sharply pointed forms and in a sense are "skeleton ranges." Some parts of the main crest of the range—in the vicinity of Mount Barnard, Mount Whitney, and Mount Langley—however, depart somewhat from that general character, the forms at these places being more fullbodied, the summits tabular or gently sloping, and the spurs broad enough to have rounding contours.

In both ranges, however, the U-shaped canyons and

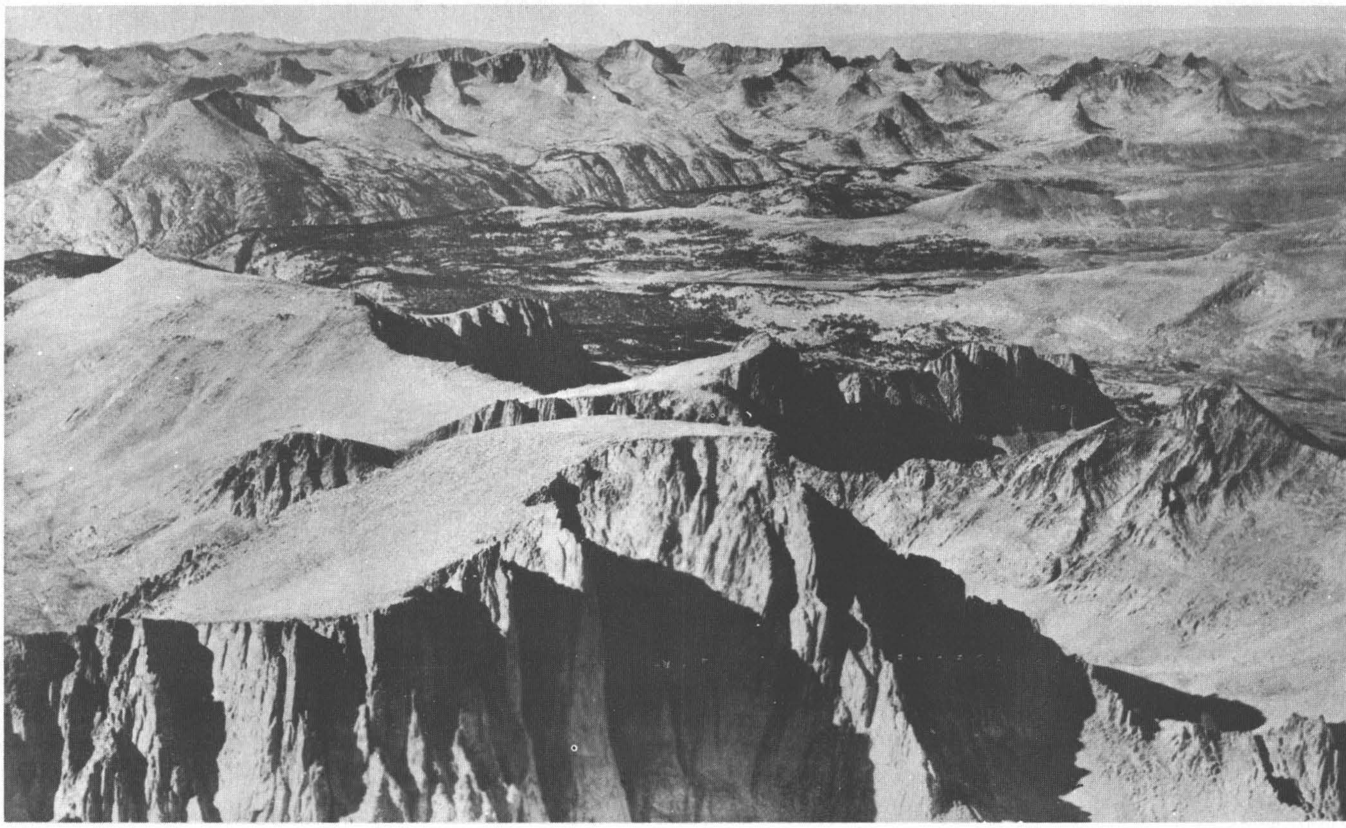


FIGURE 10.—View northwestward from the main Sierra crest across the upper Kern Basin to the Great Western Divide. An ancient erosion surface is preserved on the summits of Mount Whitney, in the foreground, and Mount Young, the adjacent peak. Other, younger erosion surfaces form the plateaus bordering the Kern Canyon. Numerous cirques scallop the main Sierra crest and the Great Western Divide. Aerial photograph by Roy Curtis.

the capacious amphitheaters seem wholly out of proportion to the small volume of the streamlets that descend through them. These streamlets in many places find their way among the knolls and bumps of the rock floors without definitely incised channels—here cascading over rock steps that as yet show no signs of stream erosion, and there meandering through grassy meadows or losing themselves in gemlike lakelets (fig. 13). These features stand out all the more vividly in the landscape because the canyons and amphitheaters lie mostly, or in some places entirely, above the timberline, in the lower fringes of what is properly termed the "Alpine zone."

From the lofty summits on the main crest of the Sierra Nevada, one looks down its precipitous east front into Owens Valley below. Particularly impressive is the view from Mount Whitney, not merely because of the great height of that peak above the valley—10,800 feet, or more than 2 miles—but because the spectator stands at the immediate, sharp-cut brink of a precipice that falls away sheer 1,500 feet beneath his feet. So breathtaking is the scene that the entire mountain front seems to drops off sheer like a wall. Yet, as is clearly shown on the accurately constructed topographic map, the foot of the range is fully 5 miles out from the peak in horizontal distance.

Even more incredible does it seem that the base of the great escarpment is itself fully 3,000 feet above the valley floor on which stands the town of Lone Pine. What appears to be a level plain at the foot of the range is in reality a slope that descends 2,000 feet in a distance of 5 miles. And what appear to be insignificant hillocks at the farther limits of the slope are the fantastically shaped crags and pinnacles of the Alabama Hills, a picturesque miniature range that looms 1,000 to 1,400 feet above Lone Pine and has furnished the weird setting for many a moving picture allegedly filmed in India within sight of the great Himalayas—this mountain system being adequately represented in the background by the Sierra Nevada.

Over the broad level floor of Owens Valley, one can readily trace the serpentine course of the Owens River, conspicuous by reason of its fringe of deep-green bushes. Beyond the river stretches the long-drawn somber-hued Inyo Range, which forms the east wall of the valley, parallel to the Sierra Nevada. From altitudes of 8,000 and 9,000 feet at its southern end, the Inyo Range

FIGURE 11.—View southeastward toward cirques on the Great Western Divide, which forms part of the boundary between Sequoia and Kings Canyon National Parks. Table Mountain, the flat-topped peak to the right of center, is one of the dominating summits of the divide. Aerial photograph by Frank Webb.

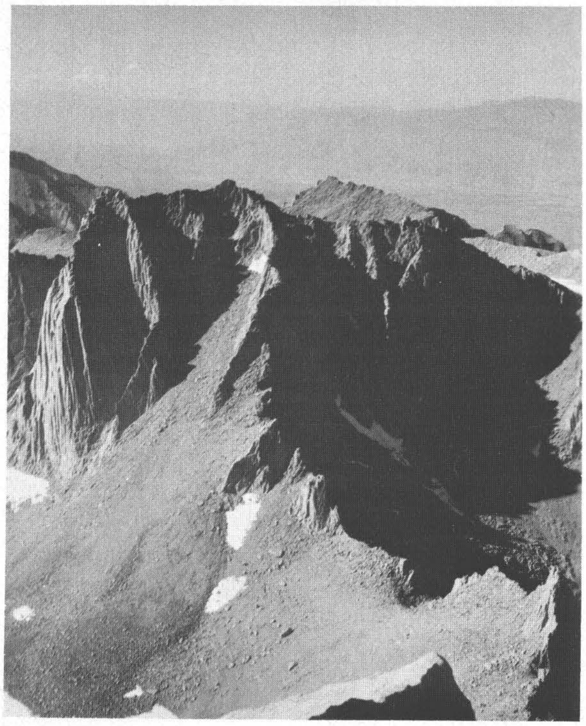


FIGURE 12.—View northward from Mount Whitney toward Mount Russell (center). Here, as a result of the headward quarrying of the glaciers that formerly occupied the opposing cirques, there remains of the former main crest of the range only the rock wall that connects the two peaks. The abundance of loose rock waste shows that the granite here breaks up readily—more readily than avalanches, running water, and gravity can remove the debris. The destructive action of alternating frost and thaw doubtless is promoted by the numerous vertical joint fractures. Photograph by Kenneth Flewelling.

rises irregularly to altitudes of 13,000 and even 14,000 feet in its northern part which, because of its contrasting light-colored rocks, is known as the White Mountains.

Southeastward, diagonally across Owens Valley and over gleaming Owens Lake in its bosom, are the relatively low Coso Mountains and several more distant mountain groups, and, more distant still, the lofty Panamint Range, behind which, deeply ensconced, lies Death Valley.

The stupendous panorama from the summit of Mount Whitney is in truth second only to the Big Trees among the park's natural exhibits as an inspiration for wonder and thought.

KERN CANYON

The great Kern Canyon extends due south through Sequoia National Park and divides that part of the Kern River basin lying within the park into two nearly equal parts.

From a geomorphological point of view, the head of the canyon may be regarded as being at Junction Meadow, where three branch canyons unite (fig. 14). The central branch canyon, though alined with the Kern Canyon, is distinctly subordinate to it in size and is separated from it by a great canyon step; this branch canyon is therefore of the rank of a tributary to the main canyon rather than a part of it.

In its 17-mile stretch from Junction Meadow to the vicinity of Coyote Creek, where it leaves the park, Kern Canyon follows a nearly straight course that doubtless reflects structural control, as suggested by Lawson (1904) and further analyzed by Webb (1936, 1946), this control being a fault or zone of faulting. The canyon is a typical glacial U-shaped trough (figs. 15, 16). Indeed, it is no overstatement to say that few glacial canyons, either in the Sierra Nevada or elsewhere, possess so nearly perfect a U-shaped form due to glacial excavation and maintained for so long a distance. The principal reason for its regularity is that the trough is sunk along the axis of a geomorphically postmature valley of great breadth and consequently has sharply defined rims, or shoulders, formed by the intersection of its precipitous walls with gently sloping uplands at both sides. (These shoulders, it is true, are broken at intervals by side canyons, and in other places on the uplands they make way for hills of moderate height.)

In the section within Sequoia National Park, the Kern Canyon is deepest at its head and becomes progressively more shallow southward. At Junction Meadow it is 2,500 to 2,600 feet deep; at the mouth of the Big Arroyo, 10 miles farther downstream, it is 2,000 feet deep, and opposite the rocky knob 14 miles below Junction Meadow, it is only 1,600 feet deep.

These depths, it may be objected, are measured from the rims of the flanking uplands, and those uplands are not a mathematical plane, but parts of an undulating, locally even hilly erosion surface. Allowance therefore should be made for the inequalities in that surface. To obviate errors from this source, the three measurements cited above were made at localities where the flanking uplands slope gently toward the rims and most probably represent the marginal parts of the ancient valley in which the U-shaped trough is sunk. Another source of error cannot be avoided. At Junction Meadow the U-shaped trough is 1¾ miles wide from rim to rim, whereas it narrows to about 1 mile in its lower half; the depth indicated at Junction Meadow is therefore likely to be excessive, for the walls of the U-shaped trough there cut higher into the sloping uplands than they do in the narrow part of the canyon. Careful examination of the topographic map, however,

FIGURE 13.—One of the many lakelets occupying glacially quarried rock basins in the upper Kern Basin, above the junction of Milestone Creek. The granite at the sides, being only sparsely fractured, was not readily quarried away and consequently shows the effects of abrasion.

FIGURE 14.—View northwestward from Mount Guyot. The Kern Canyon extends from the center of the picture toward the lower left; three branch canyons unite at its head. Photograph by Carl F. J. Overhage.

shows that the error thus introduced probably does not amount to more than a few hundred feet. That being admitted, there can be no doubt that the progressive southward shallowing of the U-shaped trough is due primarily to the fact that its floor has a decidedly lower grade than does the bordering upland surface.

The grade of the canyon floor is reliably represented on the topographic map, for a line of spirit levels was run by the Geological Survey up the bottom of the Kern Canyon from Grasshopper Meadow (4½ miles south of the park boundary) to Junction Meadow. The first stretch of 7 miles above Coyote Creek—that is, up to the mouth of the Big Arroyo—has a very low grade. This is the stretch that is aggraded behind a morainal dam. The altitude of the bench mark at Coyote Creek is 6,458 feet; the altitude of the bench mark at the mouth of the Big Arroyo is 6,664 feet. The rise in that 7-mile stretch, therefore, is only 206 feet, or, on an average, 29 feet per mile. From the Big Arroyo to the mouth of Rock Creek, the grade steepens gradually to an average of more than 100 feet per mile; and between Rock Creek and Whitney Creek it reaches locally as high as 200 feet per mile. But from the fan of Whitney Creek to Junction Meadow, it again flattens to less than 100 feet per mile.

In many of its geomorphic features, the Kern Canyon, in Sequoia National Park, resembles the Kings

FIGURE 15.—View southward down the Kern Canyon from a point on the west rim near mouth of Rattlesnake Creek. The pronounced U-shaped form of the canyon has been evolved by glacial erosion from a narrow V-shaped trench. The walls, once smooth, are now furrowed by gullies; talus slopes at their base produce the curves of a new U-shaped form superimposed on the glacially eroded one. Photograph by L. Moe.

FIGURE 16.—View southward down the Kern Canyon from a point below the rim north of Wallace Creek. The canyon is not straight throughout, although its course is probably determined by a fault or by several closely spaced parallel faults. Photograph by Kenneth Flewelling.

Canyon (canyon of the South Fork of Kings River) which adjoins it on the north (Matthes, 1926). Kern Canyon lacks imposing cliffs of massive rock like those above Zumwalt Meadows in the Kings Canyon, but it is a longer and in some respects a more impressive canyon. Its cliffs are composed of sparsely jointed granite, and along many of the vertical or nearly vertical master joints, storm waters have cut clefts, some fully 100 feet deep and with cavelike recesses. Near Junction Meadow, on the west side of the canyon, there are clefts, a hundred yards or more apart, which have been cut along oblique master joints dipping steeply southward.

The floor of the canyon, throughout this section, is so largely covered with surficial deposits that only in a very few places does the river flow over bare rock. Glacial moraines are confined to a small area at the park boundary, but alluvial and talus deposits are extensive throughout this section of the canyon. Undoubtedly some of the material mantling the bedrock floor of the canyon is glacial outwash.

At places where tributary streams join the Kern River, great boulder fans extend out from the walls of the canyon onto its floor. Such a fan, composed of mingled lava and granite boulders, occurs at the mouth of Golden Trout Creek, and across the canyon is the exceptionally large fan built by Coyote Creek at a place where Wisconsin moraines descend to the canyon floor. At the mouth of Rock Creek, the canyon floor is covered with large quantities of bouldery material deposited both by Rock Creek and by the Kern River, but here a distinct fan is lacking. Whitney Creek has a conspicuous fan, and Wallace Creek has an even larger fan which includes much material derived from lateral moraines of the Kern trunk glacier higher on the valley side. Wallace Creek now flows in a steep-walled trench that is cut across the lateral moraines and down through the upper part of the fan.

All the alluvial fans have been truncated by the river at a considerable height above the canyon floor proper. The resultant scarps, though commonly 50 to 60 feet high, vary in height, depending on how steeply the surfaces of the fans slope and on the extent to which these fans have been trimmed back by the river. As a consequence, in some places a scarp on one side of the river may be twice as high as one on the opposite side.

These features are well illustrated by the great fan of Coyote Creek, which is typically truncated by a main scarp 60 to 70 feet above the river. This scarp is old enough to have numerous short gulches worn in it, and the edge of the terrace is therefore distinctly lobate. The lower terrace is nearly 20 feet above the river. A steel suspension bridge is built at this level. Conterno's old suspension bridge, half a mile farther upstream, is built in a less favorable place, where, because the lower terrace is absent on the east side, the trail had to be cut obliquely down the scarp of the main terrace to the bridge.

The partial dismantling of the canyon walls has given rise to long talus slopes which extend along both sides of the canyon. Although these slopes are nearly continuous, there are, nevertheless, many places where rock in its original position crops out near the base of the talus. The talus slopes, which help to complete the U-shaped form of the Kern Canyon (although the canyon would be distinctly U-shaped without them), extend to various heights; near Junction Meadow the slopes apparently reach about halfway up the canyon side, but their exact upper limits are difficult to judge because of the brush cover. A puzzling feature of the talus slopes is the fact that those on the east side of the canyon are for long distances more voluminous than those on the west side. Like the alluvial fans, the talus slopes have been cut back, and scarped, by the river.

In places the canyon floor is encumbered by enormous blocks that have fallen from the bordering cliffs. Many of these blocks, which constitute one of the impressive features of the canyon, can be seen along the trail near Funston Meadows. They measure 10 to at least 50 feet in diameter but, as a result of irregular spalling, most are now much smaller than when they fell.

No true exfoliation was noted in the Kern Canyon, in striking contrast to the many exfoliating granite boulders in the Kings River and upper San Joaquin River basins. The reason for this difference is probably to be found in the occurrence of irregular minor structures in the granite of the Kern Canyon. The rock is full of shear fractures, mostly chloritized, and it tends to spall along these fractures, at least for short distances.

Where tributary streams leave the mouths of hanging valleys on the uplands and descend into the canyon, cascades and waterfalls are found. Several of these are of spectacular height and great beauty, yet are still (1964) unnamed. The most notable waterfalls occur where several streams draining Chagoopa Plateau plunge down the steep west wall of the canyon. Of this group the falls of Red Spur have the greatest drop, about 2,300 feet. Chagoopa Falls (fig. 17) descend by several deep plunges, glissades, and, farther down, broken cascades, a total fall of about 1,400 feet. As a result of stream entrenchment, some of the cascades lie in the bottom of gulches; where stream cutting has been facilitated by fractures in the rock, the gulches may be so narrow and deep that the cascades recessed in them are all but invisible (fig. 18, 51).

Immediately south of the park, there occur features which have significant bearing on the glacial history of Sequoia National Park (fig. 19). In this area, extending about 7 miles southward from the park boundary, the canyon retains its distinctive broad U-shape but loses some of its regularity and, departing from its nearly straight southward course, swings eastward around Hockett Peak.

Within this part of the canyon are ancient moraines which record the southerly limits of the Kern trunk glacier at one of its early stages. The Kern Lakes, also in this section, are not of glacial origin, however, but came into existence, as Lawson (1904, p. 343–345) correctly recognized, through two special and different causes. Kern Lake is impounded behind the fan of a streamlet coming down from a hanging valley on the east side of the canyon; Little Kern Lake, which is separated from the river by an almost continuous natural levee, is held up behind a dam resulting from a colossal rockslide which fell from the east wall of the canyon.

Of great interest also are the prominent buttresses, in the bottom of this part of the canyon, which Lawson

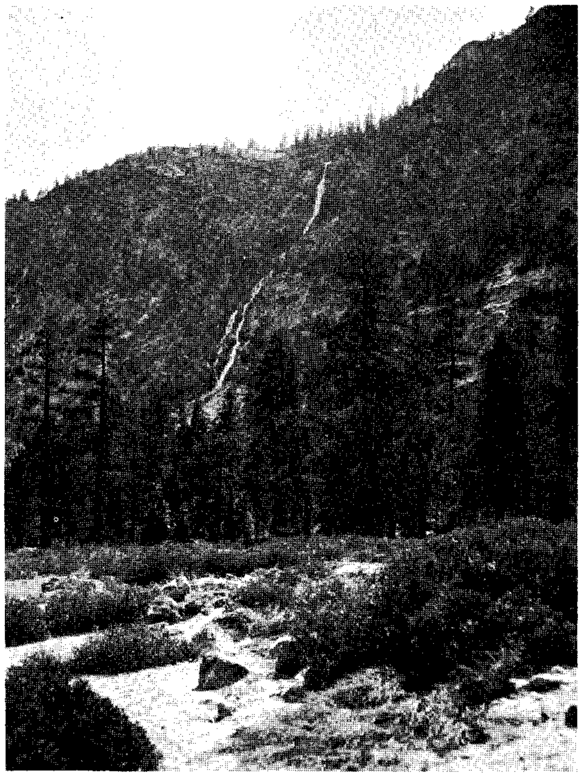


FIGURE 17.—Chagoopa Falls, which descends the steep west wall of the Kern Canyon from a small hanging valley on the Chagoopa Plateau. The side valley was left hanging primarily as the result of rapid trenching by the master stream, but its height was increased by glacial deepening of the Kern Canyon. Widening of the canyon by glacial erosion also steepened the descent of the cascades. Photograph by Kenneth Flewelling.

(1904, p. 331–343) regarded as being a type of geomorphic form not previously recognized and for which he proposed the name of "kernbut." Lawson's description of the kernbuts follows, in part:

A remarkable feature of the Upper Kern, below Volcano Creek, is the departure of the stream from the west wall of the cañon and its crowding upon the east wall. This displacement of the stream is due to obstructions in the shape of a series of rocky buttresses, which adhere to the foot of the west wall, and, projecting out beyond the middle line of the cañon, locally, constrict it, causing the stream to occupy narrow gorges between these buttresses and the east wall. In the interval between these buttresses the bottom of the cañon has its normal width of about half a mile from wall to wall. There are several of these buttresses in the vicinity of the Kern Lakes, and the two lakes lie in two of the intervals. In cross profile these buttresses have the character of rather sharp-crested ridges which run parallel to the general trend of Kern Cañon; and a buttress may be a single ridge or a series of two or three ridges, in which case the latter are successively lower in the east. The buttresses may, therefore, be distinguished as single or multiple according as they present one or more of these ridges in cross profile.

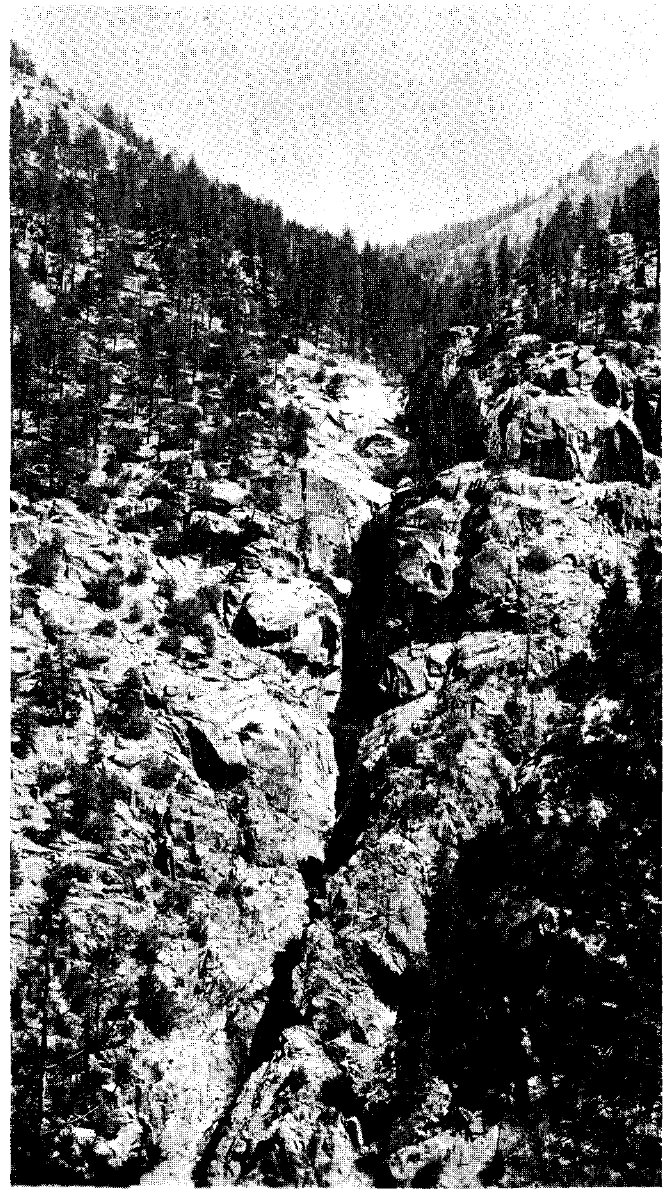


FIGURE 18.—Slotlike gulch incised in the east wall of Kern Canyon by a streamlet descending from the mouth of a hanging valley below Kern Lake. Stream cutting was facilitated here by a fracture in the granite. The cascade is now so deeply recessed as to be almost invisible. This gulch is just outside the south boundary of the park, but similar gulches are found farther north, within the park.

The correlative pass, or col, which intervenes between the kernbut and the main canyon wall or between the parallel ridges of a multiple kernbut, Lawson designated as "kerncol."

The names "kernbut" and "kerncol" were chosen, in part, because they are purely descriptive and carry with them no implication as to the genesis of the forms.

FIGURE 19.—View up the Kern Canyon from a point about 2 miles south of the park boundary. Kern Lake, in the foreground, is not a glacial lake; it was formed in 1867–68 when the Kern River became ponded through rapid growth of an alluvial fan. Beyond the lake, in the shadow, appears one of the buttresses (kernbuts) characteristic of this part of the canyon. In the Wisconsin Stage, the Kern glacier reached only to the park boundary, but in the earlier stages it extended several miles farther south and occupied the part of the canyon shown in the foreground of this view. Photograph by W. L. Huber.

GLACIATION

In the 1860's, when Professor Josiah D. Whitney (State Geologist of California, for whom Mount Whitney was named), sent the first scientific exploring parties into the Sierra Nevada, and in the 1870's, when John Muir and Professor Whitney engaged in their memorable controversy about the glaciation of the Yosemite Valley, the concept of the Ice Age, or glacial epoch, was still very new and ill defined. Sufficient evidence was at hand to show that the north-central and northeastern parts of the United States and the adjoining parts of Canada had once been covered by a vast ice sheet, but the precise limits which that ice sheet had reached were not definitely known. It was assumed to have formed part of an immense icecap that centered at the North Pole and to have mantled all the northern half of North America. Not unnaturally, this sheet was supposed to have also covered the great western mountain belt of the continent, many of whose ranges still bear glaciers at the present time. Not until later did it become clear that no icecap could have been at the North Pole of the Earth, because that pole was covered by an ocean of considerable depth. The ice sheet, it was found, originated on the North American continent itself—in Labrador and the region to the west of Hudson Bay, from which centers the ice flowed in all directions.

It was discovered, further, that this ice sheet did not overwhelm the western mountain ranges but, anomalously, stopped to the east of them, and that those ranges were independent centers of snow accumulation which generated large glaciers of their own. Those glaciers became confluent and filled the intermontane valleys with ice to depths of several thousand feet. A vast composite ice mass was thus formed that was not an icecap, strictly speaking, nor did it bury the higher peaks; yet it was continuous over the entire breadth of the mountain belt. This Cordilleran ice, as it is appropriately called, spilled eastward onto the plains and westward into the fiords of the Alaskan coast and

British Columbia. It lay almost wholly to the north of the Canadian boundary line but sent several broad lobes southward into Puget Sound, eastern Washington, and western Montana.

South of this composite ice mass, the higher mountain ranges also generated glaciers. The Sierra-Cascade chain is notable in that it bore glaciers throughout most of its great length. This chain extends for 1,000 miles over 14° of latitude from the 49th down to the 35th parallel. Thus the chain traverses regions of the utmost geographic and climatic diversity. It begins near the Canadian boundary, in a region of extremely wet, snowy climate, and terminates at the edge of the Mohave Desert, which is one of the driest and most torrid areas on the North American Continent.

The glacial covering of this chain was very extensive at the north end, where the great height and breadth of the Cascade Range, the enormous quantities of snow supplied by the westerly winds, and the prolonged winters together produced conditions favorable for glaciation. This part of the chain lay fairly smothered under snow and ice and sent forth glaciers 80 to 100 miles long.

South of Mount Rainier, however, the ice mantle contracted rapidly in breadth, mainly as a result of declining altitude. Throughout southern Washington and northern Oregon, where the crestline, not counting the isolated volcanic peaks, rises scarcely above 5,000 feet, the glaciers attained lengths of only a dozen or so miles. Still farther south, throughout the 200-mile stretch of which Crater Lake, Mount Shasta, and Lassen Peak are the dominant landmarks, there was no true ice mantle but only detached glaciers and snowfields that lay in sheltered canyons high up on the main peaks. This dearth of ice—this state of semiaridity—was due not to a further decline in altitude, for the range here again rises to 6,000 and in places even to 8,000 feet, but to deficient snowfall caused by the presence between the Cascade Range and the Pacific Ocean of a large complex of mountains which intercepted a considerable share of the moisture from the westerly winds.

Southward from the canyon of the Feather River, however, in the northern part of the Sierra Nevada, glaciation formed on an increasingly large scale, owing both to greater altitude and to greater snowfall; here the intercepting power of the Coast Ranges diminished with decline in height. In the vicinity of Lake Tahoe, where the Sierra Nevada attains altitudes of more than 9,000 feet, the icefields and ice streams were large enough to coalesce and produce trunk glaciers from 15 to 20 miles in length. And in the stretch from Lake Tahoe to Mount Lyell, in which the crest rises progressively to altitudes of 11,000, 12,000, and 13,000 feet, the snows were so abundant as to mantle the range continuously over a breadth of 20 to 30 miles and to create trunk glaciers 40 to 60 miles long. In short, another climax of glaciation was reached in this central part of the Sierra Nevada—a climax second only to that attained near the Canadian boundary, 800 miles to the north.

From Mount Lyell to Mount Whitney, over a stretch of fully 100 miles, the glacial mantle extended almost undiminished in breadth. It covered all those parts of the High Sierra which are drained by the San Joaquin, Kings, Kaweah, and Kern Rivers and which are crowned by the culminating peaks of the range. A short distance south of Mount Whitney, however, within the boundaries of Sequoia National Park, the 300-mile-long glacial mantle of the Sierra Nevada came abruptly to an end. The glacier system of the upper Kern Basin was the southernmost large system of its kind in the Sierra Nevada. Beyond this system there were only a few small detached ice bodies.

The southern limit of glaciation in the Sierra Nevada was imposed not primarily by latitude—that is, by the southward increase in warmth and consequent rise of the snowline during Pleistocene times—but by the termination of the two lofty mountain ranges that bound the upper Kern Basin, for only these two ranges were high enough to reach above the snowline during glacial times.

The precise extent of the glacial covering of the Sierra Nevada was long a subject of conjecture and dispute, but as a result of the systematic survey of glacial deposits, the margin of the glacial mantle has been definitely mapped, and its position can now be determined tentatively within narrow limits. There is thus no further doubt that the glacial mantle was confined wholly to the upper parts of the Sierra and that at no point did it reach down to, or even near, the western base of the range. In the south-central part of the range, where the glacial mantle was broadest, its western margin descended to altitudes of somewhat less than 5,000 feet. The trunk glaciers, of course, descended to still lower levels, yet even these glaciers fell far short of reaching the foot of the range. The Tuolumne glacier, which was the longest ice stream north of the Yosemite region, attained a maximum length of 60 miles and projected about a dozen miles beyond the margin of the ice mantle that lay on the adjoining uplands. The Tuolumne glacier terminated, however, fully 30 miles from the foot of the range and at an altitude of about 2,000 feet. The Yosemite glacier at the time of maximum glaciation was 37 miles long and projected 7 miles beyond the margin of the ice mantle. The terminus of this glacier lay in the Merced Canyon about 50 miles from the foot of the range and about 2,000 feet above it, just below the site of

El Portal. The San Joaquin glacier was nearly as long as the Tuolumne glacier, but it advanced only a few miles beyond the margin of the ice mantle on the flanking uplands. The San Joaquin glacier halted 45 miles from the mouth of its canyon, at an altitude of about 2,600 feet. The Kings glacier, most southerly of the great glaciers, despite the great altitude of the crest region which it drained, attained a length of only 44 miles (measured along its middle branch) and came to an end about 37 miles from the base of the range at an altitude of 2,500 feet.

The low levels reached by these trunk glaciers seem truly remarkable when it is considered that their lower parts lay wholly in the zone of wastage where, even in the shaded spots, summer heat was sufficient to remove the snows of winter. The Yosemite glacier, for instance, reached more than a mile below the level (somewhat above 8,000 ft) in which glaciers were formed in the Yosemite region. The Tuolumne glacier reached 6,000 feet below this level; the San Joaquin glacier, about 5,300 feet; the Kings glacier, about 6,000 feet. (The level of glacier generation rose gradually southward.)

The ability of these glaciers to reach such low levels in spite of the warmth that prevailed in the zone of wastage affords impressive testimony of the immense surplus of snow and ice that descended from the higher parts of the range. However, these low levels were also due in part to the protection from the sun's rays that was afforded to the glaciers by the high walls of the canyons; to the small surface areas, proportionate to bulk, that the glaciers, 3,000 to more than 4,000 feet in thickness, presented to the melting agencies; and to the relatively rapid movement of the ice, which in the thicker glaciers must have averaged several feet a day.

On its eastern flank also, the Sierra Nevada bore a great array of glaciers, there being a glacier in almost every canyon; but these glaciers were in general much shorter than those on the western flank, owing to the abruptness of the escarpment, the shortness of the canyons, and the small extent of glacier-generating territory at their heads. Most of these glaciers, nevertheless, reached down to the eastern foot of the range; not a few projected well out into the adjoining lowlands, especially in the north-central and south-central parts of the range, where these lowlands have altitudes of 5,000 to nearly 7,000 feet.

The basin of Mono Lake was invaded by no less than six ice tongues, each of which extended several miles out from the range. In the regions south of Mono Lake, the glaciers projected as a rule but little beyond the mouths of their canyons, and along the border of Owens Valley the glaciers were confined mostly to the upper parts of the canyons; still further south there were only scattered snowfields, and the array of ice bodies came to an end.

BASIS FOR DIFFERENTIATION OF THE GLACIAL STAGES

The courses of the ancient glaciers in Sequoia National Park were traced and mapped and their farthest limits were determined by the same method that had proved effective in the San Joaquin Basin and elsewhere, that is, interpretation of the testimony of glacial deposits rather than that of sculptural features; this method consists primarily of a systematic survey of the moraines that were built by the individual glaciers.

In open country such a survey can readily be executed with sufficient accuracy for a reconnaissance map by locating the moraines by eye with respect to identifiable landmarks, of which the landscape of the Sierra Nevada affords a plenty; but in the forested tracts the larger moraines must be actually followed out and, in some places, located by traverse—a laborious and time-consuming process. Fortunately, in Sequoia National Park the forested areas, though of considerable extent, are so amply diversified by topographic and drainage features, as well as by occasional meadows, that a large share of the work could be done by following the moraines, or the swales between moraines, on horseback. In the rougher areas, of course, the mapping had to be done on foot.

In the morainal deposits of Sequoia National Park, as in the areas to the north previously mentioned, abundant and unmistakable evidence was found of two distinct stages of glaciation—a later one, the Wisconsin, and an earlier one, El Portal, separated by a lengthy time interval; meager indications were also found of a third, very early stage, the Glacier Point (Matthes, 1929). Thus the observations on the morainal deposits of these different stages in Sequoia National Park bear out the correctness of the analysis that was made of the moraine systems of the other basins in the Sierra Nevada, and place on a firmer basis the author's interpretation of the succession of the events in the glacial history of the Sierra Nevada. Throughout the central and south-central Sierra Nevada, therefore, the moraine systems of the great trunk glaciers and their numerous branches spell out the same story of three distinct periods of extensive and long-continued glaciation during the Pleistocene Epoch.

The characteristics of the glacial deposits of the three stages found in Sequoia National Park and elsewhere on the west slope of the Sierra Nevada are set forth in the following sections.

WISCONSIN STAGE

The glaciers of the Wisconsin Stage are considered first, because they are most definitely known and were, for the most part, ice tongues confined to individual valleys. Having obtained a definite image of them, the reader can then visualize also the more extensive glaciers and ice fields of the earlier stages, which coalesced over divides and in part moved in disregard of them.

Throughout the Sierra Nevada the moraines of the Wisconsin Stage are, as a rule, well preserved and distinct. Many still retain, only slightly changed, the sharp-crested forms which the glaciers gave them (fig. 20). Much of the finer material has been washed from these moraines, but many boulders that form the crests remain in place, or substantially so. The frontal moraines are commonly breached by the streams, but some of the younger moraines still act as dams impounding lakes. On slopes of low or moderate declivity the lateral moraines are often splendidly developed, extending for long distances as regular embankments broken by only a few stream-cut notches. Though wholly absent on precipitous canyon walls, lateral moraines can usually still be traced along steep slopes by surviving patches of coarse debris or by single boulders.

Particularly useful as diagnostic materials are the boulders of different types of granitic rocks. Such rocks preponderate in the central and southern parts of the Sierra Nevada and make up the bulk of the moraines (figs. 21, 22). In the moraines of Wisconsin age, a large percentage of these granitic boulders are unweathered and unstained. They ring when struck with the hammer, and with fine resilience throw the hammer sharply back; this is true not only of the siliceous types of granite and granodiorite but also of the more basic rocks—the quartz diorite, diorite, and gabbro. Exception must be made, of course, for such boulders as were already weathered when picked up by the glacier.

FIGURE 20.—One of the timbered moraines of the Wisconsin Stage that surround Moraine Lake. Note horse and rider for gaging size. The meadow, which is below Moraine Lake, occupies a strip of level swampy land formed by the gradual filling of a lakelet that lay between the moraine in view and the next one to the right. Granite sand continues to be washed down from the flanking moraines, but the meadow is still too wet for the growth of lodgepole pines. A few seedlings are beginning to invade it.

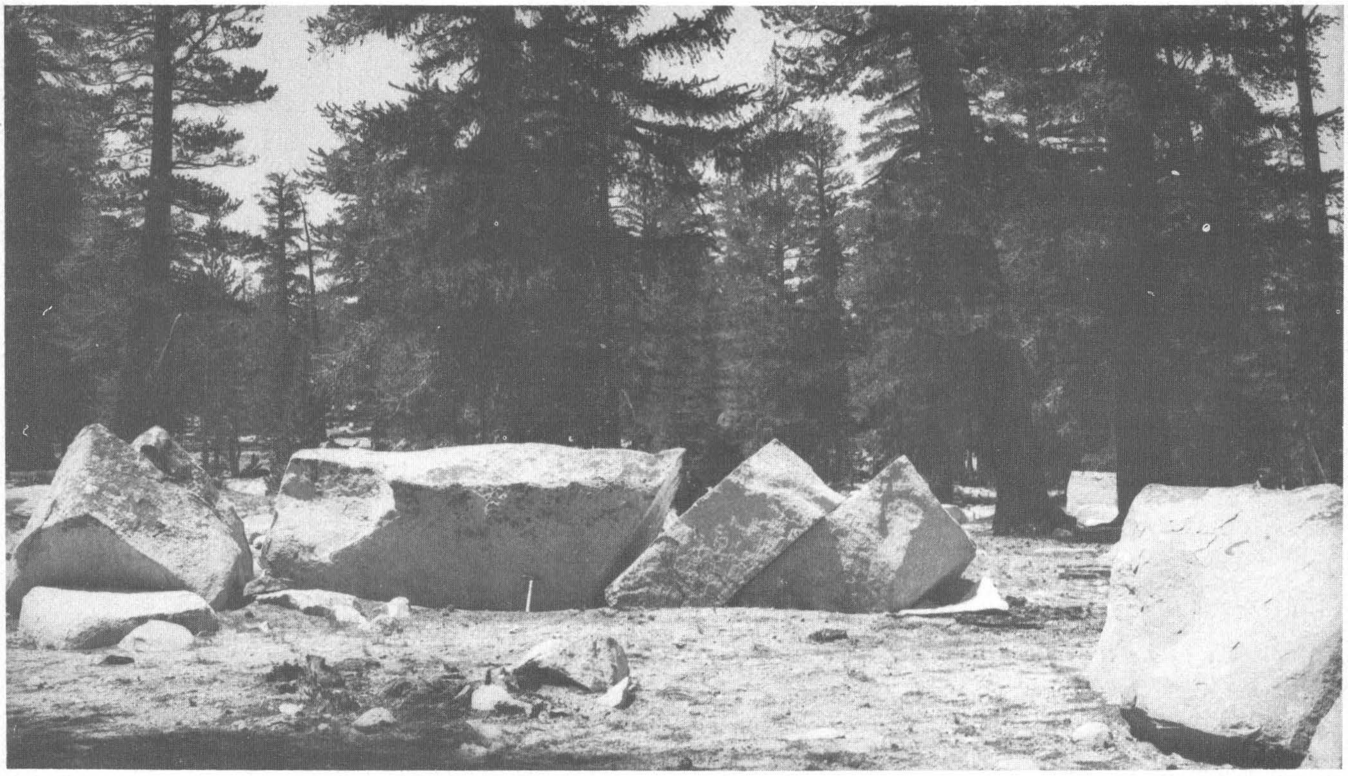


FIGURE 21.—A frost-split block of granite on one of the Wisconsin moraines that encircle Moraine Lake. Measurement of the pieces shows that originally the block was 23 feet long. It has fallen apart as a result of the force exerted by water freezing in incipient joints.

The glacial deposits of Wisconsin age are associated with smoothed and polished floors, walls, roches moutonnées, and ledges of rock in place (figs. 23, 24, 25). These surfaces are most extentive in the areas of sparsely jointed siliceous granite, and surfaces that were glaciated during the later substages of the Wisconsin naturally are more perfectly preserved than those that were glaciated during the earlier substages. From the latter surfaces, usually, most of the polish has already flaked off, but the extent to which it has disappeared depends also in some measure on the character of the rocks, the acid types retaining the polish longer than the basic ones. Whether still polished or not, however, all rock surfaces planed down by the Wisconsin ice still exhibit today the smoothed forms that are well known to be characteristic products of glacial abrasion. The actual reduction effected by weathering ranges from virtually none to as much as 2 inches.

The signs of recency in the Wisconsin moraines, whether preservation of ridge forms or freshness of boulders, are likewise somewhat more accentuated in the later than in the earlier Wisconsin deposits. In the somewhat more subdued moraines of the earlier substages, although the acidic rocks are still generally sound and hard, an increasing percentage of the basic rocks are cracked or split along joint planes, and some of these rocks are so badly disintegrated that they crumble in the hand. However, there is no need in this study to differentiate between substages of the Wisconsin Stage. The Tahoe and Tioga glaciations, which have been distinguished on the east slope of the Sierra Nevada and regarded as stages of early and late Wisconsin age, respectively (Blackwelder, 1931), are now realized to be two distinct stages in the Sierra Nevada.

Correlation of the last stage of Pleistocene glaciation in the Sierra Nevada with the Wisconsin Stage of the Laurentide glaciation was based initially on the comparable degree of preservation of their respective morainal deposits and on the largely unweathered state of the boulders in them. But there is additional warrant for the correlation in the fact reported by Alden (1932) that in northern Montana, where the Keewatin drift of Wisconsin age overlaps the moraines of the last Cordilleran glaciation, both deposits have about the same degree of freshness. There can be no doubt, on the strength of this evidence, that the last Pleistocene glaciation of the Rockies and the last Pleistocene glaciation of the adjoining plains were contemporaneous. It is assumed, further, that the last Pleistocene glaciation of the Sierra Nevada occurred at about the same time as

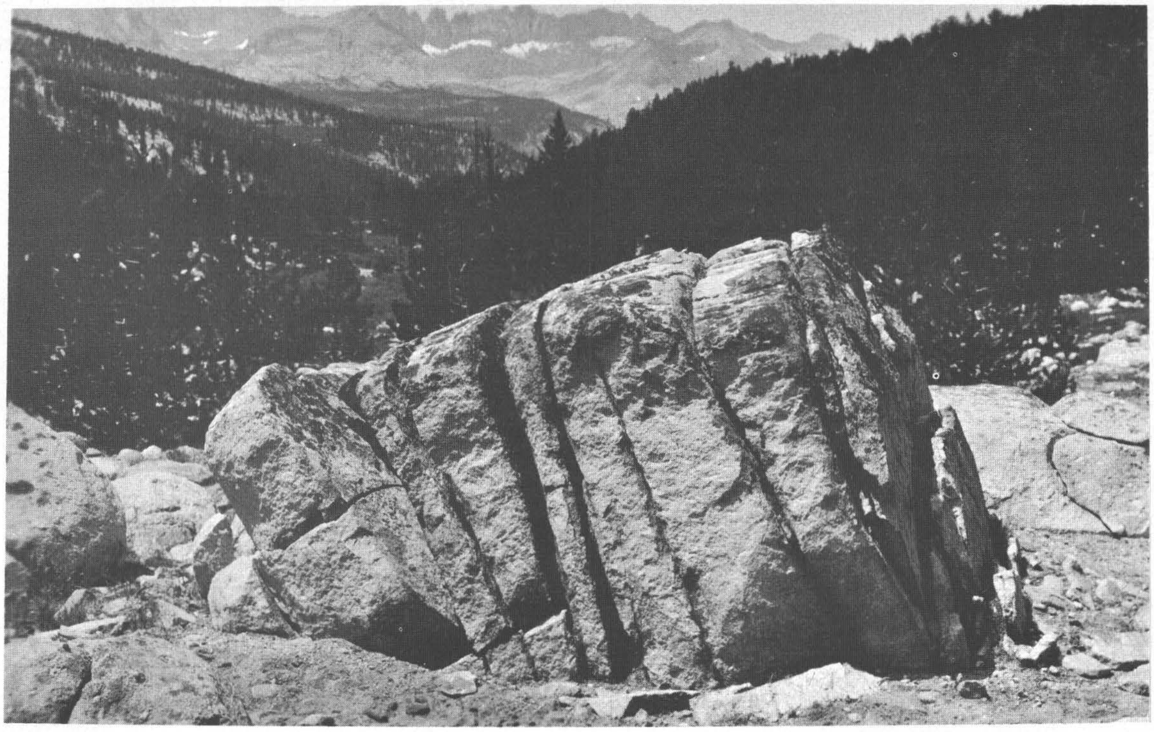


FIGURE 22.—Disrupted glacial boulder in Wallace Canyon. The boulder, when intact, measured 8 feet wide and 5 feet high and doubtless was in one piece when deposited by the glacier toward the end of the Wisconsin Stage. Opening of the originally tight joints in the granite by the freezing of infiltrated water has resolved the boulder into a series of parallel slabs.

that of the Rockies; though incontrovertible proof of this synchronism is lacking, there is at present no known reason for thinking otherwise.

EL PORTAL STAGE

The ill-defined round-backed moraines of El Portal Stage stand in striking contrast with the distinct sharp-crested moraines of the Wisconsin Stage in the Sierra Nevada. Disintegration of the boulders in El Portal moraines has continued for so long a time as to destroy completely the original crests. It has resulted also in mantling these older moraines with considerable arkose sand that gives them a smoother and less bouldery appearance than the Wisconsin moraines usually have. Although far more bulky, El Portal moraines are relatively obscure features that may easily be overlooked by an untrained observer of the landscape.

To identify these obscure moraines beyond possible doubt, their constituent materials must usually be sought in gullies, roadcuts, trailcuts, or holes left by uprooted trees. Although gullies are ordinarily plentiful, the author was obliged more than once to rely wholly on the evidence furnished by uprooted trees. Fortunately, some of these trees held boulders and cobbles aloft in their exposed roots, as if for the convenience of the geologist. Almost invariably such boulders and cobbles are light buff or yellowish because of their limonite coating. The entire deposit of which they form part is commonly of the same yellowish hue, in contrast to the morainal material of Wisconsin age, which is mostly gray. The coating on the boulders and cobbles generally masks their lithologic character and makes many of the granitic rocks indistinguishable. When broken open, the boulders and cobbles are usually found to be stained by ferric oxides to a depth of one-fourth to one-half inch.

The boulders composed of the more siliceous granites are as a rule still firm, but they have lost so much of their resilience that the hammer bounces back only feebly from them. Many break readily; some even crumble into discrete granules. The granodiorite and quartz diorite boulders usually have still less coherence, and the diorite and gabbro rocks are so weak that they are smashed to bits by a light blow. These boulders are often traversed by ramifying cracks; some are in a crumbling stage. These characteristics vary, of course, with the prevailing moisture conditions in the deposits. In well-drained locations, decomposition and disintegration make much slower progress than in poorly drained ones. On strongly isolated platforms of bare

FIGURE 23.—Glacier polish, striae, and grooves, above the head of Kern Canyon. The rock is aplite, which weathers more slowly than the coarser granite and therefore holds its glacial markings longer. Since being glaciated, the aplite has been somewhat disrupted into angular blocks by repeated frost action.

rock, which dry out quickly, scattered cobbles and boulders are apt to be surprisingly well preserved (figs. 26, 27). Boulders on top of the moraines, exposed to the heat of the sun and therefore drying quickly after a wetting, generally have some cohesive strength left, but those in the interior of the moraines are as a rule so weak that the picks of the road workers cut right through them. In some roadcuts such boulders, cut flush with the wall, appear outlined as rusty rings.

Terminal moraines of El Portal Stage are generally wanting in the main canyons of the west slope of the Sierra Nevada. Their absence can hardly be attributed to complete destruction by stream-and-weather erosion after El Portal time, for in some of the canyons the topography is decidedly favorable to the preservation of at least the wings of such moraine. A more probable explanation is that the trunk glaciers of El Portal Stage built either no terminal moraines at all or else only very small ones, because the ice fronts rested for no considerable length of time at any point during the maximal phases. Whatever the explanation, the farthest limits reached by the trunk glaciers of El Portal Stage cannot, as a rule, be determined with any great accuracy because of the lack of terminal moraines.

The lateral moraines left by the glaciers of El Portal Stage, on the other hand, are generally of massive proportions that dwarf the corresponding laterals of the Wisconsin Stage. Though gashed or even transected by gullies, and though in some places almost destroyed, they are nevertheless not difficult to trace, once they have been identified. It is, indeed, by the systematic mapping of these old lateral moraines that the courses of the glaciers of El Portal time are most surely traced.

It may appropriately be added that for polished and striated rock surfaces dating from El Portal Stage one need not search. The glistening floors, walls, ledges, and roches moutonnées that are so abundant and so impressive in some parts of the Sierra Nevada, as already noted, all date from the Wisconsin Stage—mostly from its later substages. The rocks surfaces that were planed by El Portal ice have long since been destroyed and changed beyond recognition by the granular disintegration, scaling, or spalling of the rocks

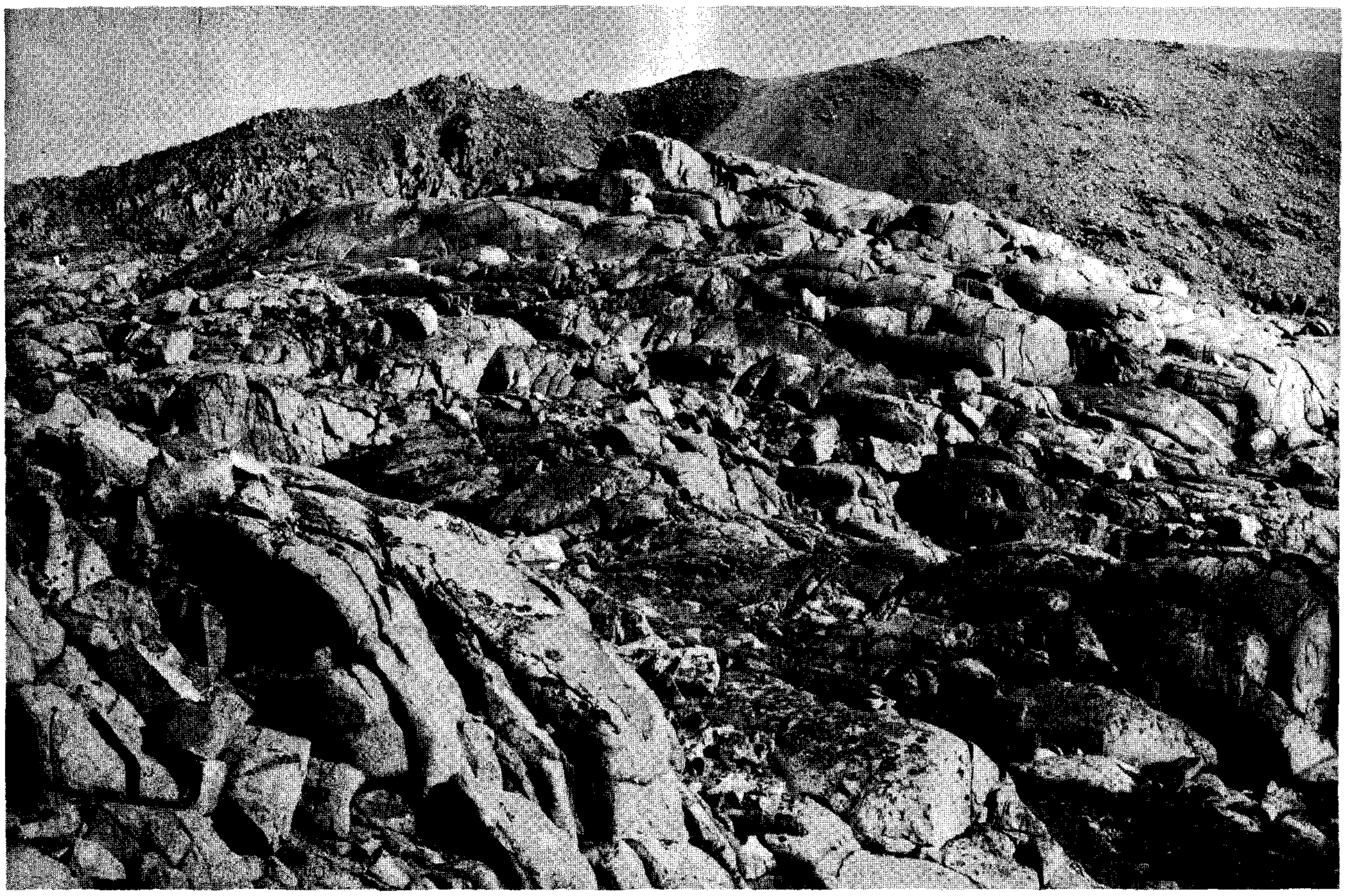


FIGURE 24.—Fantastic rock forms in the upper Kern Basin, near Lake South America. The forms were produced by glacial quarrying of joint blocks followed by abrasion and rounding of the resultant angular forms. The direction of ice movement was diagonally toward the right and away from the camera. Many blocks that were firmly attached when the glacier passed over them have since been split or loosened by postglacial frost action.

(figs. 28, 29). In many places the granitic rocks appear to have been stripped of disintegration products to depths of 10 to 12 feet. Approximate measurements of such stripping are afforded by residual rock pedestals supporting perched glacial boulders and by dikes of slow-weathering aplite that remain standing in high relief (Matthes, 1930, p. 70–74; 1950a, fig. 51; 1950b, p. 101–102; 1960, fig. 32). Several other types of criteria suggest themselves, notably the depth of stream channeling accomplished since El Portal and Wisconsin climaxes, respectively, and the erosional changes produced in valleys and other landforms; but these criteria generally furnish no more definite measures for comparison than the pedestals and dikes.

This marked difference in the depth of disintegration and stripping of the granite since El Portal Stage and since the Wisconsin Stage affords a good index of the relative antiquity of those two stages of glaciation. If the time since the climax of the Wisconsin Stage is to be measured in tens of thousands of years, then surely the time since the climax of El Portal Stage is to be reckoned in hundreds of thousands of years. Mainly for that reason the author holds that El Portal and its probable correlative on the east side of the Sierra Nevada, the Sherwin Stage (Blackwater, 1931), are not younger than the Illinoian Stage of the continental glaciation and may include deposits of two or more unseparated stages, perhaps both the Illinoian and Kansan (Matthes, 1933, p. 33).

GLACIER POINT STAGE

The earliest glaciation that has been recognized on the west slope of the Sierra Nevada, the Glacier Point Stage, which presumably corresponds to Blackwelder's McGee Stage on the east flank (Blackwelder, 1931), is indicated by morainal deposits in only a few localities in the range. Two circumstances account for the scarcity of these deposits: (1) Their obliteration over large areas by the extensive and voluminous deposits of El Portal Stage, and (2) their vestigial character, their constituent materials having in large part disintegrated and been carried away.

FIGURE 25.—View across the glaciated floor of Whitney Canyon, showing combined effects of quarrying and grinding. The glacier moved from left to right, approximately parallel to a set of vertical joints in the granite. Horizontal joints enabled the glacier to quarry out long slabs, but this quarrying proceeded slowly because of the scarcity of vertical cross joints. As a consequence, the glacier could grind and round off many of the slabs before tearing them out.

The few small deposits which the author has shown on his maps as probably belonging to the Glacier Point Stage lie, in most places, at levels 200 to 300 feet above the upper limit of the massive El Portal moraines, where they clearly have escaped obliteration. Their positions at those high levels, however, do not necessarily indicate that the ice streams of the Glacier Point Stage attained greater depth in the canyons than did the ice streams of El Portal Stage; for it stands to reason that during Glacier Point time the canyons were not yet cut to the depth which they later attained in El Portal time. A given quantity of ice would have filled them to a higher level in Glacier Point time than it would have in El Portal time.

Some of the deposits of the Glacier Point Stage lie far out on the uplands flanking the canyons, and thus show that the ice of that stage overflowed the canyon rims, whereas the moraines of El Portal Stage show that the glaciers of that stage remained largely confined within the canyons. But that fact, too, is very probably explained by the circumstance that in Glacier Point time the canyons had smaller cross-sectional areas, and therefore less capacity for holding ice, than they had later in El Portal time.

In contrast to the massive El Portal moraines, the deposits of the Glacier Point Stage have but meager volume and a decidedly depleted aspect. They are reduced for the most part to skeletonlike rows of erratic boulders composed of resistant quartzite and highly siliceous granite, the rest of the constituent materials having vanished. In some places the deposits are entirely destroyed. The weaker rocks, such as the diorites, are represented as a rule only by a chance fragment here or there. Many of the siliceous boulders, even, have lost their glacial contours as the result of spalling, exfoliation, or granular disintegration; some have been reduced to strangely cavernous or basined forms. The fact that the morainal materials have been transplanted can be established only on lithologic grounds and by a knowledge of their provenance. Needless to add, it requires a trained eye to identify such scanty, vestigial deposits; and to know where to look

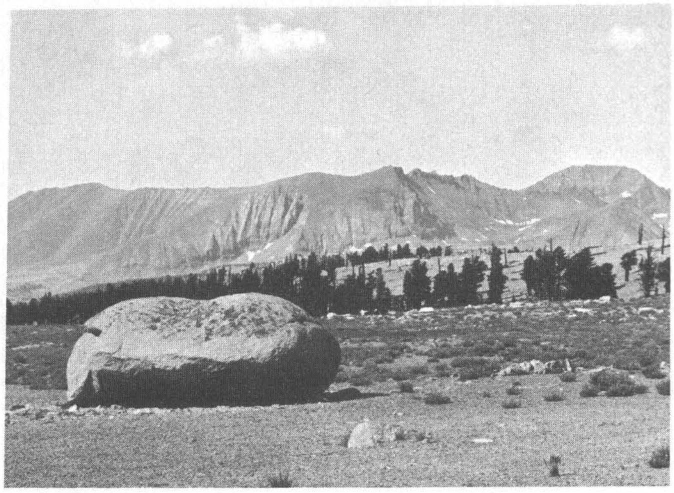


FIGURE 26.—A 16-foot erratic left on Bighorn Plateau by the ice of El Portal Stage. No continuous moraine exists here, only scattered ice-borne boulders. Many boulders are in process of breaking up; others have already disintegrated into granite sand. The fragments at the base of the large boulders are spalls split from it by frost action.

for them, one must have some conception of the extent of the earlier ice in the Sierra Nevada and also a knowledge of the habits of glaciers and the manner in which they adjust their movements to different types of topography.

That the moraines of the Glacier Point Stage are much older than the moraines of El Portal Stage is readily evident from the foregoing. Even if it be granted that the relative scantiness of the Glacier Point deposits may be due to the shorter duration of the Glacier Point Stage as compared with El Portal, it is manifest from the more advanced state of disintegration of the boulders in the Glacier Point moraines that the Glacier Point Stage preceded El Portal Stage by a considerable length of time. The Glacier Point Stage clearly is to be assigned to the early Pleistocene, and some argument may even be found for correlation with the Nebraskan, for the Glacier Point is the earliest stage of glaciation of which any recognizable deposits remain in the Sierra Nevada (Matthes, 1933, p. 33).

GLACIATION OF THE KAWEAH BASIN: KAWEAH GLACIER SYSTEM

In both the Wisconsin and El Portal Stages of the Pleistocene, the numerous converging canyons of the Kaweah Basin became pathways for cascading ice streams. However, inasmuch as even the larger of these streams attained lengths of only 10 miles, they fell short by many miles of uniting into a single Kaweah Basin glacier system or of forming a major trunk glacier comparable to the ones in the main drainage basins to the

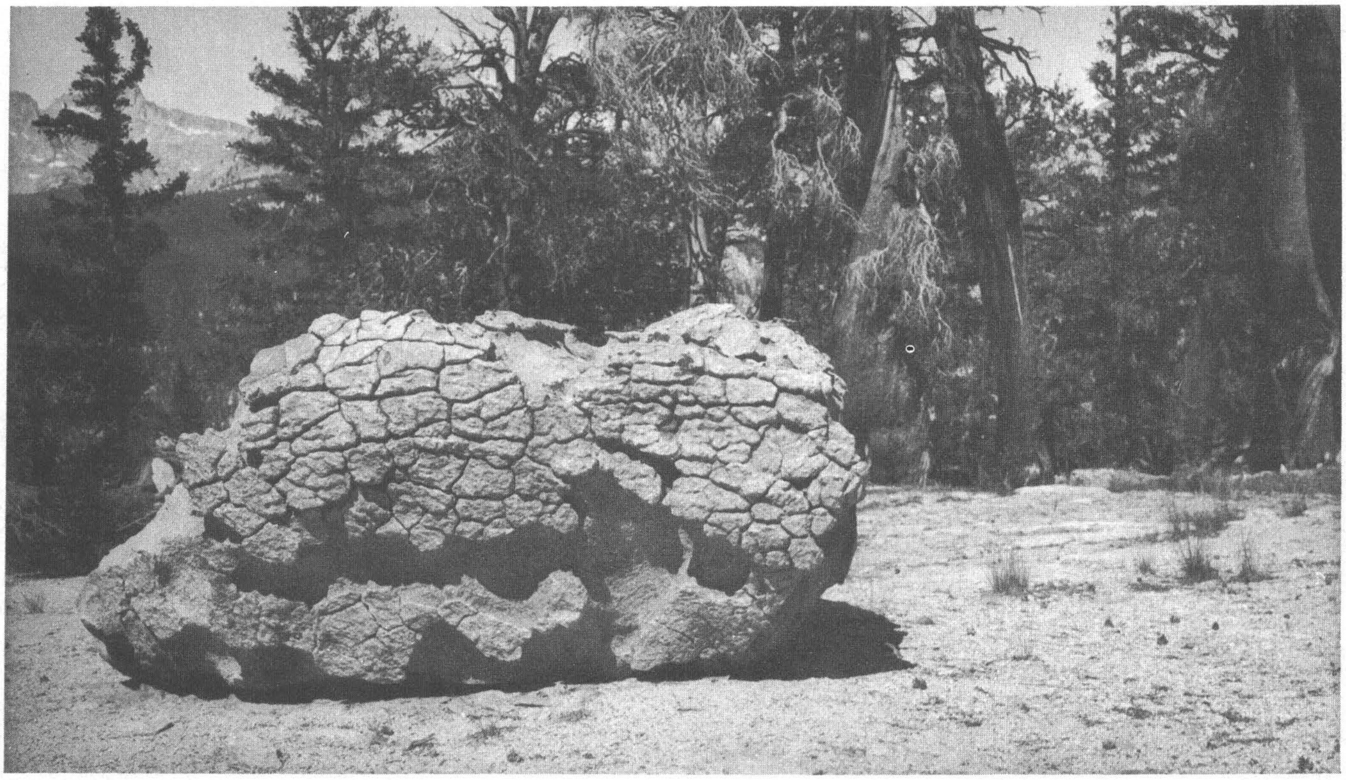


FIGURE 27.—Glacial boulder of El Portal Stage resting on a platform overlooking the Big Arroyo. Weathering has produced a bread-crust effect on the sides and weather pits 6 to 15 inches deep on the top surface.

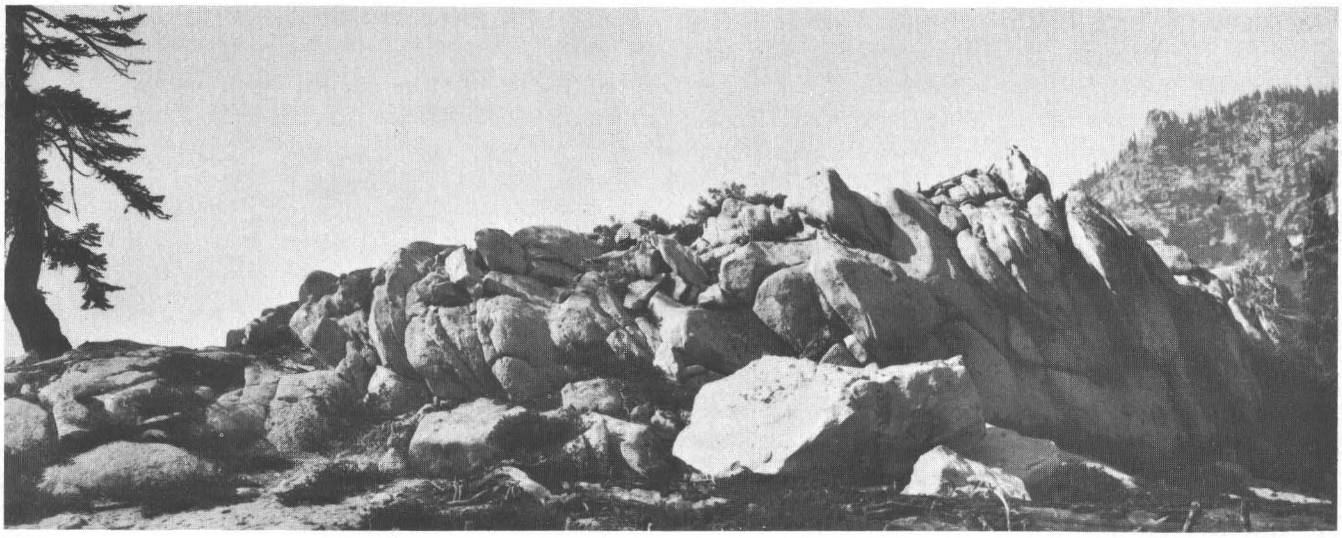


FIGURE 28.—Glaciated knob at the head of South Fork, Kaweah River. This knob was overridden by the earlier glaciers but not by those of the Wisconsin Stage, as is evident from the relative position of the older and younger moraines nearby. During the long period since it was glaciated, the knob weathered into jagged forms. Infiltration of water doubtless has been facilitated by the high angle of the jointed fractures, and, as a consequence, disruption by frost has been particularly vigorous.

FIGURE 29.—Saddle east of Tower Rock, on the east rim of Kern Canyon. This saddle was invaded by the Kern glacier of El Portal Stage. The crags and boulder in this view, which are 10 to 20 feet high, give evidence of the post-El Portal weathering that here has destroyed all traces of glaciation.

north and in the Kern Basin to the east. Because only the ice streams of adjacent tributary canyons united, there formed, instead, a series of separate glacier systems of relatively small extent—one or more in the headward areas of each of the main branches of the Kaweah Basin: the Marble Fork, the Middle Fork, the East Fork, and the South Fork. These were branching glaciers that only locally, in their upper reaches, overswept the divides; elsewhere they were confined to the canyons, which were filled only in part.

The lower limits of the Wisconsin glaciers are clearly marked, for the most part, by distinct moraines, and these indicate that the termini of the principal ice streams reached altitudes as low as 5,200 to 8,200 feet. The exact extent of El Portal glaciers is unknown and may never be known, for terminal moraines are lacking, and the lateral moraines are partly concealed by dense chaparral on the lower slopes of the canyons. However, the approximate lower limits of glaciation can be inferred from the available evidence, and, for the principal ice streams, they lay at altitudes of 4,550 to 6,500 feet—marking limits which were considerably lower, therefore, than the corresponding ones of the Wisconsin glaciation.

The limited development of the Pleistocene glaciers of the Kaweah Basin is not surprising, since this basin heads not along the main Sierra crest, as do the adjacent Kings and Kern Basins, but rather along secondary ridges 12 or more miles farther to the west—that is, this basin extends only part way up the Sierra west slope. To be sure, at the east edge of the Kaweah Basin the glacial sources lay along the bold Great Western Divide, whose peaks have altitudes of 11,000 to over 12,500 feet, not greatly inferior to those of the main crest. But elsewhere the glacial sources of the Kaweah Basin lay along secondary ridges which branch off from the Great Western Divide and are, for the most part, much lower. One of these ridges, which includes a segment called Silliman crest, extends northwestward from Triple Divide Peak and forms a part of the northeast rim of the Kaweah Basin. From this ridge, at altitudes of 10,000 to 11,600 feet, several ice streams descended into the northeasterly part of the Kaweah Basin. Another ridge, winding southwestward and southward from Florence Peak, forms the east rim of the South Fork Basin. Though for the most part only 9,000 to 11,500 feet in altitude, this ridge also gave rise to glaciers, and these descended into the canyons of the East Fork and the South Fork.

Only in the lower Kaweah Canyon were deposits found which appear to represent the earliest, or Glacier Point, stage of glaciation. Location of these deposits is not shown on plate 1 but is indicated on page A30. The deposits, being outwash materials laid down a considerable distance beyond the termini of the glaciers, give little beyond a suggestion concerning the nature and extent of this ancient glaciation in the Kaweah Basin.

MARBLE FORK
WISCONSIN STAGE

The Marble Fork glacier was one of the principal ice masses in the Kaweah Basin, reaching a length of over 9 miles and extending down Kaweah Canyon to an altitude of about 5,350 feet. The trunk glacier, in the canyon, was fed by several short tributaries from the south, which originated at altitudes of 10,000 to more than 11,000 feet on the upland bearing Alta Peak (fig. 30), and by several considerably longer tributaries from the northeast, which originated on the ridge which bears the Tableland (11,000–11,600 ft) and Silliman Crest (10,000–11,200 ft). Because of the disparity in size between the southern and northern tributaries, the glacier system as a whole had an asymmetrical pattern. The northern tributaries were confluent, across a few low places on the divide, with the heads of the Kings River glacier system; and southeast of Table Meadows an icefield 2½ miles wide connected the Marble Fork glacier with the Buck Canyon glacier, a member of the Middle Kaweah glacier system.

The valleys of Silliman Creek and Clover Creek also contained glaciers, but because these were shallow ice bodies only 2½ and 3 miles long, respectively, they did not join the trunk glacier.

Wisconsin moraine plasters the slopes along the road connecting Giant Forest and Lodge Pole and across the valley from this road. In upper Silliman Creek valley, massive embankments of Wisconsin moraine lie on both sides of the creek, and a high steep-fronted moraine that flanks the lower edge of Cahoon Meadow is trenched by the creek. In Clover Creek valley also, the main loop of Wisconsin moraine is complete, extending back as far as the mouth of the unglaciated West Fork.

The effects of vigorous glacial erosion in predominantly massive exfoliating granite are strikingly shown both in the clean-swept area extending from Tokopah Valley to the Tableland and in the vicinity of picturesque Heather, Pear, and Emerald Lakes, which lie in compound cirques. These lakes are typical tarns and are held in by barriers of massive granite. In places on the cirque walls back of these lakes the upper limit of glaciation is very plain; sheer cliffs of frost-shattered granite come down to the smoothly sloping platform that was abraded by the moving ice. The bowl of the cirque is very imperfect because of the many ledges of massive granite that could not be eroded away. The

FIGURE 30.—Alta Peak (11,211 ft). The summit is composed of frost-shattered remnants of exfoliation shells. Formerly the shells extended toward the left in a descending curve outlining a dome, but the excavation of a cirque by a small glacier has pared away the north side of the dome, thereby giving the summit the unsymmetrical profile seen in this view. The upper part of the cirque wall, which is several hundred feet high, is visible in the lower left corner.

rocks have been rounded and smoothed to pillowlike forms. Aster Lake, the small tarn below Emerald Lake, provides a good example of selective quarrying, being itself encased between masses of solid, very sparsely jointed granite.

The little valley southwest of Heather Lake held a small glacier that did not quite join the master glacier in Tokopah Valley. This valley heads in a poorly shaped cirque which may be described as a veritable glacial quarry. There the glacier left enormous quantities of quarried blocks in a terrific jumble, gleaming white among the forest trees.

EL PORTAL STAGE

The Marble Fork glacier in El Portal Stage was over 10 miles long and 25 miles square, and it reached down Kaweah Canyon to an altitude of 5,350 feet. It was joined, far downstream, by its major affluents, the Silliman Creek and Clover Creek glaciers. That these glaciers were confluent with the trunk glacier in El Portal Stage is indicated by remnants of older drift scattered over the lower slopes of both valleys.

The road from Giant Forest to Lodge Pole crosses the fairly heavy and bouldery left lateral El Portal moraine near the Wolverton Creek bridge; on the north side of the valley, in the vicinity of Willow Meadow, the J. O. Pass Trail crosses the right lateral moraine. Inasmuch as Willow Meadow lies among older moraines, some of them fairly prominent, it is evident that this divide was overswept by the earlier ice.

Seven miles below the terminus of the Marble Canyon glacier—that is, about half a mile above Ash Mountain headquarters—a deposit of material interpreted as bouldery outwash of El Portal Stage is revealed in a roadcut on the Generals Highway (Matthes, 1950a, p. 52).[2] (See fig. 31.) This material is believed to have been washed down from El Portal glaciers in the upper canyons, probably not only those in the Marble Fork but also those in the Middle Fork. The material was deposited in the streambed but, as a result of continued trenching by the river, it is now about 100 feet up the canyon side. Evidently this deposit is of considerable

[2] The above is apparently Matthes' only reference to this deposit. No mention of it appears in his field notes. F. F.

FIGURE 31.—Outwash of El Portal Stage, revealed in a roadcut on the Generals Highway, about half a mile above Ash Mountain Headquarters.

age, for all the boulders have rusty surfaces, some of them are partly decomposed, and the interstitial sand is stained reddish brown by iron oxide.

GLACIER POINT STAGE [3]

In the lower Kaweah Canyon, considerable masses of material, presumably outwash of the Glacier Point Stage, remain. (See fig. 32.) These masses occur as inconspicuous terraces on the side of the canyon about 200 feet above the river bed, and they are exposed in several roadcuts along the Generals Highway.

The great antiquity of these deposits is evident from the fact that all the boulders except the surface ones are completely decomposed and can be cut through like so much granite sand. In making these roadcuts, no blasting or crowbar work was necessary; a Civilian Conservation Corp crew with picks and spades cut with ease through the decayed boulders and the interstitial sand and shaved them back to a uniform, smooth slope. Rainwater rills have since carved little furrows in that slope, trenching both the boulders and the matrix around them to equal depth. Paradoxical as it may seem, the tops of the uppermost boulders, which project slightly above the surface of the deposit, still remain firm and would require a blow with a sledge hammer to be broken. They survive in the form of convex caps because they are in well-drained positions and are frequently exposed to the drying rays of the sun.

[3] Information in this section is taken from Matthes (1950a, p. 53) and from a letter that Matthes wrote to Robert W. Sayles dated November 29, 1940. The letter in one place refers to the deposits as "till," but this was evidently a slip, for they are otherwise termed "outwash." Location of these deposits is not shown on Matthes' maps, nor is there reference to them in his field notes. F. F.

MIDDLE FORK

During both the earlier and the later glacial stages, the converging valleys at the head of the Middle Fork Canyon were occupied by ice streams that attained sufficient length to unite into a short trunk glacier in the main canyon, below Redwood Meadow. (See fig. 33.) The glaciers of both stages were confined to their respective canyons, nowhere overflowing onto the higher parts of the intervening divides. The largest

FIGURE 32.—Glacial outwash, dating perhaps from the Glacier Point Stage, exposed in a roadcut on the Generals Highway above Camp Potwisha. This material was brought down by the Kaweah River from the glacier at its head and now forms an inconspicuous terrace on the side of the canyon, about 200 feet above the riverbed. Photograph by J. C. Patten.

FIGURE 33.—View up "River Valley," the glaciated upper canyon of Middle Fork, Kaweah River. Cliffs in the foreground show exfoliation.

ice streams, those of the Middle Fork proper and of Cliff Creek, attained lengths of approximately 10 miles in the earlier stage and 9 miles in the later stage. The principal sources of ice lay to the east, in cirques on the Great Western Divide; however, several other sources lay on the secondary divides to the north and south. In the earlier stage, the lowest altitude reached by the trunk glacier, in Middle Fork Canyon, was about 4,800 feet; in the later stage, about 5,200 feet.

Moraines deposited by the earlier Middle Fork glacier system are found in the vicinity of Redwood Meadow, which is in the triangular area between Middle Fork Creek and Cliff Fork Creek. The grove of Big Trees which gives the name to this meadow stands mainly on older drift, and old moraines also enclose the grove on both sides. A second grove, about a mile farther up Cliff Creek on the north side of the stream, stands partly on older moraine and partly above its limits.

Wisconsin moraines are also conspicuous in the vicinity of Redwood Meadow. The trail from Redwood Meadow to Little Bearpaw Meadow crosses the left lateral moraine of Middle Fork glacier. Farther to the southeast is the right lateral moraine of the Cliff Creek glacier. Big Trees stand on both of these ridges.

In Middle Fork valley, which is littered with Wisconsin morainal debris, the trail from Little Bearpaw Meadow descends through the depression back of the right lateral moraine, a ridge about 100 feet high. The trail crosses the moraine by way of a gap cut by the stream flowing from the meadow. Southwest of the gap, the moraine is less prominent. On the opposite side of the valley, the Wisconsin moraines have a distinct upper limit, above which are smooth mountain slopes densely covered with brush. In this section of the valley, glacial outwash forms terraces about 50 feet high on both sides of the Middle Fork.

The Hamilton Lakes locality, in the upper reaches of the Middle Fork Basin, impressively illustrates the erosional effects of glaciation and concomitant snow avalanching (fig. 34, frontispiece). The large lower lake (altitude 8,300 ft)—occupying a rock bowl with a smooth glaciated lip, clearly visible under the water—marks the place of confluence of glacial tributaries that issued from three cirques lying 1,700 to 2,000 feet higher. These tributaries excavated the lake basin in what is really a canyon step. Northwest of the lake, massive granite, cleft by nearly vertical joints, has been sculptured into pinnacles somewhat El Capitan-like in aspect, but more complex (fig. 35). In the vicinity of this lake, the effects of snow avalanches are evident on every hand. One avalanche chute northeast of the lake outlet has not only an avalanche cone beneath it but also a dump in the lake, visible from the trail above.

In the valley of Cliff Creek, terraces of glacial outwash 50 to 60 feet high occur near the junction with Timber Gap Creek. The trail enters the valley of

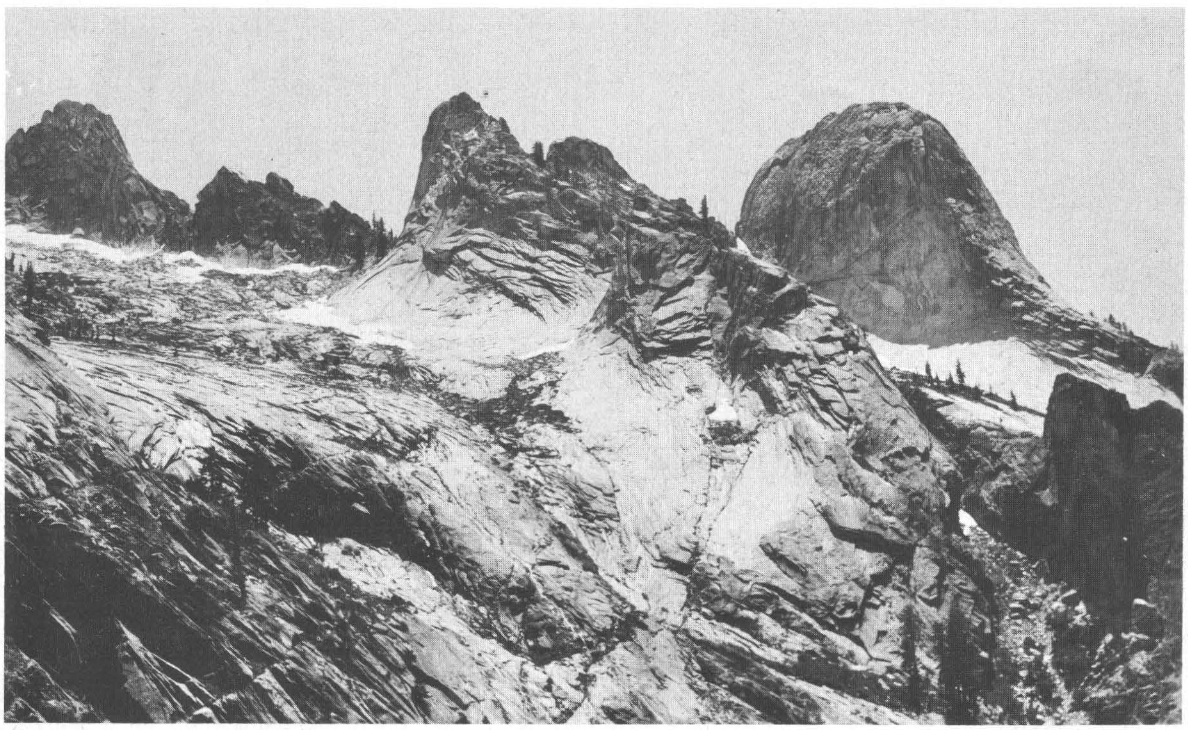


FIGURE 34.—Spectacular summits south of Hamilton Lakes. They have been produced by glacial sculpturing in massive exfoliating granite.

FIGURE 35.—View from near the source of Hamilton Creek, down the canyon across one of the Hamilton Lakes. Massive granite forms the impressive cliffs at the right and the rock barrier across which the lake has its outlet. In the center of the picture on the distant mountain, is a well-formed avalanche chute. Photograph by W. L. Huber.

Timber Gap Creek by climbing steeply over a gigantic moraine. Through this ridge the creek has cut a narrow gulch with steep bouldery sides.

In addition to the main glacier system, independent ice bodies of small size developed in the Middle Fork Basin during both glacial stages. On the north side of the basin, glaciers formed in upper Mehrten Creek Valley, Buck Canyon, and the two intervening valleys. On the south side of the basin, a single small glacier formed in the valley of Little Sand Meadow.

At the head of Mehrten Creek, southwest of Alta Peak, Wisconsin glaciation is recorded by an imperfect cirque containing a small quantity of jumbled morainal material. On the slopes below this cirque, along the Sevenmile Hill trail, are scattered morainal materials of the earlier glaciation.

In the adjacent valley, which contains Alta Meadow, the glacial record is much clearer. Here, at the lower margin of another shallow cirque, lie at least three Wisconsin moraines. They are composed of angular rock blocks, and each morainal loop protects a sloping shelf on its upslope side. Below these moraines, deposits of the earlier stage extend far down the mountainside. The High Sierra Trail crosses the older moraines, which are cut by a steep-sided gulch.

Alta Peak, the summit which bore these glaciers, has a highly asymmetric profile, its northern slopes having been vigorously glaciated and its southern slopes only mildly so (fig. 30).

A considerably larger glacier occupied Buck Canyon during both glaciations. As previously noted, the broad icefield at the head of this glacier was confluent with the Marble Fork glacier system. In the earlier stage, the ice descended the canyon a distance of 5 miles, to an altitude of 5,600 feet. The tapering ice tongue of this glacier was joined by a tributary, more than 3 miles long, that originated in a cirque northeast of Alta Peak. In the later stage, the Buck Canyon glacier was somewhat shorter, and its terminus reached only to 6,000 feet. The tributary from northwest of Alta Peak was then only 1½ miles long and therefore remained a separate glacier. The High Sierra Trail, from Giant Forest to Bearpaw Meadow, crosses Buck Creek and ascends the Wisconsin left lateral moraine deposited by the Buck

Canyon glacier—a fairly sharp moraine—and then traverses older moraines plastered against the valley-side. The latter moraines, however, do not reach to the top of the ridge between Buck Canyon and the valley of the Middle Fork.

EAST FORK

Glaciation occurred during both the Wisconsin and the El Portal Stages of the Pleistocene in the upper basin of the East Fork, not only in the main valley itself (in the Mineral King region, outside of Sequoia National Park) but also in the large tributary valley of Horse Creek.

The main valley held a many-branched glacier which, in the earlier stage, was almost 10 miles long and descended to 4,950 feet and, in the later stage, was 6 miles long and descended to 6,850 feet. The trunk glacier was fed by long, narrow tributaries, some originating at the east, in cirques on the Great Western Divide, but most originating at the south, on the secondary ridge extending westward from Florence Peak on the Great Western Divide. In the asymmetary of its pattern, the glacier system of the East Fork somewhat resembled that of the Marble Fork, with the obvious difference that the principal sources of the East Fork were on the south side of the basin instead of on the north. Indeed, the amount of ice contributed to the East Fork glacier system from the north was negligible.

During the Wisconsin Stage the most westerly tributaries of the East Fork glacier system remained as small independent glaciers. Two of these were in the upper valleys of Deer Creek.

Older moraines of the East Fork glacier occur along the road which ascends the north side of the valley. They begin at a point about 1 mile east of Silver City and continue eastward for a distance of more than 2 miles. The road enters Wisconsin deposits near the junction of the Mosquito Lakes outlet with the East Fork, and bouldery moraines of this age continue upstream to the bend of the river near Mineral King. In places these moraines have been trenched by the river. The absence of conspicuous moraines in some of the upper tributary valleys, as in the vicinity of Farewell Gap, may be attributed to two circumstances: the small size of the rock fragments derived from the metamorphic rocks which prevail here, and the changes wrought by periodic snowslides. The trail to Eagle Lake climbs a fairly smooth slope of moraine consisting mostly of small fragments and slabs of metamorphic rocks and only a scattering of granitic boulders. This entire valley appears to be sheathed with such materials.

The earlier Horse Creek glacier was about 6½ miles long and descended to 5,700 feet; the later one was about 5 miles long and descended to 6,650 feet. Most of the ice came from broad, shallow cirques to the northeast and east, but in the earlier stage, ice from the valley of Whitman Creek spilled over the north edge of the Hockett Meadows northwest of the Hockett Ranger Station, cascaded down the slope several thousand feet, and, 5 miles from its source, joined the Horse Creek glacier. In the Wisconsin Stage the Whitman Creek glacier fell just short of uniting with the Horse Creek glacier, as indicated by the moraines which extend to the lip of the Whitman Creek valley and describe their farthermost loop where this valley begins to drop off from the level of the plateau.

Northeast of Evelyn Lake is a little cirque in the lee of a summit only 8,900 feet in altitude (the actual rock rim of the cirque is at 8,700 ft.). In the earlier stage, this cirque contributed ice to the Horse Creek glacier; in the later stage, the cirque held a small independent ice body. The lower trail to Cahoon Meadow crosses the Wisconsin moraines of this glacier. Evelyn Lake occupies a steep-walled cirque which held, during both stages, a glacier formed in the lee of a plateau summit 9,100 feet in altitude. Large Wisconsin moraines composed of big angular blocks border the lake and extend about half a mile down the canyon; below these moraines lie older ones which are crossed by the trail to Cahoon Meadows. The features at Evelyn Lake well illustrate the effectiveness of erosion by even a small glacier. Furthermore, this glacier and its small neighbor are of special interest because of the low altitudes at which they originated.

SOUTH FORK

The upper South Fork Basin was occupied, during both glacial stages, by an irregularly shaped compound ice mass. In the earlier stage this glacier not only discharged down the canyon of the South Fork but also was continuous with the Whitman Creek glacier northward through Hockett Meadows. The South Fork was then 8½ miles long, measured from its source above the Blossom Lakes to its terminus at 6,200 feet in the South Fork Canyon. In the later stage this glacier was a mile shorter and extended down only to 7,500 feet.

This broad, shallow ice mass left a covering of moraines and scattered debris on the country across which it spread. Some of these deposits are crossed by the trail from Wet Meadow to Hockett Ranger Station. Ice advancing from the vicinity of Sand Meadow scooped out the shallow basins of the Hockett Lakes, overrode the ridge to the west of these lakes, and spilled down into South Fork Canyon.

From the evidence of glacial boulders which strew Tuohy Meadow and the South Fork Meadows, it is clear that all of this part of the South Fork basin was covered by ice streams converging from the numerous pockets in the high southern and southeastern rims of the plateau.

During both stages, a small isolated glacier lay on the north side of the peak (9,405 ft.) at the northeast end of Dennison Ridge. The trail leading from the Hockett Lakes to the Garfield Grove of Big Trees crosses the moraines of this glacier.

The so-called "sand dune" which gives name to Sand Meadows is a nearly circular, rounded deposit composed of sand, subangular gravel, cobbles, and boulders as much as 9 inches in diameter (fig. 36). The dune is obviously not aeolian but is the remnant of an outwash deposit formed late in the Wisconsin Stage when the meadow lay under a shallow wasting ice sheet. A stream of meltwater probably deposited the material in an embayment of the ice mass. When the ice melted, the deposit was left without supporting walls, and under the influence of gravity and rainwash it gradually assumed its present oval form. To the southeast of this deposit are two much smaller and flatter deposits of similar material. Both are still largely bare of vegetation but are being encroached upon. The main "dune" bears no vegetation whatever but is surrounded by a carpet of xerophytes and a partial circle of small lodgepole pine. East of the main dune, in a fringe of timber on a low rock ridge covered with Wisconsin moraines, is a small spur that is composed also of gravel and cobbles mixed with sand. This spur may be a record of the glacial stream channel through which the sand, gravel, and coarser materials were washed out to the main "dune."

GLACIATION OF THE UPPER KERN BASIN: KERN GLACIER SYSTEM

As previously noted, the climax of glaciation in the Sierra Nevada occurred in the central part of the range. At the heads of the Merced and Tuolumne Basins, for instance, the cirques and their short outflow canyons were filled with Pleistocene ice nearly to their full depth; some were completely filled, and the ice overflowed the dividing ridges and spurs on a large scale. Still farther northwest, in the rugged northern part of Yosemite National Park and the adjoining headwater areas of the Stanislaus and Mokelumne Rivers, the ice, even during the relatively moderate Wisconsin Stage of glaciation, covered the mountains except for a few of the highest peaks. The ice formed a local, flatly domed cap whose gently curving surface did not reflect the character of the topography underneath. Only isolated nunataks stood out above the ice.

To any observer trained to read the signs of alpine glaciation, it cannot fail to be evident, as he travels southward from this area of maximum glaciation across the upper Merced, upper San Joaquin, and upper Kings River basins, that ice accumulation decreased by degrees, that the cirques and canyons were filled to progressively less depth, and that the intermediate peaks and crests stood above the ice with greater height

FIGURE 36.—Sand Meadows. These meadows and the neighboring Hockett Meadows are on a glaciated platform at an altitude of 8,500 to 9,000 feet in the Kaweah Basin. At the left, in front of the trees, is the so-called "sand dune," in reality an outwash deposit. In the foreground, the meadow is strewn with glacial boulders.

and in more continuous chains. Nor did the ice in each of these basins possess a continuously domed surface; on the contrary, it had a broadly concave surface, each basin being an independent area of accumulation.

In the upper Kern Basin, it will be clear from the foregoing, the paucity of ice, as compared with that in the other major basins to the north, was greatest of all. In spite of the great altitude of the upper Kern Basin—whose floor ranges for the most part from 10,000 to 11,500 feet—and in spite also of the great height of the surrounding peaks—which range from 12,000 to more than 13,000 feet on the Great Western Divide and the Kings-Kern Divide, and from 13,000 to well over 14,000 feet on the main crest of the Sierra Nevada—the upper Kern Basin at no time during the Pleistocene Epoch, not even during the earlier stages of glaciation, contained an extensive unbroken ice sheet such as filled the upper Tuolumne Basin above the Yosemite region (Matthes, 1930, p. 77 and map, pl. 39). The glaciers that issued from the cirques on the surrounding crests converged toward the central canyon as distinct ice streams separated from one another by mountain spurs or low divides. Coalescence of these glaciers across interspaces occurred only in the uppermost part of the basin, but even there several spurs remained emergent above the ice. Nor did the ice attain great thickness. It averaged little more than 1,000 feet in depth on the broad plateaulike benches and reached maximum depths of 2,000 to 3,000 feet only in the main canyons.

Systematic mapping of the individual branch glaciers showed that they filled the cirques to not more than two-thirds of their depth and filled the canyons leading out from the cirques to only about one-half of their depth. On the walls of those canyons, the upper limit of glaciation is in many places distinctly marked, owing to the fact that above that limit the walls are fluted directly downward by recurrent avalanche action, but below the limit they are smoothed by longitudinal glacial action.

The paucity of ice thus revealed at and near the centers of ice accumulation surrounding the upper Kern Basin contrasts strikingly with the abundance of ice in comparable places farther north in the High Sierra. The scarcity was due not only to the far southern latitude of the basin and to its southward exposure but also to the effect of the Great Western Divide, which exacted a toll of precipitation from the moisture-bearing westerly winds and thus reduced the amount of snow available for distribution over the upper Kern Basin. Nearness to the deserts east and southeast of the Sierra Nevada undoubtedly was also a determining factor, during Pleistocene time, as at present, the hot dry air from those areas causing much of the fallen snow to waste away by evaporation.

That the ice in the upper Kern Basin constituted a separate system, which was independent of ice accumulations in adjoining drainage basins and was of strictly local origin, may be attributed to the following circumstances: Only a few gaps in the encircling mountain crests were low enough to permit diversions of ice across them; furthermore, these few diversions were outgoing rather than incoming, owing to the great altitude of the upper Kern basin and the relatively deep dissection of the adjoining mountain areas—the Kaweah Basin on the west, the Kings Basin on the north, and the Sierra escarpment on the east.

The term "Kern glacier system" may appropriately be used to apply, broadly, to all the Pleistocene ice bodies, large and small, of the upper Kern Basin. The specific members of that system are: First and foremost, the great Kern glacier itself—that is, the Kern trunk glacier and its many branches; the scattered little glaciers west of the canyon, at the sources of the Little Kern River and the Tule River; and, finally, those glaciers east of the Kern Canyon, also small, at the sources of Golden Trout Creek and the South Fork of the Kern River. In the following pages the various members of the Kern glacier system are discussed in the order in which they have just been named. By far the greater part of the system falls within Sequoia National Park but, in the interests of completeness, the parts of the system outside the park will also be considered briefly. Actually these outlying parts are, with but a few exceptions, only a short distance from the park boundaries.

KERN CANYON AND TRIBUTARY VALLEYS

The Kern glacier was a great, many-branched ice body fed from ranks of cirques along the high bordering ranges, the Great Western Divide (altitudes 10,000 to more than 12,500 ft), the Kings-Kern Divide (12,500 to more than 13,000 ft), and the main crest of the Sierra Nevada (13,000 to almost 14,500 ft), as well as on ridges subsidiary to these crests. Because the Kern Canyon extends in a nearly straight line through the middle of the upper Kern Basin and the tributary canyons branch from it like the ribs in an oak leaf from the main rib, the Kern glacier had much the same pattern. During the Wisconsin Stage, the tributary ice streams lay entirely confined in the side canyons, but during the El Portal Stage the ice spread locally across intervening divides and over the benchlands on either side of the main canyon.

It has long been assumed that the Kern glacier never extended beyond the terminal moraine that loops across the floor of the Kern Canyon a mile south of Golden

Trout Creek. However, the present reconnaissance showed that this moraine marks only the limits which the glacier reached during the Wisconsin Stage and that during El Portal Stage the glacier extended about 7 miles farther down the canyon, to the vicinity of Hockett Peak. It appears, then, that during the Wisconsin Stage the Kern glacier attained a length of 25 miles, and during El Portal Stage a length of about 32 miles. In Glacier Point time, the glacier probably reached a length approximately equal to that reached during El Portal Stage.

WISCONSIN STAGE

KERN CANYON

The lower limits of the great Kern trunk glacier of Wisconsin time are clearly indicated by the remnants of moraines in the vicinity of the Kern Canyon Ranger Station (pl. 1). These moraines were first made known by Lawson (1904, p. 345–348). The author's reconnaissance provided opportunity for examination of the moraines described by Lawson and for noting several others belonging to the same series but not previously reported. The author's observations served to emphasize the close correspondence which exists between the Wisconsin moraines in Kern Canyon and the comparable series in the Yosemite Valley (Matthes, 1930, p. 56–58).

As was made clear by Lawson, the most southerly of the moraines is a V-shaped loop, whose apex is directed down the canyon, about three-quarters of a mile south-southwest of the Kern Canyon Ranger Station. The moraine is an inconspicuous one, being on the average only 25 feet high. Beginning at the west side of the canyon, this moraine runs out obliquely into a depression bounded, on the east, by a linear rock ridge rising from the central part of the Kern Canyon, adjacent to the Kern River. This rock ridge is in the category which Lawson designated as "kernbuts." After making a pointed loop in this depression, the moraine ascends to the top of the kernbut.

Immediately north of the end moraine, and very similar to it, are two recessional moraines, also reported by Lawson, the northerly one of which is double crested. In crossing from the west canyon wall to the kernbut, these moraines also form V-shaped loops.

As Lawson recognized, these moraines outline the positions of a small frontal lobe of the Kern trunk glacier which was thrust into the depression between the west canyon wall and the rock ridge. However, Lawson evidently did not observe that morainic material also lies on the steep east side of the rock ridge and that east of the Kern River there is at least one distinct moraine loop, standing 10 to 15 feet above an outwash terrace. This moraine must represent the eastern equivalent of one of the three loops west of the rock ridge, probably the southerly one. Thus the rock ridge appears to have divided the glacier, at its terminus, into two small lobes.

In this reconnaissance, several other indistinct moraines were noted a little farther upstream, in the area just south of Coyote Creek. Also, a prominent moraine was traced from the Kern Canyon Ranger Station west-northwest along the north side of Coyote Creek as far as the lower west slope of the canyon. Where Coyote Creek debouches on the canyon floor, it is difficult to distinguish the material of this moraine from that of the boulder levees along the stream. Still farther north, likewise on the west side of the Kern River (immediately north-northeast of Soda Spring), are two other fairly prominent Wisconsin moraines, each the remnant of a moraine loop.

Finally, outside the mouth of Golden Trout valley is the beautifully symmetrical moraine described by Lawson which is notable as the largest and most northerly member of the morainal series left by the Kern trunk glacier. This moraine also is V-shaped in ground plan and, having been breached at the apex by the Kern River, actually consists of two separate wings, one on either side of the river. These wings are even-crested massive ridges, each almost half a mile long and in places rising nearly 100 feet above the flat along the river. This moraine may correspond to the one in Yosemite Valley which formed the dam of Yosemite Lake (Matthes, 1930, p. 57).

Throughout the 1½-mile section of the Kern Canyon occupied by these moraines a jumble of material, both morainal and outwash, mantles the rock floor to an appreciable depth. What this depth may be is suggested at a point a few hundred yards downstream from the ranger station where the river has cut through the mantle into the underlying granite (fig. 37). Here, on the east side of the river, the mantle does not appear to be over 30 feet deep, but up the valley, toward the upper moraine, the mantle may well gain in thickness.

Northeast of Volcano Falls, the old Conterno Trail connecting the floor of Kern Canyon with the valley of Golden Trout Creek climbs the left lateral moraine of the Kern trunk glacier, reaching the top at 7,000 feet. This fairly conspicuous moraine at one time evidently formed a barrier across the mouth of the small hanging valley north of the Conterno Trail, but the moraine is now crossed by a narrow gorge. The height of the moraine shows that the Wisconsin glacier at this point had a thickness of 600 feet plus the thickness of the glacial and alluvial material that now encumbers the valley floor—probably at least 50 feet. It follows that in a distance of nearly 2 miles the Kern trunk glacier

FIGURE 37.—Kern River, cutting in bedrock, near Kern Canyon Ranger Station at south border of Sequoia National Park.

tapered down from a thickness of about 650 feet to its terminus.

Farther up Kern Canyon, no moraines of the trunk glacier are found through a distance of more than 15 miles, but beyond that, in the head of the canyon, a fine series of lateral moraines is present (Lawson, 1904, p. 354, 358). (These moraines and others mentioned on following pages are not shown on pl. 1.) Those on the east side of the canyon are "several miles in length and rise to an altitude of probably 1,500 feet" above the bottom of the canyon (Lawson, 1904, p. 354); they extend from just beyond the mouth of Wallace Creek northward beyond the head of the Kern Canyon into the canyon of Tyndall Creek.

TRIBUTARY VALLEYS

On the west side of the Kern Canyon, from Coyote Peaks to the Big Arroyo, the valleys tributary to the Kern are successively longer to the north, because the Great Western Divide, from which the tributary valleys descend, diverges northwestward away from the northward-trending Kern Canyon. Because of this situation and also because the Great Western Divide gains in altitude toward the northwest, the Wisconsin glaciers in these canyons were progressively larger to the north.

The valley of Coyote Creek and also two little valleys heading just south of the Coyote Peaks held glaciers which were the most southerly ice bodies generated along the Great Western Divide; in fact, they were among the most southerly in the Sierra Nevada. These glaciers were not long enough to fill the entire length of their canyons and reach the Kern Canyon. However, ice streams in two of the branches of Coyote Creek did unite to form a very short trunk glacier. The prominent right lateral moraine of the north branch of this glacier can be seen from the trail to Coyote Pass. Farther up toward the pass, the trail crosses the right lateral moraine of a small separate glacier which descended from the cirque north of Coyote Pass.

Considerably more impressive were the ice streams in the canyons of Laurel Creek and Rattlesnake Creek. These, like all the branch glaciers to the north of them, were tributaries of the Kern trunk glacier. They headed in compound cirques on the Great Western Divide, and at the mouths of their canyons, which were hanging, they cascaded down to the trunk glacier in the Kern Canyon. The Laurel Creek glacier was 6 miles long, the Rattlesnake Creek glacier 8 miles long.

The Big Arroyo glacier, almost 14 miles long, was the largest and most complex of the tributary ice streams in the entire Kern Basin; in fact, it constituted a major glacier system in itself. Most of the sources of this glacier lay along the Great Western Divide, in a 15-mile rank of capacious cirques, but some lay to the northeast, in cirques of the Kaweah Peaks Ridge.

As a result of severe glacial erosion, Big Arroyo Canyon, like Lyell Canyon in Yosemite National Park, has a smoothly U-shaped cross section, and the canyon shoulders are rounded from overriding by the main glacier (figs. 38, 39). Upper reaches of the canyon, which are mostly devoid of timber as a result of snowslides, are broadly open. Many of the cirques along the Great Western Divide are remarkably smooth-floored and clear of debris; the little debris that is present is usually concentrated in a few narrow belts. In these cirques lie numerous scattered lakes and chains of lakes.

These erosional features are strikingly visible from the High Sierra Trail, which crosses Kaweah Gap and descends along the left side of the Big Arroyo to Kern Canyon. So also are some of the Wisconsin lateral moraines of the main glacier and its tributaries. The sloping platforms at the base of the Black and Red Kaweah Peaks, for example, are littered with moraines and erratics, mostly above timberline.

The most interesting display of moraines is to be found on the southwestern part of the Chagoopa Plateau, which is also traversed by the High Sierra Trail. Moraine Lake, in this area, is one of the few wholly moraine-impounded lakes in the Kern Basin (figs. 40, 41). The little valley which the lake occupies was invaded by a side lobe of the Big Arroyo glacier. This lobe left a series of concentric moraine loops, the last-formed and smallest loop being one at the lower end of Moraine Lake (the impounded water seeps out from the lake through this embankment). West of Sky Parlor Meadow the concentric moraines are separated by strips of meadow formed where sand has been washed down from the flanking moraines. The outermost moraine forms the west boundary of Sky Parlor Meadow. This moraine, when followed to the southeast, reaches the crest of a ridge and here makes an abrupt turn toward the southeast; it then continues parallel to the general course of the Big Arroyo glacier.

FIGURE 38.—View from the vicinity of the Nine Lake Basin southward down Big Arroyo, which, in the distance (left), becomes a deep U-shaped canyon flanked by forested plateaus. Photograph by W. L. Huber.

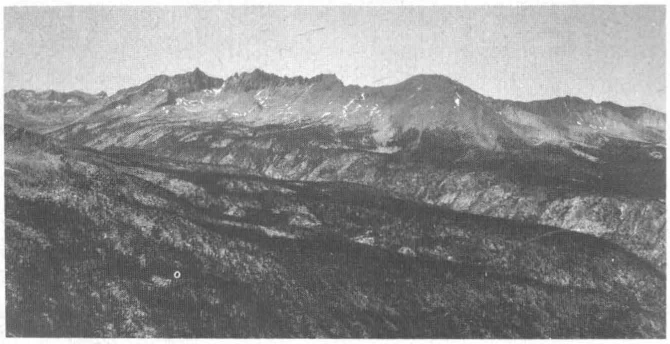


FIGURE 39.—View across Big Arroyo from an unnamed mountain east of Little Clair Lake. Big Arroyo, like the Kern Canyon, is a stream-cut canyon modified by glacial action. The broad peak to the right of center is Mount Kaweah. On the far side of Big Arroyo is part of Chagoopa Plateau.

The moraine, when followed north along the edge of Sky Parlor Meadows, describes a big arc. In this section it has several subsidiary crests, and its steep front increases in height to 100 feet or more. Sky Parlor Meadow follows around the arc of the Wisconsin moraine and gradually narrows into a point. Beyond it lie the smooth older moraines.

The westerly tributary glaciers which remain to be considered ranged from 3 to 8 miles in length and therefore were small as compared with the Big Arroyo glacier. These ice streams headed along the Kaweah Peaks Ridge or its subsidiary spurs, with the exception of the Kern-Kaweah glacier, which originated along three different crests: the Kaweah Peaks Ridge, the Great Western Divide, and the Kern Ridge.

The several small glaciers on the southerly slopes of Mount Kaweah and the Red Spur descended onto the northern part of the Chagoopa Plateau; here they coalesced to form a small compound ice sheet which discharged southeastward into Kern Canyon through the hanging valleys of Red Spur Creek and the next stream to the south.

The Kern-Kaweah glacier had broad, capacious collecting basins which were among the largest of the entire Kern glacier system, and it was therefore a major affluent of the Kern trunk glacier. It will be recalled that the Kern-Kaweah glacier was one of the three ice streams whose union formed the head of the Kern trunk glacier.

The glacier formed the apex of the Kern Canyon glacier system, in that it lay in line with the trunk glacier at the very head of the main canyon; it was a

FIGURE 40.—Chagoopa Plateau and Moraine Lake, viewed from the edge of Big Arroyo. The plateau and timbered benches on the far side of Big Arroyo are remnants of an erosion surface left after trenching of the canyon.

FIGURE 41.—Moraine Lake, on the Chagoopa Plateau, one of the few wholly moraine-enclosed lakes in the Kern Basin. The water seeps out through a morainal embankment at the lower end of the lake. Photograph by W. L Huber.

complex ice body about 8 miles long and almost as broad. This glacier was the central member of the three whose union gave origin to the Kern trunk glacier. The many cirques of this central glacier lay on the four crests, Kern Ridge, the Great Western Divide, the Kings-Kern Divide, and the main Sierra crest, which formed a lofty rim encircling the Kern glacier on all sides except the southwest.

Where the canyon "steps up" from main Kern Canyon just above the junction of the Kern-Kaweah River, a moraine loop of this glacier is crossed by the trail. The river has cut through the moraine and into the underlying bedrock; it thus gives rise to a series of falls. More conspicuous evidence of the Wisconsin glaciation occurs at higher altitudes, where there are 60-odd lakes along the upper stream courses and within the cirques of this basin as well as a multitude of smoothly rounded ledges among which the trail precariously makes its way up to the sources of the Kern River. Many of the knolls and ridges, curiously, reverse the relationship typical of ordinary roches moutonnées in that they are more abrupt on the upvalley side than on the opposite side. Their anomalous profiles reflect the control of two joint sets, one dipping rather steeply upvalley, the other dipping less steeply downvalley.

The Tyndall glacier deposited a series of bouldery left lateral moraines which the John Muir Trail crosses in its course south of Tyndall Creek. One of these moraines holds in the long, narrow lake west of the long spur extending southwest from Mount Tyndall. The moraines are not very prominent, except for the topmost one which is a barren, sharply defined ridge contrasting rather sharply with the smooth bare slopes of the Bighorn Plateau above it (fig. 42).

The three easterly tributaries of the Kern trunk glacier—Wallace glacier, Whitney glacier, and Rock glacier—all came from the highest of the crests bordering the Kern basin—that is, from the main Sierra divide, which in this section bears several 14,000-foot peaks and many summits which are but little lower.

Wallace glacier, about 7 miles in length, was joined by a major branch from the northeast, the Wright glacier. The numerous moraines of this glacier system are bouldery and regular (fig. 43), and some are

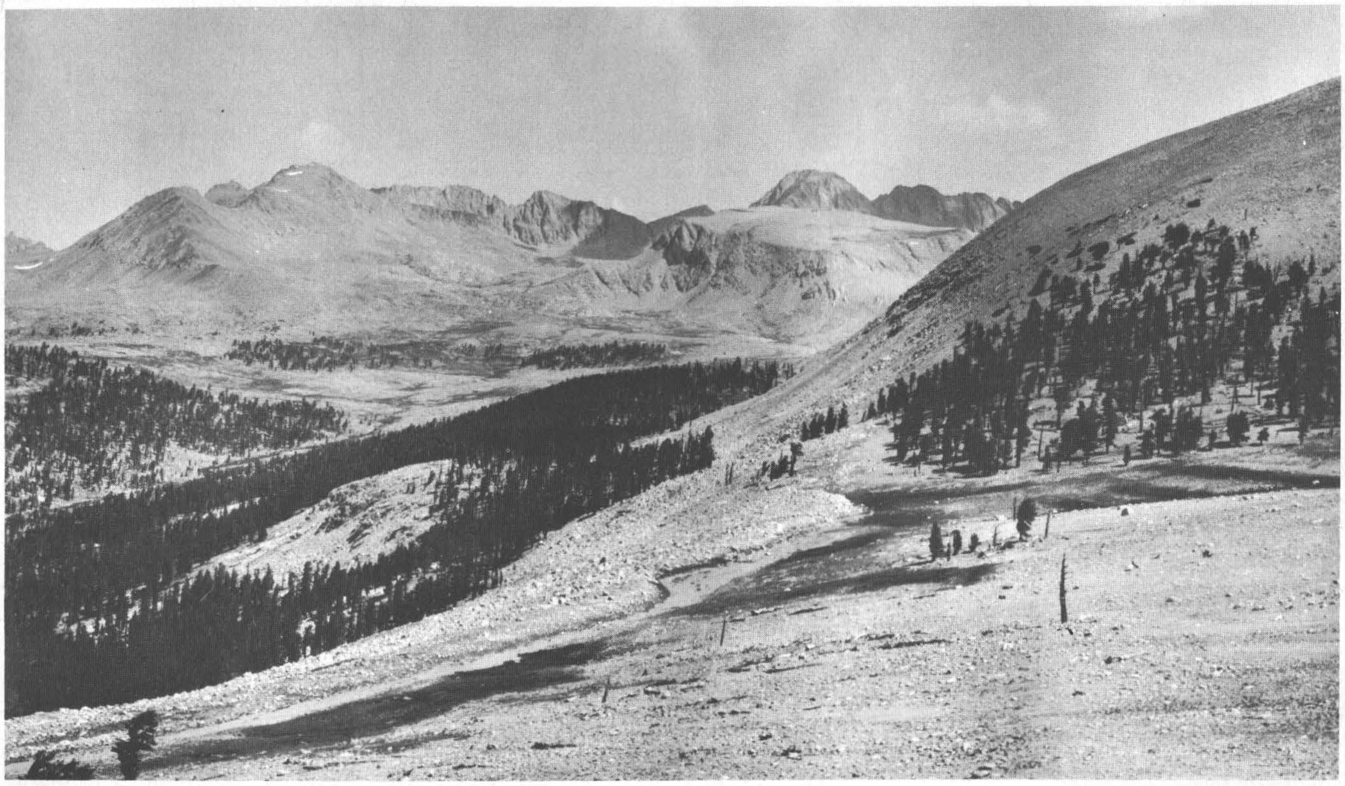


FIGURE 42.—View up the valley of Tyndall Creek from the Bighorn Plateau, which appears in the lower right foreground. The flat-topped peak to the right of center is Diamond Mesa. The barren ridges of rock debris extending toward the lower left-hand corner of the photograph are lateral moraines of the Wisconsin Stage. The uppermost moraine marks the highest level reached by the Tyndall glacier during that stage. The lower, timber-covered moraines were laid down during the recession of the glacier. The smooth slope of the Bighorn Plateau seems devoid of glacial features, yet in places it bears scattered erratic boulders left from El Portal Stage. (See fig. 26.)

unusually prominent. The John Muir Trail traverses them in its course across the basin, above the junction of Wright and Wallace Creeks. There are at least four right laterals and two left laterals of the Wright glacier, and three left laterals and two right laterals of the upper Wallace glacier. A medial moraine given off from the end of the ridge between Wright and Whitney Creeks extends west-southwestward down the valley for about a mile, as far as Wright Creek.

Wallace, Tulainyo, and Wales Lakes, in upper Wallace Creek basin, are glacial lakes of exceptionally large size, each being more than half a mile long. Wallace Lake, which is probably at least 100 feet deep, lies in a great compound cirque; it marks the confluence of two ice streams, one from a cirque on Mount Barnard, the other from a larger, higher cirque under the summit of Mount Russell. Tulainyo Lake (fig. 44) lies in the latter cirque. The environment of both lakes, being above timberline, has a grim, barren aspect. Tulainyo Lake (altitude 12,856 ft), said to be the highest body of water in North America, occupies a cirque that doubtless held a small glacier until very recently. The lake is enclosed by a massive moraine through which the water seeps out. Wales Lake lies in a short tributary canyon which, from the evidence of glacial sculpturing on its walls, held an ice tongue about 1,000 feet deep.

On the granite around Wallace Lake, surprisingly little glacial polish remains, and in some places weather pits have been formed in the surfaces of horizontal platforms. This condition implies very rapid postglacial disintegration as compared with that observed in the Yosemite region.

Half a mile below Wallace Lake is a striking exhibit of glacially quarried rock; several sheer rock faces are determined by vertical master joints. The cliff below Wales Lake also exhibits glacial plucking and abrasion guided by joints.

Where the John Muir Trail crosses Wallace Creek, the stream through a stretch of 400 feet has trenched the bedrock to a depth of 25 to 50 feet (fig. 45). The gorge has vertical walls along which stand tottering joint slabs. The stream cutting here, which must be wholly postglacial, contrasts vividly with the slight erosion effected by the Merced River above Vernal and Nevada Falls (Matthes, 1930, p. 69). The differ-

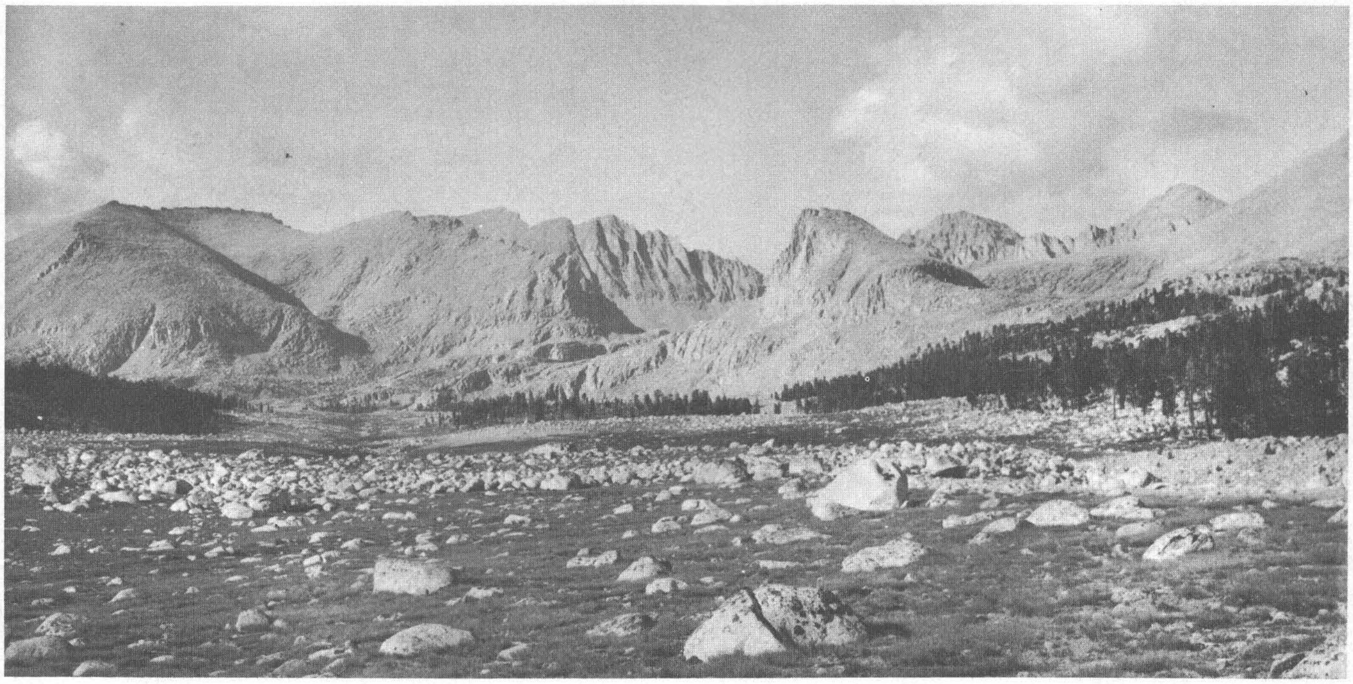


FIGURE 43.—View northeastward up the valley of Wright Creek toward Mount Tyndall (central peak with gullied slopes). Stretching across the valley floor are two moraines that mark brief halts in the recession of the Wright glacier. In the canyon to the right of Mount Tyndall, the level at which the surface of the glacier lay is clearly defined by the lower limit of the gullies cut in the cliff. These gullies are due to avalanche erosion.

ence may be attributed to the fact that, at the gorge, Wallace Creek is cutting into granite having numerous intersecting joints which divide the rock into blocks and slabs of moderate size, whereas above Vernal and Nevada Falls the Merced is flowing over massive granite. Wherever the granite is sparsely jointed or wholly undivided over considerable distances—and there are many such places in the High Sierra—postglacial stream erosion can be measured in inches rather than feet. Along Wallace Creek, less than 300 yards to the north of the gorge the same granite, where sparsely crossed by joints (10–20 in. apart), forms a smooth, untrenched valley floor.

The Whitney glacier was a forked ice body, its south branch, the Crabtree glacier, being almost as long as the upper part of Whitney glacier itself. Thus this glacier system somewhat resembled the Wallace system but was smaller and only 6 miles long. It is noteworthy that the sources of this glacier were on that lofty section of the Sierra crest that includes Mount Whitney (14,495 ft), the highest peak in the continental United States outside of Alaska (figs. 10, 46). From the glacial sculpturing and avalanche fluting on its valley walls, described below, the Whitney glacier seems to have been about 1,200 feet thick in its upper reaches and 900 to 500 feet thick in its lower valley.

On both sides of the valley, below the fork, the trail from Sandy Meadow to Guyot Flat crosses several lateral moraines of the Whitney glacier. The left laterals, composed in large part of big angular boulders, are exceedingly rough. In places the trail follows sandy strips between the moraines.

Upper Whitney Creek, like upper Wallace Creek, has entrenched itself in the canyon floor to depths of about 20 feet in those places where stream erosion has been facilitated and directed by vertical master joints.

In Upper Whitney and Crabtree Canyons, the floors and sides are irregular as a result of selective glacial quarrying (figs. 47, 48); the sheer headwalls strikingly exhibit avalanche sculpture (Matthes, 1938, 1950a). The north wall of Mount Hitchcock, for example, is deeply cleft by numerous sharply incised recesses, a special form of avalanche chutes cut across a system of well-formed vertical joints (fig. 49). Debris cones, which were still covered with snow when observed, give evidence of continued avalanche action. The east face of Mount Hitchcock, on the other hand, has deeply cut avalanche chutes that have been controlled by vertically sheeted structure in the rock (fig. 50). The southwest flank of Mount Young is rather intricately sculptured by avalanches, and, between the chutes, the ribs stand out as sharp pinnacles. Parts of the west side of Mount Muir and the crest extending south from

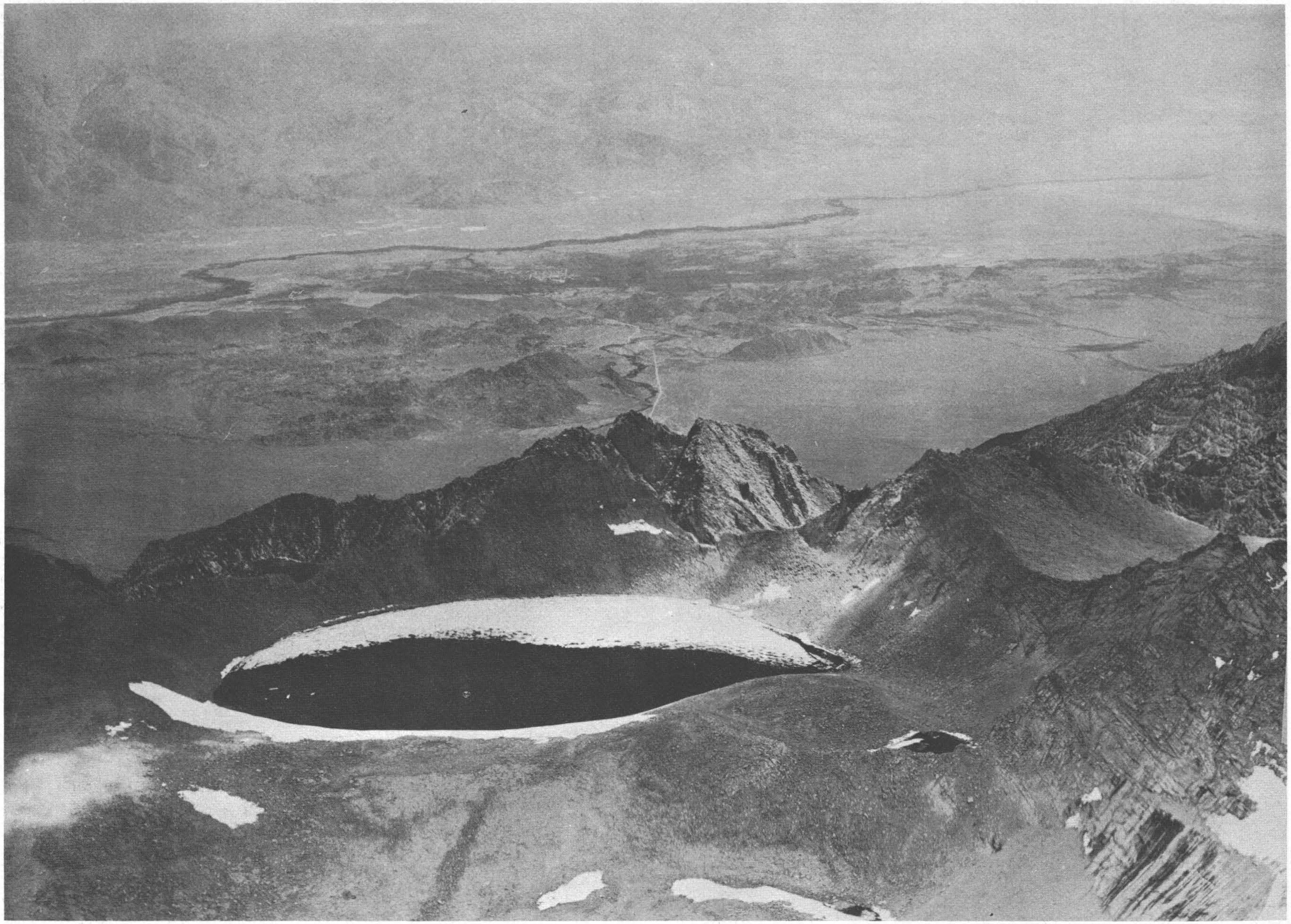


FIGURE 44.—Tulainyo Lake, high on the main crest of the Sierra Nevada; view from the west. Owens Valley is seen in the distance. Aerial photograph by Frank Webb.

FIGURE 45.—Gorge 50 feet deep, cut by Wallace Creek, for the most part in postglacial time. Note man standing on the right brink. Stream erosion here has been facilitated by the numerous intersecting joints.

this peak have been subjected to avalanche erosion; that part of the ridge to the west of Whitney Pass has sharp ribs between chutes. The trail laid across these features is in a precarious position and is inevitably subject to being swept away periodically by avalanches. Some of the ribs are particularly frail and picturesque. The long spur south of Crabtree Creek is also avalanche scarred on the north side.

A small independent glacier that descended the north slope of Mount Guyot left records which attest to its great eroding power. The cirque of this glacier is shallow but unmistakable, and a bouldery outer moraine indicates that this little glacier turned west and, at an altitude of 10,000 feet, a mile below its source, ended in a narrow tongue.

The Rock glacier was the most southerly and the longest (11 miles) of the tributaries which joined the Kern trunk glacier from the east. The moraines of the Rock glacier cloak both slopes of the lower valley, and several small moraines forming partial loops occur on the bottom of the canyon. Intermediate spaces consist, for the most part, of wet, boggy meadow. In the lower valley of Guyot Creek, moraines outline a small Wisconsin glacier which fell short of joining the Rock glacier, and at the heads of two tributaries of the South Fork Rock Creek, southwest of Siberian Outpost, there are records of two other, even smaller, Wisconsin glaciers.

EL PORTAL STAGE

On the basis of the characteristics of the glacial deposits of El Portal age as set forth on previous pages, the deposits of this early stage in the Kern Canyon and in its branches may now be described.

To the author it was soon apparent that El Portal moraines in the Kern Canyon at the junction of Coyote Creek are situated with respect to the Wisconsin moraines precisely as are El Portal moraines in the Yosemite Valley. In that valley the author discovered, in 1913, that at a point 1 mile below the terminal moraine of the Wisconsin Stage the highest left lateral of El Portal Stage lay 2,200 to 2,300 feet above the valley floor (Matthes, 1930, p. 66–68). A few miles farther down the valley, the right lateral was at a corresponding height. Once identified, both laterals were readily traced down the Merced Canyon to the vicinity of El Portal. In the Kern Canyon, similarly, the lateral moraines of El Portal Stage lie at heights ranging from 1,600 to 2,000 feet above the terminal moraine of the Wisconsin Stage.

FIGURE 46.—Mount Whitney, viewed from the west. The precipitous cliffs of the mountain, the scoured bedrock floor of the canyon, and the small lake in the foreground are typical features of the glaciated upper Kern Basin. The cliffs are furrowed by avalanche chutes. Photograph by W. L. Huber.

Search for these older glacial deposits was begun on the west side of the Kern Canyon. The upper zigzags of the trail that leads to the hanging valley of Coyote Creek were cut into a large body of El Portal mineral; they thus afford abundant exposures of the limonite-coated boulders in the material. The mass reaches all the way up to the mouth of the hanging valley, but inasmuch as this mass connects there with old deposits of the tributary Coyote glacier, it was deemed advisable to extend the search northward along the shoulder of the canyon. There, patches of the mass were found on a part of the upland where none could have been contributed by either the ancient Coyote glacier or the ancient Laurel glacier, the next tributary ice stream to the north. This old glacial material is for the most part hidden from view by a mantle of forest soil and granite sand, but cobbles of characteristic El Portal aspect occur in the holes left by uprooted trees. The upper margin of the deposit is ill defined but seems to range from 8,000 to 8,100 feet in altitude. It therefore lies 1,600 to 1,700 feet above the canyon floor; and, because the canyon floor is covered with late-glacial and alluvial deposits to a depth of probably 100 feet, the total thickness of the ancient Kern glacier indicated is about 1,700 to 1,800 feet.

The search on the east side of the canyon gave even better results. The old Conterno Trail to the upland valley of Golden Trout Creek first ascends the left lateral moraine of the Wisconsin Stage. The trail surmounts the sharp bouldery crest at an altitude of about 6,900 feet and then winds up the gully between the crest and the mountainside as far as the mouth of a small hanging valley at an altitude of 7,000 feet. The lateral moraine at one time doubtless formed a barrier across this hanging valley, but it has since been notched by the streamlet. In the hanging valley itself, which is little more than a recess in the canyon wall, the topographic forms are not in the least suggestive of glacial action. They consist of alternating spurs and ravines converging toward the central drainage line; yet these features, clearly because of normal subaerial weathering and stream erosion, are carved largely from glacial deposits of El Portal age. The entire recess is lined with such material, and because there is no evidence of this recess having contained a small tributary glacier, the deposits in question can be attributed only to the Kern glacier

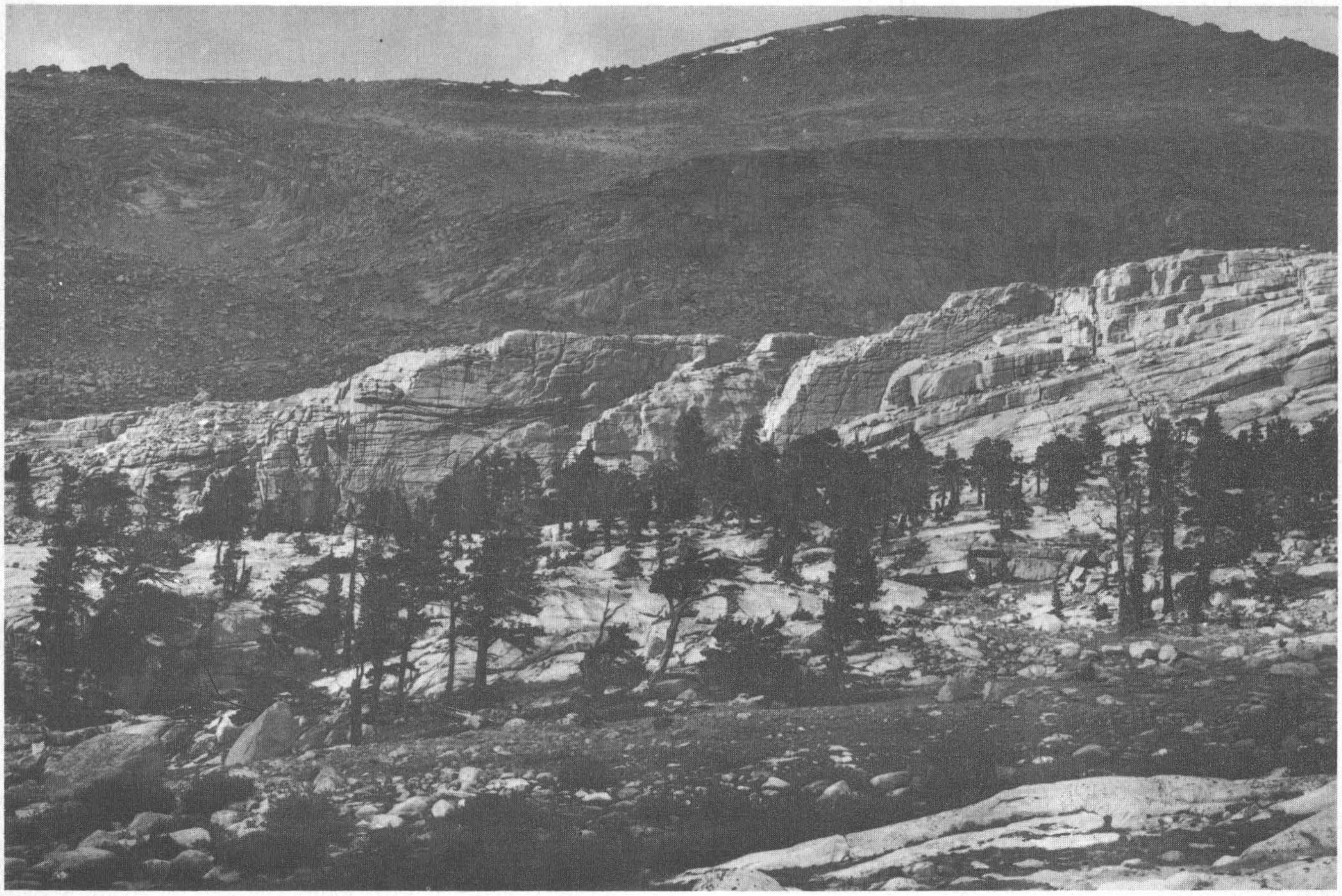


FIGURE 47.—Junction of Crabtree Canyon (foreground) and Whitney Canyon (background). The sparsely jointed floor of Crabtree Canyon shows the effects of glacial quarrying. The intercanyon ridge in the middle distance has angular hackly forms produced by glacial quarrying in well-jointed granite. The Whitney glacier spilled over the ridge and quarried its downstream side. The well-jointed canyon slopes in the background also exhibit the effects of glacial quarrying.

itself. In fact, several obscure lateral moraines of that glacier, arranged in tiers one above another, like terraces, are discernable. The highest, which lies at an altitude of about 8,500 feet, shows that the Kern glacier of the El Portal Stage here filled the main canyon to a depth of fully 2,000 feet above the present floor; and, inasmuch as this floor is underlain by an estimated 100 feet or more of late-glacial and alluvial deposits, the total depth of ice may have amounted to 2,100 feet.

The Conterno Trail, after making several zigzags, turns southward toward the valley of Golden Trout Creek. Along this stretch of the trail only occasional cobbles of El Portal age are found, the canyon sides being too steep to retain much loose material. But in the saddle behind the projecting crag marked 8,119 feet on the topographic map, a small body of El Portal material remains preserved (fig. 51). This body lies fully 500 feet above the adjacent part of the valley of Golden Trout Creek, and, inasmuch as the ancient Kern glacier doubtless rose at least 200 to 300 feet higher, there seemed good reason to believe that a side lobe of that glacier had pushed up into the valley. A rapid examination of the valley, indeed, showed that such had happened. Although the farthest limits reached by the lobe are not marked by a distinct moraine, granitic boulders left by the ice lie scattered on the surface of the basalt flow that fills the bottom of the valley. Along the southern edge of the basalt flow, at an altitude of about 8,100 feet, there is also a continuous moraine composed of a mixture of basaltic and granitic boulders. That moraine extends about 1 mile up the valley and indicates the approximate length of the ice lobe. At the mouth of the valley the moraine is indistinct, but it can be traced to an altitude of nearly 8,300 feet. Here, then, the ancient Kern glacier attained a thickness of about 1,900 feet in the main canyon. This measurement accords well with that obtained in the recess to the north of Golden Trout Creek, for the ancient glacier must have decreased in thickness downvalley in this part of its course.

FIGURE 48.—View from the Whitney Trail across upper Whitney Canyon and Hitchcock Lake (foreground) at Mount Hitchcock (center). Zones of fracturing in the floor of the canyon have controlled the erosive action of the glacier. Lakes and snowdrifts mark the depressions quarried out in these zones. The intermediate humps, composed of sparsely fractured rock, have been subject chiefly to the slower process of grinding. Except for the accumulation of rock debris at the base of Mount Hitchcock, this part of the canyon has undergone only insignificant changes since the disappearance of the glacier. Photograph by Kenneth Flewelling.

Thus the great depth of ice in the Kern Canyon that is consistently indicated at three different points implies, of course, that the glacier of El Portal Stage extended several miles beyond the terminal moraine which Lawson believed marked the southernmost limit of glaciation. A methodical search for remnants of lateral moraine of El Portal age in recesses in the canyon walls was clearly called for, but because the time available did not permit such a search, it was deemed best to examine the area about the southern end of Grasshopper Meadow, where the canyon contracts from its broad U-shape to a narrow V-shape and where, presumably, glacial erosion had been largely supplanted by deposition under the thinning sluggish terminal part of the glacier. There, indeed, a considerable body of El Portal moraine was discovered to the east of the trail, in the reentrant through which the trail ascends to the col at the head of the defile called Trout Meadows. The deposit is partly covered by soil and forest litter, but the cobbles in it are plainly visible on the slope to the east of a sharp-cut gully. The upper limit was determined, by aneroid, at an altitude of about 6,600 feet—that is, at a height of 900 feet above the bed of the Kern River, according to the contour lines on the topographic map. If it be assumed that the river has deepened its bed 200 feet since El Portal time—observations made in other canyons farther north in the Sierra Nevada indicate that a greater amount is not probable—the ancient Kern glacier at this lower point still was about 700 feet thick. The glacier may be reasonably supposed, therefore, to have penetrated at least 2 miles farther down the canyon, and the ice front, accordingly, must have lain at an altitude of approximately 5,700 feet about 7 miles south of the terminal moraine of the Wisconsin Stage—that is, at a place locally called "Hole-in-the-ground" (name not indicated on topo-

FIGURE 49.—North side of Mount Hitchcock, viewed across Whitney Canyon. An unusually fine series of parallel avalanche chutes is here shown. These chutes have been formed across a system of vertical joint fractures in the granite; their positions are not determined by master joints extending parallel to their axes. The chutes all terminate at the upper limit of glacial action, below which the canyon wall is straight, although it is hackled in detail by glacial sculpturing.

graphic map), which is within the bend of the canyon north of Hockett Peak.

Inasmuch as the morainal deposit has been traced to a point only 50 feet below the col at the head of the Trout Meadows defile and may not truly indicate the highest level attained by the ice, it seemed possible that for a brief period the ice had risen high enough to spill through the col. Search for morainal material was therefore made in the upper part of Trout Meadows, but none was found. It was concluded, therefore, that the Kern glacier of El Portal Stage had remained confined to the canyon.

On the way down the canyon, and on the way back, a lookout was kept for El Portal deposits. Only scattered boulders and occasional small patches of cobbles were observed on the canyon floor. The large kernbut to the south of Kern Lake was also examined for old glacial material because it was realized that if this kernbut, which stands only about 300 feet high, was in existence at the time of El Portal glaciation, it would have been overtopped by the ice. No glacial material was found on the main summit, which is directly east of the col that is traversed by the trail, but on the somewhat lower crest to the west of the trail there is a roundish boulder of granite nearly 3 feet in longest diameter. That boulder very probably is a glacial erratic; it owes its roundish shape not to glacial abrasion but to the spalling off of thin curving shells, some of which lie at its sides. A few feet away is a fragment derived from it that has an exposed part measuring 23 inches in length, 18 inches in breadth, and 9 inches in height. Boulders of pre-Wisconsin age in the Sierra Nevada commonly break up in this very manner. The boulder in question is composed of a fine-grained even-textured granite, as yet unstained by ferric oxides; however, the local rock, which crops out on the crest, only 10 feet away, consists of a coarse-grained and obscurely porphyritic granite stained a ruddy tint as the result of the oxidation of its ferromagnesian minerals. Nor was any fine-grained granite, such as that of this boulder, discovered elsewhere in the vicinity. That the boulder is foreign to the locality and was dropped on the crest by El Portal ice, therefore, seems a reasonable presumption.

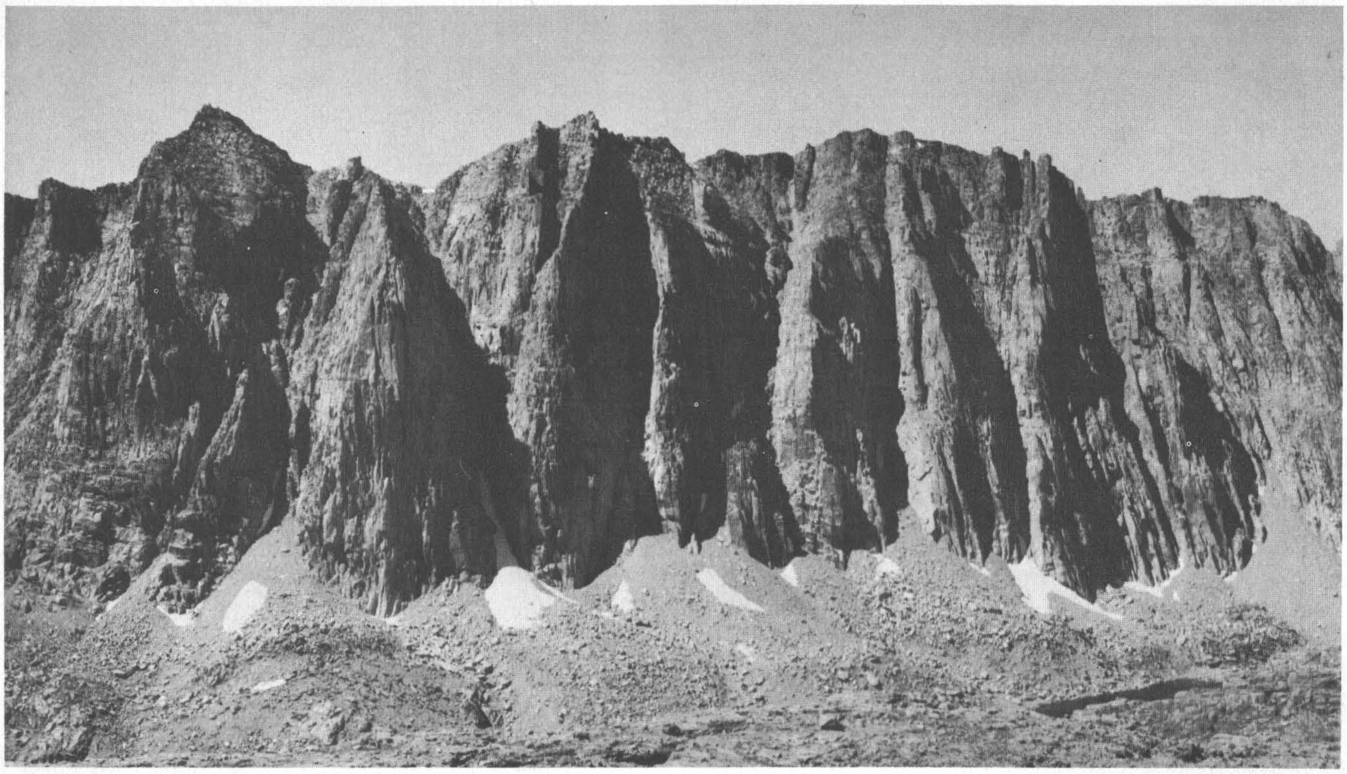


FIGURE 50.—East face of Mount Hitchcock. The entire mountain has a vertically sheeted structure, and infiltration of water and consequent frost action are facilitated along the weaker zones. There the rock is split into thin plates and slivers; the fragments loosened by frost are then swept down by avalanches. These chutes stand in marked contrast to those shown on the frontispiece, which are not controlled by fractures but are worn in massive granite.

To the south of this kernbut, the trail hugs the west side of the canyon (the location of the trail is not shown correctly on the topographic map), winding its way among the crags and blocks that have been brought down by rockslides. All this slide debris is angular and is gray in tone, but among the debris lie rounded rust-hued boulders and cobbles that are typical El Portal material. They must be derived from an old lateral moraine high up on the canyon side. Such boulders and cobbles are more abundant farther on, in the fan built by the streamlet that empties into Little Kern Lake. These doubtless have been washed down from the older moraines of the small hanging glacier that headed under the Coyote Peaks.

Particularly significant is the presence of El Portal material on the north slope of the next great kernbut—the one immediately south of Little Kern Lake. There is nothing to suggest that this material has been dislodged and redeposited; it appears to lie in the place where the Kern glacier left it.

A thorough search for morainal material on the top of the kernbut could not be made in the time that was available. None was found, but it is reasonably certain, nevertheless, that El Portal ice passed over the kernbut, because interpolation between the altitude, 8,300 feet, of the right lateral moraine south of Coyote Creek and its altitude, 6,600 feet, in the recess near the Trout Meadows col indicates that at the kernbut in question the surface of the ice lay at about 7,300 feet—that is, fully 300 feet higher than the top of the kernbut, which, according to the topographic map, has an altitude of 6,981 feet.

South of the kernbut, in the wide space of Grasshopper Meadow, the canyon floor is aggraded with large quantities of coarse angular rock debris derived from the toe of the great rockslide on the west side of the canyon. Some of this debris has recently been cut away by the river, and as a result there is now a flight of five clean-cut terraces about 50 feet in aggregate height; but the glaciated floor of the canyon and whatever morainal material may rest on it remain hidden from view.

No attempt was made to determine the farthest limits which El Portal ice might have reached in the Kern Canyon, previous search in other canyons on the west slope of the Sierra Nevada having demonstrated that as a general rule the trunk glaciers of El Portal Stage have left no recognizable terminal moraines and

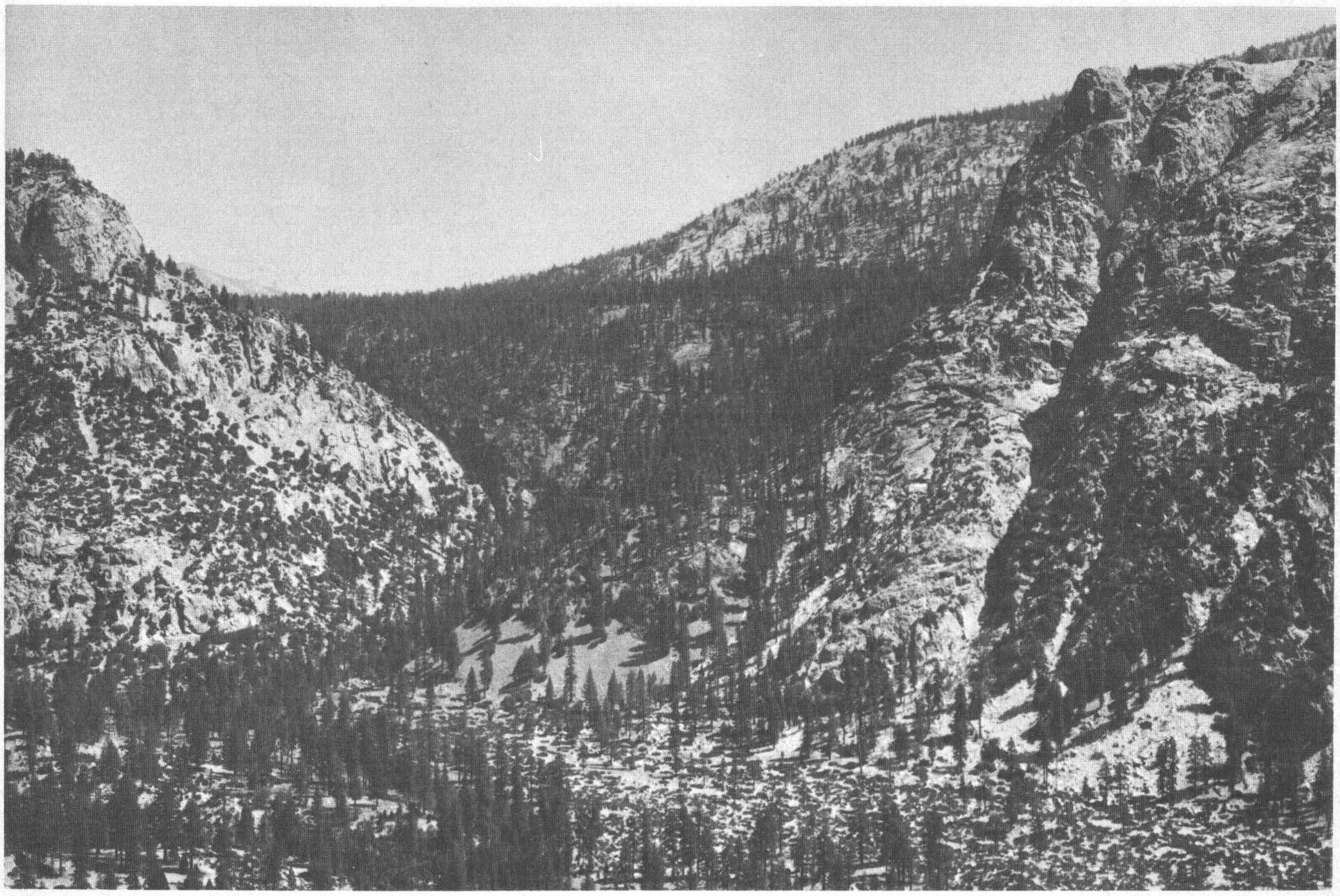


FIGURE 51.—View eastward across the Kern Canyon in the vicinity of Kern Canyon Ranger Station. The light-colored spur to the left is granite; the gray tonguelike mass to the right is a lava flow of basalt that cascaded down from the valley of Golden Trout Creek. At the near edge of the lava flow, Golden Trout Creek has incised a deep, slotlike gorge in the basalt and even in the granite underneath. At the upper left is a rocky promontory; in the saddle behind it, 1,500 to 1,600 feet above the floor of Kern Canyon, occurs moraine of El Portal Stage.

that, for this reason and because of the erosional changes that have taken place in the canyons, the farthest limits attained by those ancient glaciers are not definitely marked. Besides, it seemed probable that the aggraded conditions noted in Grasshopper Meadow would extend some distance farther down the canyon and that but little loose glacial debris would find lodgement on the steep canyon walls.

It remains to note the occurrences of El Portal moraine at scattered localities within some of the valleys tributary to the Kern Canyon and on the interfluves between these valleys. One of these deposits, at the mouth of the hanging valley of Coyote Creek, has already been mentioned. Farther north, the Chagoopa Plateau is littered with the relatively smooth moraines of this age, which extend across Sky Parlor Meadow and to the southeast of it.

Near the head of the Kern River basin, the smooth, bare slopes of the Bighorn Plateau, between Tyndall Creek and Wright Creek, though seemingly devoid of glacial features, are covered with formless older morainal material, the disintegration of which has produced the abundant sand on the plateau. In places the plateau bears scattered erratic boulders, many of which are in process of being broken up. One large erratic, south of the nameless pond in the middle of the plateau, measures 16 by 6 by 7 feet (fig. 26). It is composed of bluish granodiorite containing abundant biotite and hornblende crystals and is obscurely porphyritic. In these respects it contrasts with the local granite, which is conspicuously porphyritic, with phenocrysts or orthoclase 2 to 3 inches in length.

El Portal moraine also veneers several other wide tracts lying east of the Kern Canyon: the Sand Meadows region, between Wallace Creek and Whitney Creek, the broad upland south of the mouth of Whitney Canyon, and both sides of the lower valley of Guyot Creek. The deposits northwest of Guyot Creek are doubtless remnants of the right lateral moraine of the earlier Guyot glacier; those deposits southeast of the creek probably are composite, including both the left lateral of the Guyot glacier and the right lateral of the Rock glacier. The deposits are very sandy, except where the slope is sufficiently steep to permit rainwater to wash away the sand; there many boulders are exposed.

GLACIER POINT STAGE

In only three localities in the upper Kern Basin were any glacial deposits observed that might with some assurance be assigned to the Glacier Point Stage (see pl. 1). Two of these localities are on the Chagoopa Plateau and permit no safe inferences regarding the depth which the Glacier Point ice may have attained.[4] The third locality is 2 miles north of Golden Trout Creek, and the deposit there, fortunately, is of such character and so situated that there can be little doubt that it belongs to the Glacier Point Stage and marks approximately the highest level attained by the ice of that stage.

The deposit last mentioned lies on the otherwise bare level summit platform of the rocky knob that stands north of the little hanging valley previously mentioned (page A46). The material is very scanty, consisting of some cobbles and pebbles of granitic rocks. These rocks, however, have, with one exception, subangular forms such as are produced characteristically by glacial action. The exception is a smoothly rounded elongate pebble that is unquestionably stream worn; but such pebbles are bound to occur here and there in glacial deposits. All the cobbles and pebbles are deeply stained by ferric oxides and break readily under the hammer. In general appearance these deposits do not differ from morainal material of El Portal age, but their position at an altitude of 9,000 feet, 500 feet above the highest El Portal moraines in the little hanging valley nearby, would seem to preclude the possibility of their belonging to that series of moraines. That these cobbles and pebbles do not look more deeply decayed than El Portal material is probably due to the fact that they lie on an almost clean platform that is well drained and thoroughly insolated, and where, consequently, the conditions are unfavorable for the action of chemical processes of rock decay.

The position of this ancient glacial material on the rocky knob implies that the ice of the Glacier Point Stage spread laterally over the upland to the east of the canyons. The ice may have invaded the upland for a distance of three-quarters of a mile, as far as the 9,000-foot contour line shown on the topographic map. There should consequently remain some patches of Glacier Point material here and there on the upland and, likewise, vestiges of a lateral moraine in the vicinity of the 9,000-foot contour line or even somewhat higher up. For such vestigial remnants, however, the author was unable to make a yard-by-yard search in the time that was available for the reconnaissance. It is hoped that others who may be interested in the problems of the Kern Canyon will someday make a thorough search on the upland surrounding the rocky knob and as far south as the valley of Golden Trout Creek.

Inasmuch as the rocky knob has an altitude of about 9,000 feet, the glacial deposit on it lies fully 2,500 feet above the present aggraded floor of the Kern Canyon and, therefore, probably as much as 2,600 feet above its glacially excavated rock floor. These relations, however, do not imply that the Kern glacier of the Glacier Point Stage here attained a maximum depth of 2,600 feet, for during that early stage the canyon had not yet been excavated to anywhere near its present depth (as measured to the rock floor)—most likely 400 to 500 feet greater now at the locality under consideration than during the Glacier Point Stage. The glacier therefore was presumably only about 2,000 feet thick; but if so, it is noteworthy that this glacier was as thick as its successor of El Portal Stage. It does not follow, however, that the glacier was either as long or as powerful, for during Glacier Point time the canyon doubtless had not yet been much enlarged from its narrow stream-worn V-shape and therefore offered a much less perfect channel for the ice to flow through than later, when the canyon had acquired a capacious U-shape. Nor did the Kern glacier of the Glacier Point Stage possess as great kinetic energy as its successor of the El Portal Stage, for a larger proportion of its mass was diverted laterally over the uplands and therefore did not take part in the organized flow movement of the ice stream within the canyon. Yet, in spite of these adverse circumstances, the Kern glacier of the Glacier Point Stage probably extended down the canyon several miles beyond the terminal moraine of the Wisconsin Stage. The farthest point attained by this glacier remains, for the present, a matter of conjecture, but, to judge by the rates at which other trunk glaciers of comparable magnitude on the west slope of the Sierra Nevada appear to have decreased in thickness toward their termini, it seems not unlikely that the Kern glacier of the Glacier Point Stage reached at least as far as the upper end of Grasshopper Flat, perhaps even as far as the lower end.

[4] These two localities are both indicated on Matthes' maps, but only the southerly one, southeast of Sky Parlor Meadow, is mentioned in his field notes. According to these notes, this southerly locality is on a small knob of diorite which stands perhaps 60 to 70 feet above the level of the surrounding surface. The knob bears several erratics of siliceous granite of different types. One erratic 4 feet in diameter, near the summit of the knob, is exfoliating. F. F.

SUMMARY STATEMENT

The upper Kern Basin was occupied, in the Pleistocene Epoch, by the most southerly of the great glacier systems of the Sierra Nevada. Being less favorably situated, in certain respects, than its principal neighbors to the north, the Kern glacier was of smaller volume, but nevertheless it attained impressive size during each of the three recorded glaciations: the Glacier Point Stage, El Portal Stage, and the Wisconsin Stage.

Ranks of cirques on the Great Western Divide, the Kings-Kern Divide, and the main crest of the Sierra Nevada fed the many branch glaciers which, in imposing succession, joined the trunk glacier in the main canyon.

The maximum extent reached by the Kern glacier during the earliest, or Glacier Point Stage, cannot be determined with certainty; however, the fact that in the region above Golden Trout Creek the glacier attained about the same thickness as its successor of the second, or El Portal Stage, would seem to warrant the inference that it advanced approximately the same distance—that is, to a point in the Kern Canyon about 7 miles south of the park boundary.

The record of El Portal Stage, though incomplete and decipherable only with difficulty in many places where it is preserved, can be spelled out with much greater assurance. The distribution of El Portal glacial deposits in and about the Kern Canyon indicates that the ancient Kern glacier of this stage, though in most respects similar to its successor of the latest, or Wisconsin Stage, attained greater volume of ice and, accordingly, greater thickness and length. There being more ice than the canyons could hold, in some places, the ice locally spread across intervening divides and over the benchlands on either side of the main canyon to a total breadth of 4 to 6 miles; thus a central ice sheet of about 30 square miles was produced—a remarkable fact considering that the entire expanse sloped southward and lay exposed to the rays of the midday sun. The trunk glacier extended fully 7 miles beyond the limit reached in the Wisconsin Stage—that is, it advanced 7 miles south of the boundary of Sequoia National Park—the evidence indicating that the terminus of the glacier, when farthest down the canyon, lay at an altitude of 5,700 feet in the bend to the north of Hockett Peak, at lat 36°14′ N. (This latitude may represent the most southerly point reached by glacial ice in the Sierra Nevada.) The overall length of the Kern glacier system was then 32 miles. The thickness of the trunk glacier is reliably indicated at several points where its gradually thinning lower portion once rested; this thickness ranged from about 2,100 feet at the mouth of the small hanging valley just north of Golden Trout Creek to 700 feet at the entrance to the Trout Meadows defile.

In the Wisconsin Stage the Kern glacier system remained a sprawling ice body whose trunk and branches lay confined within their respective canyons as distinct ice streams separated from one another by mountain spurs or low divides. The overall length of the system was 25 miles. Seven of its tributaries were 6 to 11 miles long, and the Big Arroyo tributary was 15 miles long. At the mouth of Wallace Creek canyon, the trunk glacier was fully 2,700 feet thick; and where joined by Whitney glacier, 2 miles farther downstream, its thickness was still almost undiminished, being between 2,600 and 2,700 feet. Thence, however, its thickness declined rapidly toward the terminus, being about 1,900 feet at the Big Arroyo glacier, 1,600 feet at the Rattlesnake glacier, 650 feet at the mouth of the hanging valley just north of Golden Trout Creek, and 200 feet opposite Tower Rock. The farthest point reached by the terminus of the trunk glacier coincides with the south boundary of Sequoia National Park, the boundary posts of the park standing, at an altitude of 6,350 feet, on the curving outer moraine marking the extreme limits of the Wisconsin glaciation.

The trunk glacier, so much more powerful than its confluent tributaries, excavated its trough hundreds of feet below the level of their canyons, leaving them hanging. The many side valleys joining the Kern Canyon farther south have also been left hanging. Doubtless they became so in the first place in preglacial time as a result of the rapid trenching of the Kern River induced by the latest Sierra uplift (Matthes, 1950a, p. 9–13). Some of the smaller side valleys, like those in the interval between Rock Creek and Golden Trout Creek, remained unglaciated and had their hanging aspect greatly enhanced by the glacial deepening and widening of the main canyon. The larger side valleys contained glaciers of their own, and therefore were themselves deepened and widened into U-shaped troughs, but nevertheless they remained hanging because of the superior eroding power of the trunk glacier. (The small valleys on the Chagoopa Plateau were glaciated but on the whole probably underwent little change—that is, with reference to their gradients.) As a result of postglacial stream cutting, the lower reaches of the hanging valleys are now deeply trenched for some distance back from the Kern Canyon. The larger and more powerful streams, such as Wallace Creek, have made the most progress in cutting their hanging valleys down to the level of the master stream.

The pronounced U-shaped form of the Kern Canyon has been evolved by glacial erosion from a narrow V-shaped trench which the Kern River had cut as a result of the latest Sierra uplift. The canyon has been glaciated three times and is therefore a product of alternating stream and glacial erosion. Its present U-shaped form is not precisely the one which was cut by the glacier, for many changes have taken place in the canyon since glacial action ceased. The rock floor is buried under thick deposits of boulders, gravel, and sand—in part morainal, in part stream borne. The low gradient of the canyon floor over a stretch of several miles suggests that the glaciated rock floor underneath was excavated into a chain of lake basins which are now filled and covered up. The walls, once smooth, are now furrowed by gullies; and talus slopes at the base of the walls form the curves of a new U-shaped form superimposed upon the glacially eroded one. Deposition in the canyon is at present proceeding faster than erosion by the river.

LOCAL GLACIATION SOUTH OF SEQUOIA NATIONAL PARK (WEST OF MAIN SIERRA CREST)

SOURCES OF THE LITTLE KERN RIVER

The extreme head of Shotgun Creek in Wisconsin time held a small glacier that excavated the cirque now occupied by Silver Lake. In the main valley of the Little Kern, above the junction with Shotgun Creek, Wisconsin moraines plaster the slopes on both sides of the stream. These moraines were noted by Lawson (1904, p. 355), who wrote, "* * * huge lateral moraines were deposited notably on the east side of the canyon above the mouth of Shotgun Creek. This moraine has a height of perhaps 500 feet above the Little Kern, and spilled over the crest of the spur which separates Shotgun Creek from the Little Kern into the basin of the former." There is here the record of a glacier of considerable volume that descended the valley from the vicinity of Vandever Mountain. Its length was about 6 miles, and it reached down to an altitude of 7,300 feet. This glacier was joined by another ice stream that cascaded down from the large cirque above Wet Meadows. The trail from lower Wet Meadows to Quinn Horse Camp crosses the lateral moraines of this system. Moraines of the older stage are probably present in Shotgun and Little Kern valleys, but opportunity to search for them was not provided.

Glaciers also formed in the two valleys of Soda Spring Creek, immediately south of Wet Meadows. In the more southerly of these branches, vigorous glacial erosion has attenuated the ridge at the valley head, and the floor of the cirque is roughened by many converging bouldery moraines of both stages. Quinn's Ranger Station is at the lower edge of a wet meadow held in by one of the many older moraines. The positions and outlines of the small glaciers that occupied the several headwaters of Soda Spring Creek in the Wisconsin Stage are clearly indicated by other moraines.

At the head of Pecks Canyon is another broad compound cirque, in which lie a number of scattered tarns. This cirque—the rim has an altitude of 9,800 feet—was produced by a shallow glacier that, at least in Wisconsin time, lay on the slopes southeast of the ridge bearing Sheep Mountain.

SOURCES OF THE TULE RIVER

On the northwest side of Sheep Mountain, at one of the headwaters of the Tule River basin, is another tarn, Summit Lake, in a little cirque that straddles the south boundary of Sequoia National Park. The lake is held in partly by ledges of metamorphic rock and partly by a small moraine. The moraine has been supplemented by an artificial dam, 4 to 5 feet high, that formerly had a gate with a handwheel and screw stem to raise it. These no longer function properly, and the water finds its way through the dam as best it can.

Northwest of Summit Lake, two other valley heads, also draining into tributaries of the Tule River, have been mildly glaciated, the westerly one apparently only in the earlier stage. Headwalls of the cirques here and at Summit Lake are only 9,000 to 9,500 feet in altitude.

SOURCES OF GOLDEN TROUT CREEK AND THE SOUTH FORK OF THE KERN RIVER

Southeast of Sequoia National Park, five glaciers formed on the southerly flanks of the ridge between Rock Creek and Golden Trout Creek basins. These glaciers originated in cirques whose headwalls are at altitudes of 11,000 to 12,000 feet, and they descended the tributary valleys of Golden Trout Creek distances of 1 to 3½ miles in the Wisconsin Stage and somewhat greater distances in El Portal Stage. During the earlier glaciation, the three glaciers south of Siberian Pass united to form a common ice mass that spread widely over Whitney Meadows.

East of this rank of glaciers, a sixth and even smaller ice body formed on the west side of the main Sierra crest, about a mile southeast of Cirque Peak. A typical cirque, containing a lake, attests to the existence of this glacier. Thirteen miles farther southeast on the Sierra crest, at one of the headwaters of the South Fork of the Kern River, a small glacier formed on Olancha Peak. Situated at an altitude of about 10,000 feet at lat 36°15′ N., this glacier (not shown on pl. 1) may have originated farther south than any other in the Sierra Nevada.

South of the Golden Trout Creek basin, the configuration of certain valley heads on the steep northerly slopes of the Toowa Range (highest summit, Kern Peak, 11,-

493 ft) indicate that the range bore several small glaciers, at least in the later glacial stage. The most easterly of these glaciers discharged into one of the sources of the South Fork of the Kern River.

SELECTED REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

Axelrod, D. I. and Ting, W. S., 1960, Late Pliocene floras east of the Sierra Nevada: California Univ. Dept. Geol. Sci. Bull., v. 39, no. 1, p. 1–118.

Birman, J. H., 1954, Pleistocene glaciation in the upper San Joaquin basin, Sierra Nevada, [pt.] 6, *in* Jahns, R. H., ed., Geology of southern California: California Div. of Mines Bull. 170, p. 41–44.

——— 1957, Glacial geology of the upper San Joaquin drainage, Sierra Nevada, California: Los Angeles, California Univ., Ph. D. thesis, 237 p. (unpublished).

Blackwelder, Eliot, 1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geol. Soc. America Bull., v. 42, no. 4, p. 865–922.

Brewer, W. H., (Farquhar, F. P., ed.), 1930, Up and down California in 1860–1864: New Haven, Conn., Yale Univ. Press, 601 p.

Durrell, Cordell, 1940, Metamorphism in the southern Sierra Nevada northeast of Visalia, California: California Univ. Dept. Geol. Bull., v. 25, no. 1, p. 1–117.

Farquhar, F. P., 1926, Place names of the High Sierra: San Francisco, The Sierra Club, 125 p.

——— 1929, The story of Mount Whitney: Sierra Club Bull., v. 14, p. 39–57.

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, John Wiley & Sons, 553 p.

Flint, R. F., and others, 1945, Glacier map of North America: Geol. Soc. America Spec. Paper 60, 37 p.

Fry, Walter, and White, J. R., 1930, The Big Trees: Palo Alto, Calif., Stanford Univ. Press, 126 p.

Fryxell, Fritiof, 1956, Memorial to François Emile Matthes (1874–1948): Geol. Soc. America Proc. 1955, p. 153–168.

Fryxell, Fritiof, ed., 1962, François Matthes and the marks of time: San Francisco, The Sierra Club, 192 p.

Gilbert, G. K., 1904, Systematic asymmetry of crest lines in the High Sierra of California: Jour. Geology, v. 12, p. 579–588; Sierra Club Bull., v. 5, p. 279–286 [1905].

Hake, B. F., 1928, Scarps of the southwestern Sierra Nevada, California: Geol. Soc. America Bull., v. 39, no. 4, p. 1017–1030.

Hills, T. M., 1928, Glaciation of the upper Kern Canyon and its tributaries: Sierra Club Bull., v. 12, p. 17–19.

Hinds, N. E. A., 1952, Evolution of the California landscape: California Div. Mines Bull. 158, 240 p.

Hudson, F. S., 1960, Post-Pliocene uplift of the Sierra Nevada, California: Geol. Soc. America Bull., v. 71, no. 11, p. 1547–1573.

Jenkins, O. P., 1938, Geologic map of California: California Div. Mines, scale 1 : 500,000.

Jepson, W. L., 1910, The Silva of California: Berkeley, California Univ. Mem., v. 2, 480 p.

King, Clarence, 1872, Mountaineering in the Sierra Nevada: Boston, James R. Osgood & Co., 292 p.

Knopf, Adolph, 1918, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California, *with a section on* The stratigraphy of the Inyo Range, by Edwin Kirk: U.S. Geol. Survey Prof. Paper 110, 130 p.

Knopf, Adolph, and Thelen, P., 1905, Sketch of the geology of Mineral King, California: California Univ. Dept. Geology Bull., v. 4, no. 12, p. 227–262.

Lawson, A. C., 1904, The Geomorphogeny of the upper Kern Basin: California Univ. Dept. Geology Bull., v. 3, no. 15, p. 291–376.

——— 1906, The geomorphic features of the middle Kern [California]: California Univ. Dept. Geology Bull., v. 4, no. 16, p. 397–409.

LeConte, J. N., 1907, The High Sierra of California: Alpina Americana, no. 1, p. 1–16.

Matthes, F. E., 1926, Kings River Canyon and Yosemite Valley: Sierra Club Bull., v. 12, no. 3, p. 224–236.

——— 1929, Multiple glaciation in the Sierra Nevada: Science, new series, v. 70, p. 75–76.

——— 1930, Geologic history of the Yosemite Valley: U.S. Geol. Survey Prof. Paper 160, 137 p.

——— 1933, Geography and geology of the Sierra Nevada, *in* Middle California and western Nevada: Internat. Geol. Cong., 16th, Washington, D.C., Guidebook 16, p. 26–40.

——— 1937, The geologic history of Mount Whitney: Sierra Club Bull., v. 22, no. 1, p. 1–18.

——— 1938, Avalanche sculpture in the Sierra Nevada of California: Internat. Geodetic and Geophys. Union, Assoc. Internat. Hydrol. Sci. Bull. 23, p. 631–637.

——— 1947, A geologist's view, *in* Peattie, Roderick, ed., The Sierra Nevada: New York, Vanguard Press, p. 166–214.

Matthes, F. E. (Fryxell, Fritiof, ed.), 1950a, Sequoia National Park, a geological album: Berkeley, California Univ. Press, 136 p.

——— 1950b, The incomparable valley, a geological interpretation of the Yosemite: Berkeley, California Univ. Press, 160 p.

Matthes, F. E., 1960, Reconnaissance of the geomorphology and glacial geology of the San Joaquin Basin, Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 329, 62 p.

Mayo, E. B., 1941, Deformation in the interval Mount Lyell–Mount Whitney, California: Geol. Soc. America Bull., v. 52, no. 7, p. 1001–1084.

——— 1947, Structure plan of the southern Sierra Nevada: Geol. Soc. America Bull., v. 58, no. 6, p. 495–504.

Miller, W. J., 1931, Geologic sections across the southern Sierra Nevada of California: California Univ. Dept. Geol. Sci. Bull., v. 20, no. 9, p. 331–360.

Muir, John, (Colby, W. E., ed.), 1950, Studies in the Sierra: San Francisco, The Sierra Club, 103 p.

Russell, R. J., 1938, Climates of California: Berkeley, California Univ. Pubs. Geography, v. 2, p. 73–84.

——— 1947, Sierra climate, *in* Peattie, Roderick, ed., The Sierra Nevada—The range of light: New York, Vanguard Press, p. 323–340.

Sierra Club, 1893–1961: Sierra Club Bull., v. 1–46.

Starr, W. A., Jr., 1953, Guide to the John Muir Trail and the High Sierra region: 5th ed., San Francisco, The Sierra Club, 130 p.

Sudworth, George B., 1908, Forest trees of the Pacific slope: U.S. Dept. Agriculture Forest Service, 441 p.

Voge, Hervey, 1937, The age of the top of Mount Whitney: Science, new series, v. 86, supp. 2226, p. 6.

Voge, Hervey, ed., 1954, A climber's guide to the High Sierra: San Francisco, The Sierra Club, 301 p.

Webb, R. W., 1936, Kern Canyon fault, southern Sierra Nevada: Jour. Geology, v. 44, no. 5, p. 631–638.

——— 1938, Relations between wall rock and intrusives in the crystalline complex of the southern Sierra Nevada of California: Jour. Geology, v. 46, no. 3, p. 310–320.

——— 1946, Geomorphology of the middle Kern River Basin, southern Sierra Nevada, California: Geol. Soc. America Bull., v. 57, no. 4, p. 355–382.

Webb, R. W., 1950, Volcanic geology of Toowa Valley, southern Sierra Nevada, California: Geol. Soc. America Bull., v. 61, no. 4, p. 349–357.

——— 1952, Upland meadows of southern Sierra Nevada, California [abs.]; Geol. Soc. America Bull., v. 63, no. 12, p. 1309.

White, J. R., and Pusateri, S. J., 1949, Sequoia and Kings Canyon National Parks: Palo Alto, Calif., Stanford Univ. Press, 212 p.

Whitney, J. D., 1865, Report of progress and synopsis of the field work from 1860–1864, v. 1 *of* Geology: California Geol. Survey, 498 p.

INDEX

[Major references are in italic]