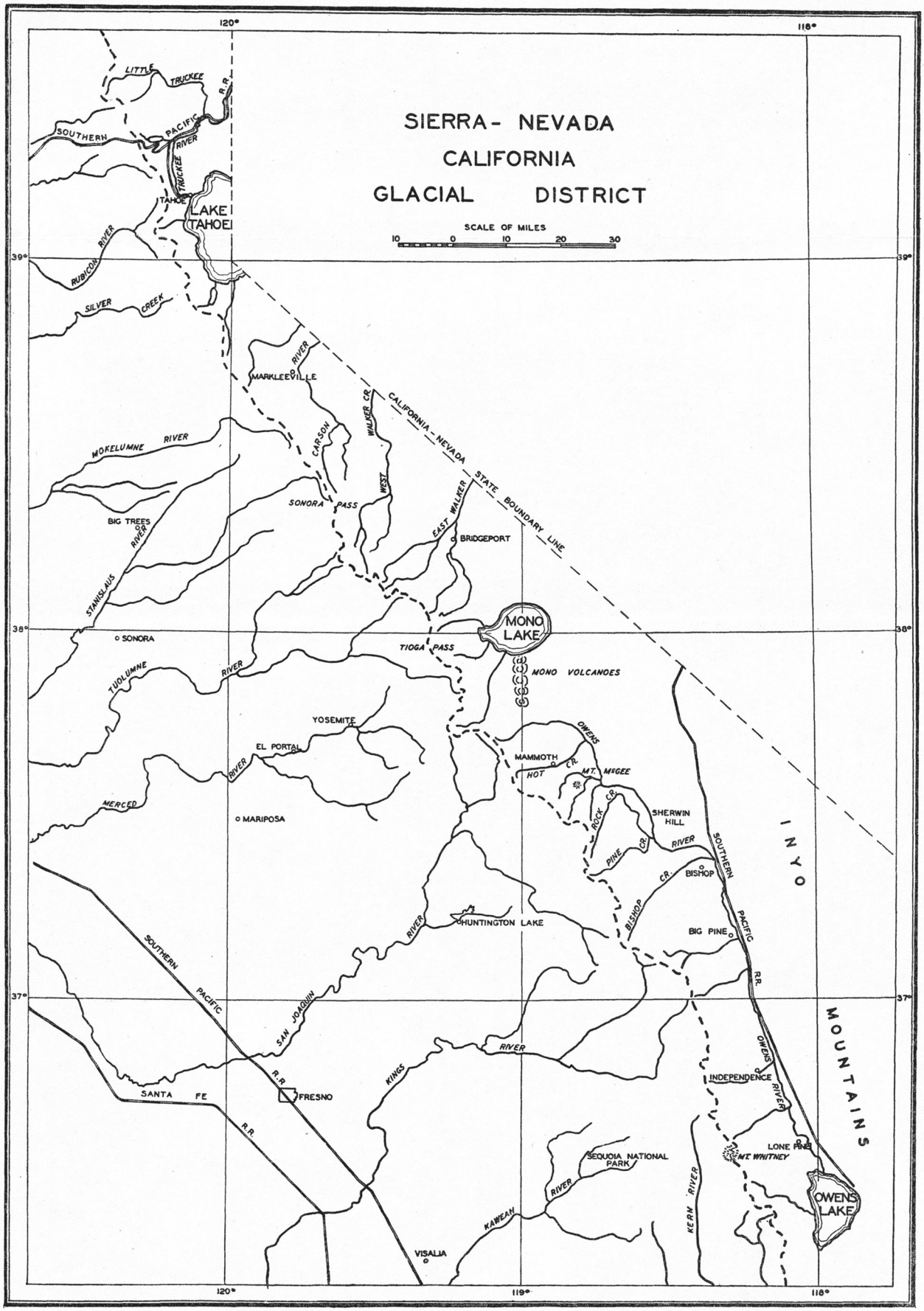

MAP OF THE SIERRA NEVADA SHOWING LOCALITIES MENTIONED IN THE PAPER.

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PLEISTOCENE GLACIATION IN THE SIERRA NEVADA AND BASIN RANGES [1]

BY ELIOT BLACKWELDER

(Read before the Geological Society December 27, 1929)

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INTRODUCTION

Lest the title of this paper may lead the reader to suppose that it contains a detailed account of the glacial phenomena of this vast region, it should be explained at the outset that it is concerned with the general facts of glacial history and the correlation of the events with those already better known in the Rocky Mountains and the eastern States. Although

[1] Manuscript received by the Secretary of the Society May 12, 1931.

the writer has reconnoitered most of the ranges in the Great Basin, he has devoted his attention largely to the study of the dry eastern slope of the Sierra Nevada, where the glacial features are best displayed free from obscuring forests. There he has visited most of the glaciated valleys but has mapped only a few of them in the detail which their interest merits. It will take many years to complete the mapping, and that work will necessarily be done largely by others.

Earlier Work

That the Sierra Navada and other ranges of the West were formerly modified by glacial action was recognized as early as the time of J. D. Whitney (1865) and was a commonplace in the days of the Survey of the 40th Parallel (1871–1878). John Muir (1872) announced that small living glaciers still exist in the high Sierra.

King and Hague (1878) and I. C. Russell (1885) reported the effects of local glaciation in the Ruby, Shoshone, Star Peak, and Granite ranges of Nevada. Others have observed cirques and moraines in the Snake, Schell Creek, and Carson ranges in Nevada, the Onequi Range of Utah and the White Mountains of California. It is probable that most of the Basin Ranges that reach altitudes of 10,000–11,000 feet harbored small glaciers in the later part of the Pleistocene period.

For several decades there was a controversy regarding the effects of the glaciers upon the topography of the range. Some, of whom John Muir was the leader, ascribed to ice action the chief sculptural features of the present scenery. Turner, Matthes, and others, on the contrary, regarded the glaciers as only modifiers of a stream-carved mountain complex. The latter view now prevails.

Current knowledge of the glacial history of the Sierra Nevada has been derived largely from the studies of Russell, Johnson, and Knopf on the eastern slope, and of Turner and Matthes on the western slope. Russell (1889, pages 341 and 392), who was assisted in the field for a time by W J McGee and W. D. Johnson, recognized that there had been three distinct glacial advances, each followed by a retreat, but did not venture the opinion that there were distinct interglacial epochs. He did, however, conclude (page 371) that the two principal advances of the glaciers were contemporaneous with the two high-water stages of Lakes Bonneville and Lahontan. This hesitancy to recognize two distinct glacial epochs is the more strange, because Gilbert (1890), under whose direction Russell has been working, had previously inferred that there must have been two glacial epochs in the Cordilleran region in general. Turner

(1898), in describing the geology of the Big Trees Quadrangle, on the western slope, appears to have been the first to state definitely that two separate stages were recognizable in the Sierra Nevada.

In the years 1905–6–7 Willard D. Johnson, of the United States Geological Survey, made a detailed survey of the glacial features along the east flank of the Sierra Nevada between the West Walker River and Mono Lake. His previous experience in the Mono Lake basin, under the able guidance of I. C. Russell, enhanced his fitness for extending his glacial studies along the range. In the course of this work he recognized moraines of two distinct ages and eroded remnants of till that was much older. On account of his sudden and untimely death, Johnson left no report of these studies and nothing has been published regarding them. His field notes and an excellent series of annotated photographs, preserved in the files of the United States Geological Survey, however, reveal the plain fact that he found and recognized these three glacial stages long before any one else had worked them out. Through the kindness of Mr. F. E. Matthes the writer has been permitted to examine part of the material in the Survey's possession. As the district examined by Johnson is one of the most favorable anywhere in the Pacific mountain belt, it is regrettable that his results were not published at the time.

In 1918 Knopf described the old and young moraines in the Owens Valley section of the eastern front of the range, and added some interesting new proofs of their distinctness. He was the first to publish a map of part of the Sierra Nevada on which the early and late moraines were separately delineated.

The most elaborate glacial study thus far made in the Sierra Nevada has been carried on by Matthes on the western slope, from the Yosemite National Park southward to Kings River. Part of his results are embodied in the excellent memoir (Matthes, 1931) which came from the press after this paper was completed. No report on the glaciation of any other western district equals it.

The existence of three sets of moraines, originally suggested by Russell (1889, page 341), was more definitely announced in 1927, when Blackwelder (1928) presented the evidence for the eastern slope before the Geological Society of America. Matthes (1928) independently published similar evidence for the western slope. In the following year Blackwelder (1930) found deposits believed to represent a fourth and still older glaciation. Evidence already in hand suggests the early realization of Antevs' (1925) prediction that five glacial stages may in time be recognized in the western mountains, corresponding to the five stages in

FIGURE 1.—*Blacksmith Canyon, Southwest of Bridgeport*

The photograph shows bare glacial canyon and ragged granitic mountains (altitude 12,000 feet) of the Tioga stage.

the central plains region of the United States. Assuming that glacial epochs are due to general changes of climate of worldwide influence, it is logical to suppose that similar advances and retreats of the ice occurred in many parts of the globe at the same times.

The writer's own studies have been carried on principally along the eastern side of the Sierra Nevada, from the Truckee Valley on the north to Owens Valley on the south, but they have also included the careful examination of such canyons as the Yosemite, Stanislaus, American, and Yuba on the western slope. The eastern side is a much more favorable place for glacial studies, because it is almost free from the dense forest that hinders geologic observations on the western slope, and there is much less soil on the older moraines. The region[2] around Mono Lake and within 60 miles of it to the northwest and southeast appears to offer the best opportunity for deciphering the glacial history, and therefore the attention of the writer has been concentrated upon that district. From Lake Tahoe northward the forest becomes a serious hindrance on the eastern slope as well as on the west.

Eastern Slope of the Sierra Nevada

Validity and number of the glacial stages

It has been suggested that the Pleistocene period on the Pacific slope comprised only one glacial epoch, but that there were notable retreats and advances of the ice within that single epoch. Under this view, even modern times might be considered a part of the glacial epoch, since a few of the Sierra Nevada glaciers have not entirely disappeared but have merely shrunk back into their cirques. Mount Shasta and other high peaks farther north harbor glaciers of considerable size, and in Alaska there are great ice tongues much larger than any that existed in the Sierra Nevada, even during the time of severest glaciation. The difference of opinion is more apparent than real. It is only a matter of definition or viewpoint.

Since it seems not improbable that the Pleistocene period will in time be divided into several epochs of widespread application, as recently suggested by Eaton (1928) and others, the writer will use at present the terms *age* and *stage* for the times and deposits of the major individual glacial and interglacial advances and retreats. A glacial age will be regarded as a time when many of the deep canyons of the Sierra Nevada were occupied by long tongues of ice. An interglacial age, on the con-

[2] Shown on Pyramid Peak, Markleeville, Dardanelles, Bridgeport, Mount Lyell, Mount Morrison, Mount Goddard, Bishop, and Mount Whitney quadrangles, of the U. S. Geological Survey's Topographic Map of the United States.

trary, was a time when such glaciers shrank to mere vestiges or entirely disappeared. The main canyons were then occupied by lakes and streams, and the activities of glaciers became negligible, although remnants of them may have existed in the valley-head cirques.

It has also been objected that the time between the last two ages recognized in this paper was so short that they should be regarded as merely two subdivisions of one age, but geologic ages have no standard length. In general, the later periods and epochs of Earth history are progressively shorter, because their events can be elaborated in more detail. Adhering to the definition of glacial and interglacial ages stated above, the writer recognizes four ages of glaciation, frankly admitting that they were not equally spaced in time. In so doing he is following the current usage of the central and eastern United States.

Although the district has been carefully studied at the more favorable localities, so that the four glacial epochs in the Pleistocene period in California may be clearly distinguished, a much larger amount of detailed work remains to be done before all the individual glacial features can be classified according to their age and a complete historical map compiled. In this paper it is purposed to explain the evidence on which is based the general conclusion that we may divide the glacial period in the Sierra Nevada into four and perhaps five ages. It is not an exhaustive report on the glaciation of the region.

The four glacial stages now recognized are herein designated by local names which will permit the addition of others that may be discovered later, as a numerical series would not, and on the other hand will not arouse controversy regarding correlation, as would the use of such terms as "Wisconsin," "Iowan," or "Kansan." In stratigraphic order, these stages are:

4. Tioga stage
3. Tahoe stage
2. Sherwin stage
1. McGee stage

If a fifth glacial stage is eventually differentiated, evidence now in hand suggests that it will lie between the Sherwin and Tahoe stages of the above table. The best localities for the study of this evidence are southwest of Mono Lake, near the fork of West Walker River and near Truckee.

CRITERIA OF AGE

In differentiating the glacial stages of the Sierra Nevada many kinds of evidence have been used. Some of the criteria that are commonly

utilized in the eastern United States have been found to be of little value or of only local applicability in California, but fortunately others have been found to take their places. For example, the soil profile is so in-

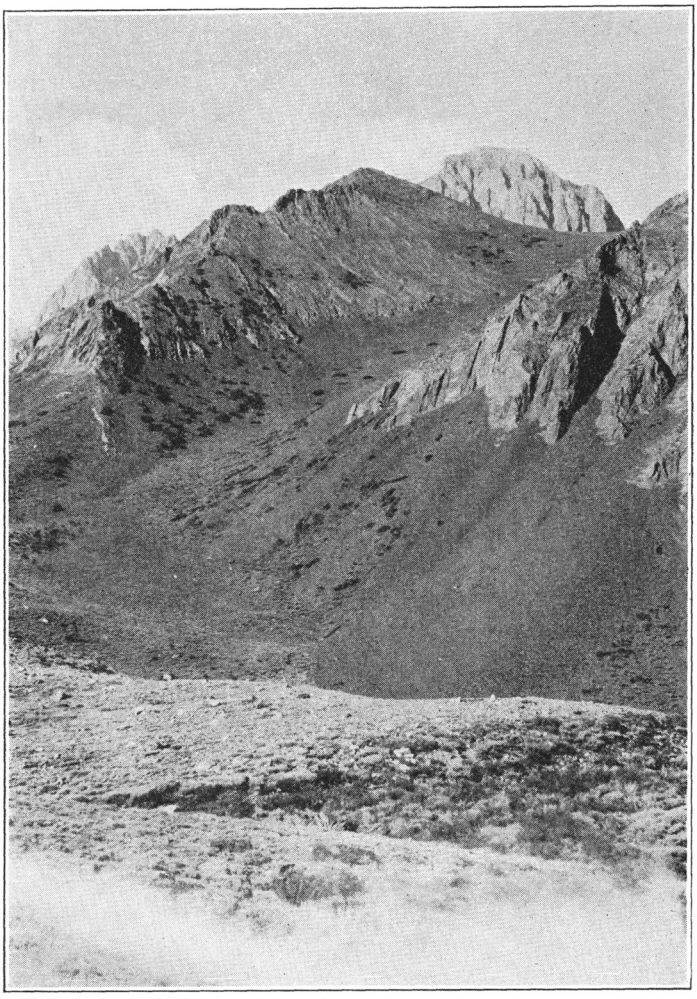


FIGURE 2.—*Talus-filled Glacial Valleys of the Tahoe Stage*
Locality is northwest of Mount McGee. Photograph by George L. Green.

completely developed in the semiarid regions that instead of being one of the chief reliances of the glacialist, as it is in Iowa and Illinois (Kay, 1929; Leighton and MacClintock, 1930), it has not yet been found to give decisive results in the West. No old interbedded soil zones or sheets of

loess and no interglacial fossils have thus far been found in the region. On the other hand, topographic relations, the progress of decay of glacial boulders, and erosional forms have proved to be much more serviceable in California than in the plains that were covered by the great ice sheets. Altogether about 20 distinct criteria have been used in the field during the study of this subject. It seems advisable to explain them somewhat fully at this juncture, so that other students of the region may under-

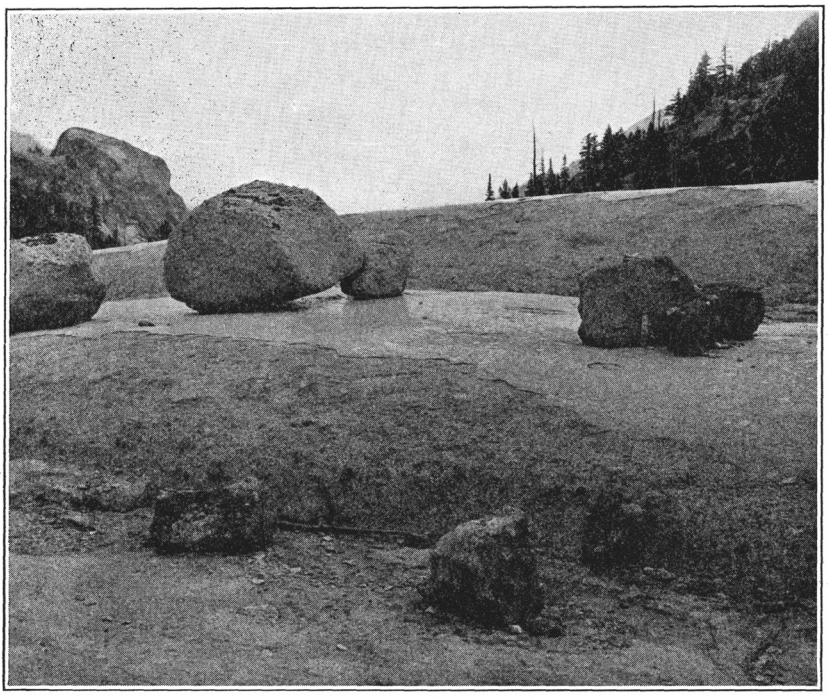


FIGURE 3.—*Glaciated Surface of Granite, of the Tioga Stage*
The glass-like polished surface has been partly destroyed by some process of exfoliation. (Six-inch scale against boulder.)

stand the basis of the opinions expressed later in this paper. Most of the criteria depend on the changes that have taken place since the glacial action ceased. Others have to do with the relations of the glaciers to other features, such as lakes and volcanoes.

In general, it has been found that the moraines of each of the several stages were less extensive than those of the next preceding. Hence, in a particular valley the moraines nearest the head are the youngest and those farthest out are commonly the oldest. It has also been found that the

moraines of the latest stage were generally puny in size as compared with the bulky embankments of the Tahoe stage. These criteria, however, are not decisive. They are merely suggestive.

The advance of talus cones, especially in the cirques, is a criterion of some value in differentiating the last two stages, but is useless for earlier times because the older cirques have been destroyed by erosion. It is essential in each case to consider the kind of rock and the joint systems. One should compare only cirques of similar lithology and structure or else make due allowance for the differences. A young cirque in closely

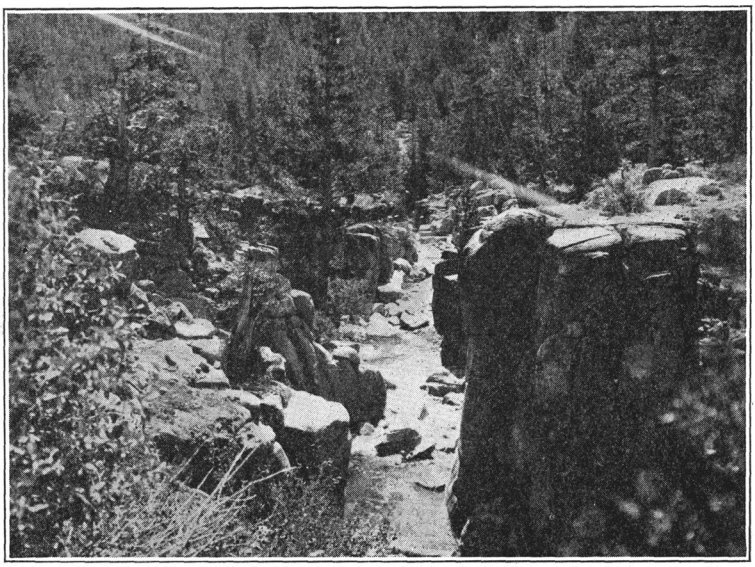


FIGURE 4.—*Leavitt Creek, East of Sonora Pass*

The photograph shows a gorge eroded to a depth of 35 feet in well-jointed granite since the Tahoe age.

jointed lava or slate may contain more talus than an old cirque in massive granite, because the rate of talus formation is very different in the two cases.

The fresh ragged appearance of cirques is a related criterion subject to much the same limitations. Allowing for lithology and jointing, the older cirques are decidedly less craggy and wildly picturesque, have more soil and hence more vegetation upon their slopes. One speaks of them as being subdued.

The preservation of polished and striated rock surfaces on roches moutonnées and elsewhere is a useful criterion if applied with careful regard to the nature of the rock and the extent to which it has been exposed to destructive surface agencies. Dense siliceous rocks preserve striæ and even polish for vast lengths of time, while such rocks as granite and marble lose them quickly by weathering. A cover of only a few inches of soil protects against forest fires, which are by far the most destructive agent of

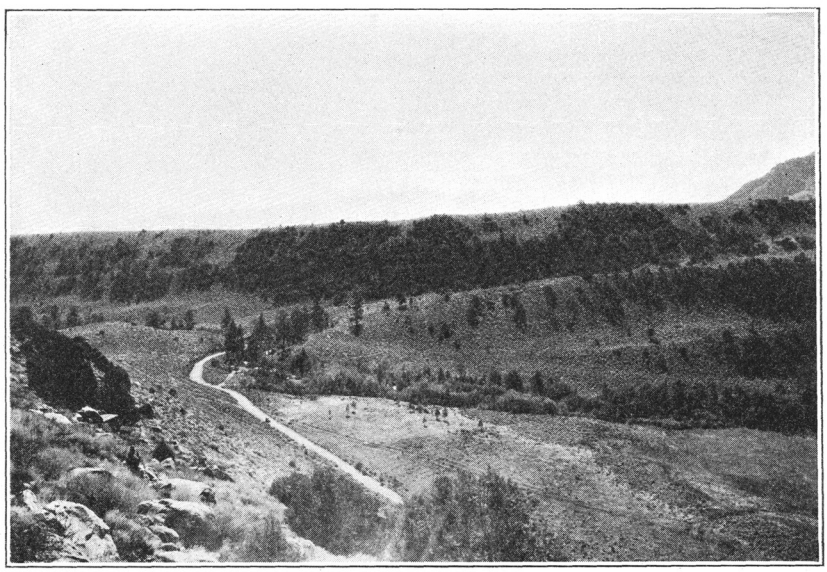


FIGURE 5.—*Postglacial Notch in a Terminal Moraine of the Tioga Stage*

The locality is Leevining Canyon, near Mono Lake. The stream passes through to the right of the sharp bend in the road. In the rear a huge lateral moraine of the Tahoe stage extends across the view.

weathering in the mountains, but such a covering favors chemical alterations. Allowing for the variables, one may say that striated surfaces of Tioga age are extensively preserved even on granite, whereas those of Tahoe age are seldom preserved on granite but are well retained on quartz and aplite veins, quartzite, hornfels, and the harder slates. Glaciated rock surfaces of still earlier ages have rarely been found on the western slope, although striated boulders are locally rather common in fresh excavations.

The depth of valleys cut by axial creeks in the glacial floor is a criterion of importance, but one that likewise must be used with discrimination. Creeks of different sizes and gradients excavate at different rates. They

may sink their channels deeply in till, not so deeply in jointed lava, and only slightly in massive granite that has widely spaced joints. Extensive observations enable one to judge whether the gorge cut by a certain stream under the local conditions is appropriate to the duration of post-Tioga or post-Tahoe time. No general rule can be given.

The extent to which the terminal moraine has been destroyed by the axial stream in widening its flood plain after it has cut down to grade (profile of equilibrium) is a significant type of evidence related to the last one. Generally the Tioga moraines have been merely notched and the axial creeks are still above grade. The Tahoe moraines have, on the other hand, been breached more or less widely and in many cases the frontal part has been entirely consumed in the development of a spacious flood plain. As in the preceding case, the local factors must have due consideration, for they modify the results.

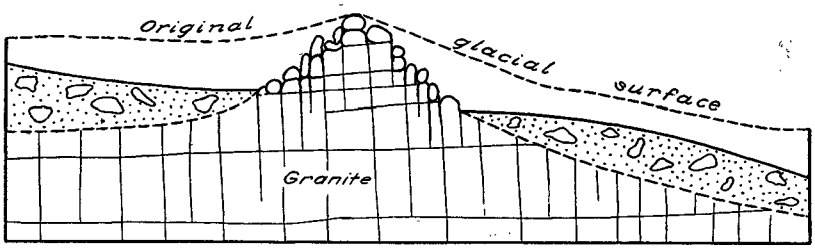


FIGURE 6.—*Diagram of a Granite Knoll*

This knoll has been developed by erosion and weathering on the site of a till-veneered rock mound which has not been glaciated since the Sherwin epoch. The locality is Dog Creek, south of Bridgeport.

The general extent of valley growth in the moraines is one of the most useful considerations. Near large streams and on steep slopes ravines advance rapidly in till. A moraine with but few short ravines is probably younger than another of broad gentle contour into which long graded branching ravines have advanced. In general the Sherwin till has been maturely dissected, but the Tahoe moraines still retain most of their distinctive glacial features.

The wastage of moraines by the complex action of weathering, wind, and rain-rills tends to leave rocky knolls standing out from their surfaces. Such crags of granite are rather common in areas of Sherwin till which have probably lost much of their original thickness by wind and rill action. They are lacking in the younger moraines or appear only as rounded ice-scoured mounds.

The destruction of lakes, either by lowering of outlets or by the advance of deltas, has made little progress since the last glacial age, but since Tahoe time it has been almost completed. The lakes of the latter age are now represented by gravelly plains more or less intrenched. Still older lakes can be recognized only by their deposits, since their original topography has been quite destroyed by erosion.

The depth of wind-laid deposits on moraines is locally of value in distinguishing different stages. Near Mono Lake a linear row of obsidian

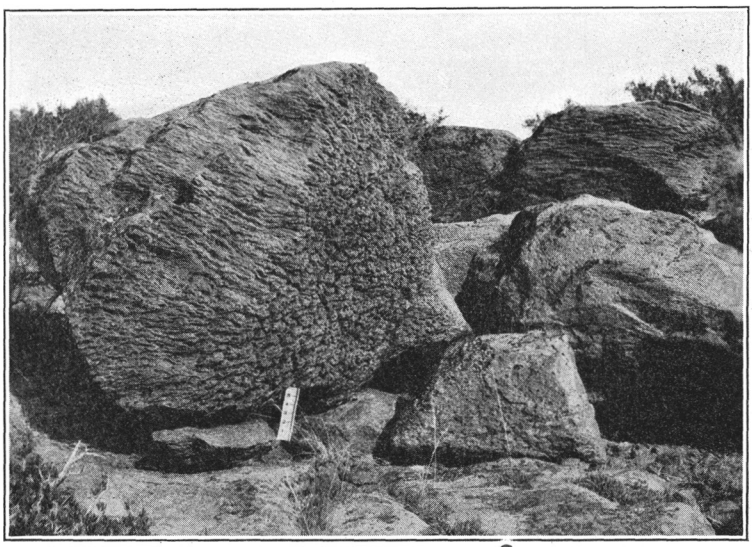


FIGURE 7.—*Top of Hunnewill Hill near Bridgeport*

The boulders of andesite were drilled and grooved by sandblasting during the Tahoe age. The wind came from the right.

volcanoes was formed by eruptions in the Pleistocene period. Copious showers of ash and pumice lapilli were then scattered for many miles. On the youngest moraines in the vicinity there is but little ash, except very near the cones, where it may exceed 2 feet in depth. On the next older moraine there is a thicker coat (2–7 feet) and on the Sherwin till there is locally enough (6–20 feet) to obliterate the morainic surface. Elsewhere the fine "soil" that mantles the Sherwin till in many places, in contrast with the Tahoe and especially with the Tioga moraines, is probably loessial in large part and its thickness is a rough measure of age. This criterion has not yet been much applied in the West but seems to offer some promise.

Weathering of the till is a familiar indication of age but one that has been much less used in the West than in the East. It is probably worthy of more study than has been given it thus far. The western tills are not so calcareous as those in the East and hence acid tests for leaching have not given significant results. The aridity in most parts of the West inhibits the development of a true soil profile; but on the moist western slope of the Sierra Nevada the Sherwin till has weathered to a somewhat rusty or tawny hue as compared with the light-buff color of the Tahoe till and the ashen gray of the youngest till. The depth to which the reddening has penetrated has not been satisfactorily determined.

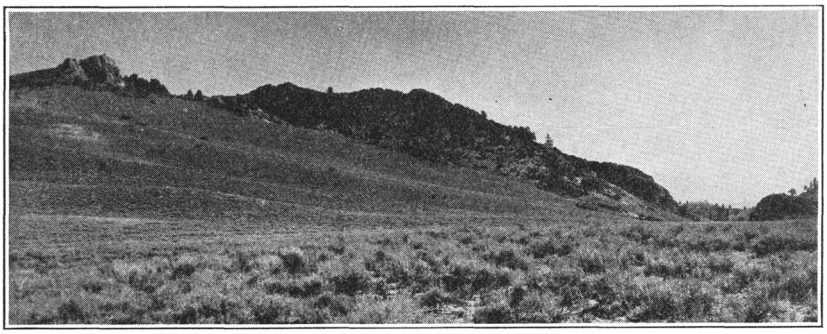


FIGURE 8.—*An Area Southeast of Fales Hot Spring, West Walker River*

The area shows scarcity of boulders on the maturely eroded surface of an ancient moraine of the Sherwin stage. The granite crags in the rear may be in part outside the glacial limit.

Weathering of boulders in the till is, however, one of the criteria that was found most useful in this investigation. Since the weathering of such rocks as quartzite, basalt, slate, granite, and marble can not be readily compared, it was found best to concentrate attention on a single type of rock—the average granodiorite of the Sierra Nevada batholith. Fortunately this occurs abundantly in most of the tills in the region. Boulders of this rock were then counted at certain places and classified as being (*a*) almost unweathered, (*b*) notably decayed on the surface but still solid, (*c*) greatly weathered, cavernous, or rotten. These figures constitute a ratio known in the field as the G. W. R. or "granite weathering ratio." A ratio of 90–10–0 would be sure indication of the latest age; one of 30–60–10 would be typical of the Tahoe stage; while one of 0–30–70 would be afforded by only the older tills. These ratios were found to apply in nearly every locality, but it was noted that on the moist western

slope of the Sierra Nevada decay has gone farther, and so the proportion of decayed boulders there is slightly greater in each stage than it is in the more arid regions. Since forest fires have done great damage in these wooded mountains and since fire shatters boulders rapidly and severely, one must learn to distinguish the effects of fire from those of chemical decay and consider only the latter in his classification for this purpose.

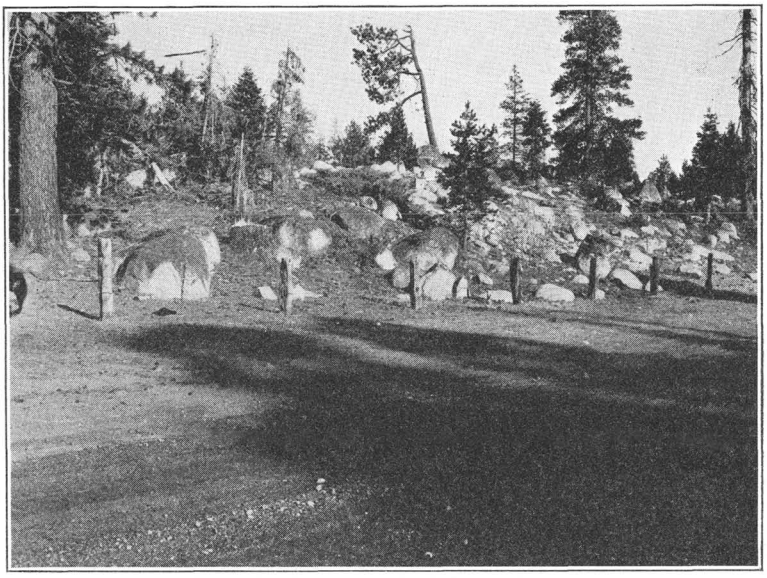


FIGURE 9.—*View South of Lake Tahoe*

Showing abundance of boulders on a low moraine of the Tioga stage.

The effects of the sandblast (Blackwelder, 1929) on boulders of the Tioga stage moraines are generally slight, but locally where such effects appear they are still fresh. On the Tahoe moraines many boulders properly situated with reference to wind exposure are notably chiselled by the sandblast, but the worn surfaces are now dull, partly crumbling, and somewhat exfoliated. On the Sherwin till similar surfaces are much more weathered. Although the sandblast may have operated at various times there is strong evidence to show that the rocks were generally carved during the presence of the glacier that made the moraine.

The frequency of boulders on the undisturbed till surfaces is a criterion of less value than weathering but is useful because it can be observed at long range and even in photographs. In general, the younger moraines are more bouldery than the older ones. In order to reduce this general

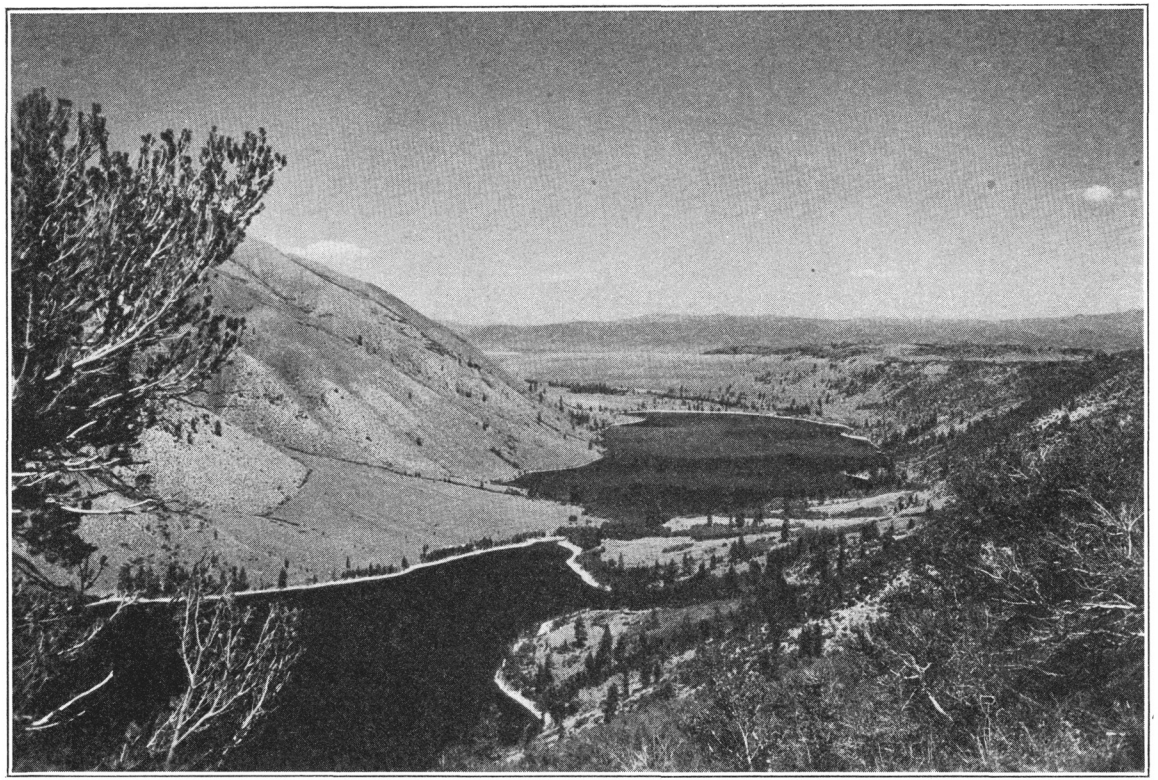


FIGURE 10.—*Lakes of the Tioga Stage*

Originally there was only one lake, which was held in by a low frontal moraine. Later the advance of mudflow fans from the adjacent lateral moraines constricted the valley and thus formed Twin Lakes, near Bridgeport. The large lateral moraine on the right belongs to the Tahoe stage.

fact to at least a rough quantitative basis, many counts were made along measured straight lines which could be easily reduced to terms of area. Thus, 34 boulders in 850 feet indicate 75 boulders per acre. Arbitrarily the count was limited to boulders over 1 foot in diameter. In regions of closely jointed rocks boulders are fewer than in those of massive blocky rocks. In certain topographic situations, as on the ridge crests and terrace brinks, boulders are relatively more abundant, because the earthy matter tends to be swept away from them. Boulders in depressions tend to become buried by the same process. These and other modifying factors will occur to the careful field student. By using due care the value of this criterion may be preserved. It is easy to apply and is generally available.

Much significance can be derived from the relations between the glacial features and other physiographic forms about which some age information is already available. Thus the shore terraces carved on the Tahoe moraines by the waves of greater Mono Lake show that the moraines are older than the last rise of the lake. The deltas made in the lakes can in some cases be traced back to a moraine. In a few places small faults cut the moraines or are covered by them. Near the Mono volcanoes a lava flow has poured down over a moraine and in other places moraines have been plastered upon lava flows of interglacial age.

The most useful criterion of this kind is the stream terraces that have been formed as a result of the aggrading and subsequent trenching of glacial valley trains. A careful study and measurement of these terraces showed a surprising uniformity for the several ages. The post-Tioga terraces are generally 15–30 feet high and the post-Tahoe terraces 50–75 feet. The still older terraces are harder to trace, but are usually much higher. On account of the length of the terrace systems it may become possible, by the careful tracing of them, to link them to other features, such as distant lakes, deposits of known age, and volcanic outflows. The study of these terraces has only begun.

Of all these criteria only a few can usually be applied in any one place. One of them alone affords only a tentative opinion, but when several of them all point to the same conclusion confidence is much strengthened.

RELATIVE LENGTHS OF THE AGES

There is no basis thus far for estimating in terms of years the times represented by the various glacial and interglacial stages. The best that can be done is to consider the lapse of time since the latest glaciers built their terminal moraines and to estimate roughly the duration of the other ages in terms of that unit.

So fresh and unaltered are the moraines and rock-scoured surfaces of the Tioga stage that one can not allow many thousands of years for the postglacial age. If one accepts the conclusions of De Geer and Antevs (1925) and the correlation of the Tioga with the Wisconsin and Würm stages, then the time since the retreat started may have been about 25,000 years and the present condition of deglaciation may have endured some 10,000 years.

The interval between the Tahoe and Tioga ages was estimated by Knopf (1918) to be about five units and by Miss Russell (1925) to be about two and a half units. Judging from the depth of erosion in rock by the axial creeks, the writer favors the former estimate rather than the latter.

The interval between the Sherwin and Tahoe stages has apparently not been estimated by any one thus far. All the evidence indicates a much longer time than the post-Tahoe interval. It seems more probable that it was of the order of 50 units rather than less.

The post-McGee interglacial age permitted the excavation of great mountain canyons several times as deep and spacious as those of the post-Sherwin age. Judging from this and the nearly complete destruction of the moraine system, the writer is disposed to consider this earliest interglacial age to have been about three to five times as long as the one following the Sherwin stage, or perhaps 150–250 units.

It will be readily conceded that very little confidence can be placed in such estimates, and yet they have their value in adding a certain amount of perspective to the historical view.

So closely are the Tioga and Tahoe stages related in time and in other respects that they might well be bracketed together as subdivisions of a single epoch. Such a course is urged by Matthes and others, while similar plans have been proposed recently by Kay (1931) and Leighton (1931) for the Iowan and Wisconsin stages of the central United States. It has the merit of indicating the fact of closer relationship.

GLACIAL STAGES ON THE EAST SIDE OF THE SIERRA NEVADA

Tioga stage.—Because it is best understood and may therefore be used as a basis for comparison, the latest age will be discussed first. In view of the possibility that still other ages may eventually be added to the four now recognized, geographic names have been adopted for them, in preference to the numbers which would otherwise be more convenient.

The latest of the four stages here recognized is so clearly identical with the Wisconsin, as defined in the Rocky Mountains and in the eastern

United States, that Matthes (1931) has adopted that name for the latest epoch in the Yosemite region. For the present, however, it seems best to retain a local name; and none of the names available seems more suitable than Tioga, for a glacier of this age occupied Tioga Pass and its lobes descended both southwest and northeast therefrom, leaving characteristic moraines and lakes. East slope localities where the moraines of this epoch are well displayed are Convict Lake, June Lake, Grant Lake, Leevining Canyon, Twin Lakes (Bridgeport Basin), Fallen Leaf Lake, and Donner Lake west of Truckee.

The glacial features that were made by the ice tongues of the Tioga epoch are even now almost as fresh and unaltered as at the time of their formation. The cirques are still as bare and ragged as if recently abandoned by the ice. Talus cones are few and small where the rocks are not closely jointed, and have not grown to large size even where the closer spacing of joints is favorable to frost action. The original polished and striated surface is still rather generally intact, even on such easily weathered rocks as coarse granite. Acres of polished and grooved rock are a familiar sight near Tenaya Lake (Yosemite National Park) and many other places in the high Sierra. If it were not for the destructive effects of forest fires, such surfaces would be even more completely preserved.

The lateral moraines generally stand out as bold embankments, marred only by a few landslides and by sharp ravines where tributary brooks descend the canyon sides. The terminal moraines are still complete, except for V-shaped notches through which the main streams tumble down to the plains beyond. As the distinctive glacial topography of the moraines is almost entirely preserved, it is generally an easy task to map them continuously.

Most of the valleys that were inhabited by glaciers of the fourth epoch now contain clear lakes 50 to 300 feet deep, some of which are a mile or more in length. The bouldery slopes commonly descend steeply into the water. Deltas at the upper ends of these lakes have grown forward only a small fraction of the original length of the lake, and the outlet streams have incised their morainic dams only 10–75 feet. Fallen Leaf Lake, near Lake Tahoe, held in by a compound loop of terminal moraines, is the largest lake of this type on the eastern slope of the range. Independence, Convict, and Donner lakes are similar. Only a few of the smaller and shallower lakes of this age have already disappeared. The rock-bound mountain tarns in the upper parts of the glacial troughs, largely surrounded by bare ice-scored rock mounds, are in substantially the same condition now as when the glaciers left them.

Typically the moraines of the Tioga epoch are very bouldery. The boulder frequency[4] averages about 2,000 (300–7,000) per acre. This excessive abundance of boulders on the surface is probably to be explained partly by the fact that few if any of them have been disintegrated by weathering, but chiefly by the fact that so little windblown dust has been deposited in postglacial time that the smaller boulders have not been buried.

Chemical weathering has made but little progress since the Tioga stage. Even among the granodiorite boulders many still retain striated surfaces, and about nine-tenths of them have suffered very little external change except where forest fires have shattered them. The fresh appearance of the average light gray granitic boulders, without rusty discoloration, soon becomes familiar. The color of the till itself is ashy gray, rather than buff or rusty as it is in the older tills.

In suitable situations, boulders of the Tioga stage have been slightly grooved and polished by sandblast action. Such surfaces are relatively fresh in appearance as contrasted with those on the Tahoe moraines.

In contrast to even the ravines which the axial streams have excavated in the till, are the narrow slots, only 1 to 8 feet deep, that they have worn in the bed rock, and even these narrow chanels may have been excavated largely by streams issuing from the ends of the glaciers during their final retreat. Such turbid streams must have been much more active rasps than the clear brooks that now occupy these channels.

In the canyons beyond the termini of the Tioga glaciers, gravel trains were built and later intrenched. The terraces thus formed are more continuous than any older ones and generally stand only 15–25 feet above normal stream-level. These lowest terraces have in several instances been traced directly into the Tioga stage moraines. The relations are well shown west of Truckee and southwest of Bishop. An exception is to be noted in Mono Valley where the fall of the lake surface some 600 feet on account of excessive evaporation caused a correspondingly greater intrenchment of the glacio-fluvial deposits.

The volcanic activity, of which there is abundant evidence in and south of Mono Lake, seems to have ceased almost entirely before the last glacial epoch. As shown by Russell (1889), there are a few small pit craters and low cones that appear to be very recent, and the one at the north end of the Mono volcanic chain was clearly formed after Mono Lake receded from its highest level. Since this expansion of the lake is reasonably to

[4] By this is meant the number of boulders over one foot in diameter actually exposed on the surface, per acre. See page 880.

be correlated with the Tioga glacial epoch, these youngest craters may be regarded as postglacial in age. Unlike the older moraines of that district, the youngest moraines have so little volcanic ash upon their surfaces that it appears to form a layer of appreciable thickness in only a few localities near the Mono cones. Northeast of June Lake, road cuts show that the coat of ash is as much as 2–4 feet thick.

The glaciers of the Tioga epoch were smaller than their predecessors, and so their moraines are now generally found arranged concentrically within the earlier moraines of the Tahoe stage. The average relief of the moraine fronts is about 25 feet. Few are more than 75 feet and some are hardly 10 feet high. Being much less conspicuous, these younger moraines have often been overlooked or regarded as mere recessional loops related to the great laterals which are here referred to the preceding Tahoe stage. A rough estimate of relative bulks indicates that the great Tahoe moraines of Bridgeport Basin contain about 50 times as much material as the Tioga moraine loops in the same valley.

Although some of the Tioga stage glaciers on the western slope descended to elevations less than 6,000 feet above sealevel, those on the dry eastern slope were unable to creep down so far, partly no doubt because the climatic conditions were much less favorable to glacier growth than on the west side, but partly because the base of the range stands, in most places, above 6,000 feet. The average elevation of the ends of fifteen terminal moraines of this epoch along the eastern side of the Sierra Nevada proved to be about 7,500 feet and the lowest one thus far examined by the writer (Big Pine) extends down to about 5,750 feet above sealevel.

Tahoe stage.—The most conspicuous moraines in the Sierra Nevada are those of the Tahoe age. They are well developed and easily studied in the Big Pine, Bishop, and Pine Creek districts of Owens Valley and in nearly every important canyon northward to Truckee and beyond. In general, moraines of this age have been recognized in all the valleys that also contained glaciers of the Tioga age and also in some that did not. One of the most favorable localities for the study of such moraines is west and south of Mono Lake. The name is derived from Lake Tahoe, along the western shore of which several large glaciers of this age descended from the Sierra Nevada and built strong moraines. Lake Tahoe itself is, however, not of glacial origin.

The primary glacial features of the Tahoe epoch are still fairly well preserved and are easily recognizable, although they have been notably marred and obscured by the processes of weathering, stream erosion, and deposition. The fact that they are generally associated closely with the

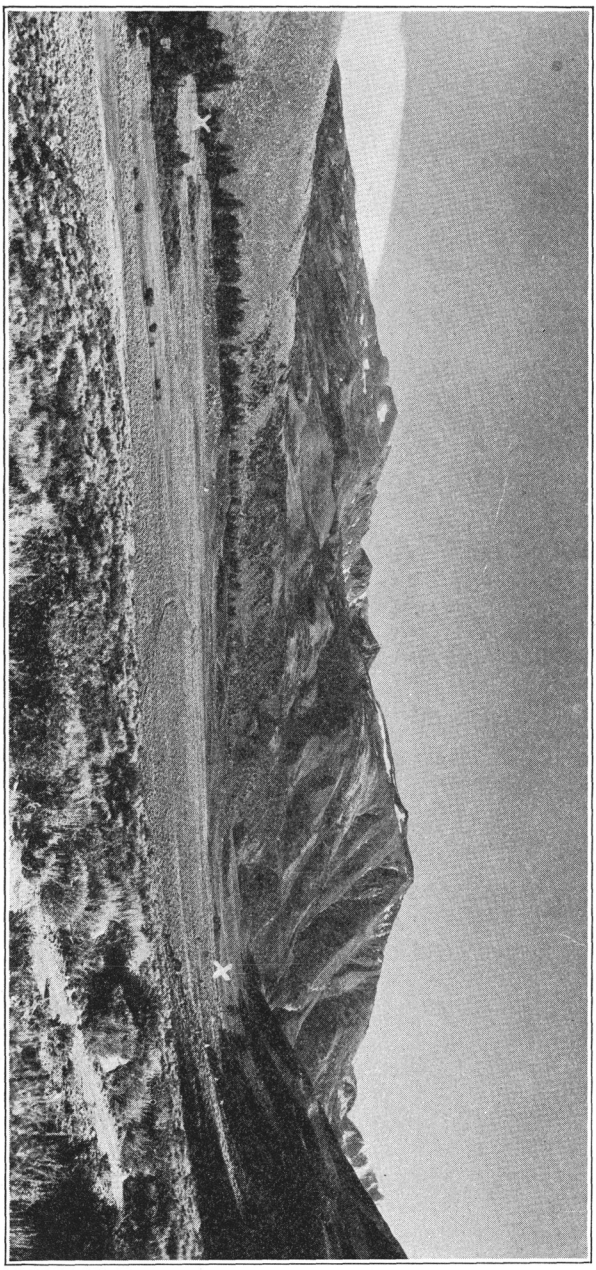


FIGURE 11.—*Robinson Canyon near Bridgeport*

The view shows a frontal moraine of the Tioga stage (XX) only 30 feet high, with a 700-foot lateral moraine of the earlier (Tahoe) stage on the left.

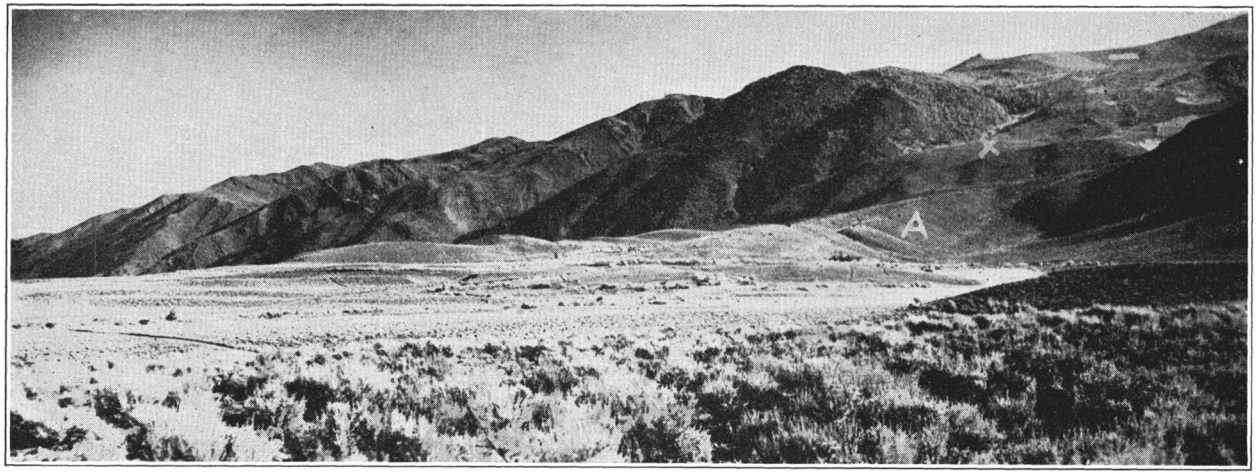


FIGURE 12.—*Lacustrine Terraces of post-Tahoe Age*

The locality is the front of the Sierra Nevada west of Mono Lake. A long morainal tongue (*A*) protrudes from Lundy Canyon. The waves of Mono Lake during the Tioga stage engraved six or more terraces upon the flanks of the moraine. Much older till of the Sherwin stage appears on the rocky spurs to the right (X).

corresponding features of the Tioga epoch facilitates comparisons between the two. Even so, close scrutiny is often required to distinguish them. Some observers have been so impressed with the close relations between the Tioga and Tahoe stages that, although conceding the differences, they have preferred to regard them as one stage with two advances separated by a retreat. Knopf (1918) and others have, however, considered them distinct.

Many of the cirques that were excavated during the Tahoe epoch were reoccupied and rejuvenated during the Tioga epoch. In such cases the

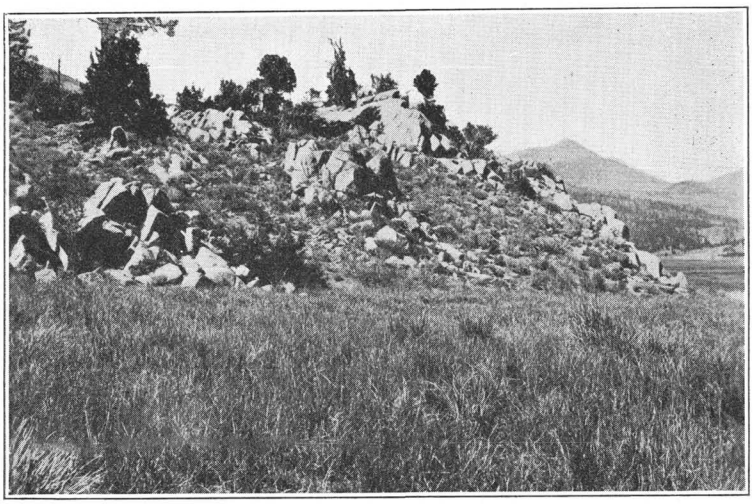


FIGURE 13.—*A granite Roche Moutonnée of the Tahoe Stage*

The view, taken in Leavitt Meadow, shows how weathering and erosion have changed its original smooth, rounded contour to one that is more angular and ragged.

forms left by the earlier glaciers have been largely effaced by their successors. Many of the old cirques, however, were not occupied by more recent glaciers, and hence their contours are now subdued by weathering, so that they lack the barren, ragged aspect of the younger ones. Some have been gashed by ravines. Talus and even soil have formed in others to such an extent that the plucked rock surfaces are much obscured. The accumulation of soil has permitted the growth of forest and shrubbery which further help to conceal the original glacial features and soften their appearance. Although in some cases it is uncertain whether a particular cirque dates from the Tahoe epoch, there is nevertheless a prevailing difference in aspect which becomes familiar to one who studies

and compares a series of these glaciated valleys. Above elevations of 6,000–8,000 feet the Sierra Nevada is characterized by vast areas of comparatively bare granite, upon which so little forest grows that the rock stands out gray or white. Some of this dates from the latest or Tioga age, but by far the greatest expanse is a legacy of the Tahoe age, when the heads of the great glaciers on the western slope were largely confluent across the divides.

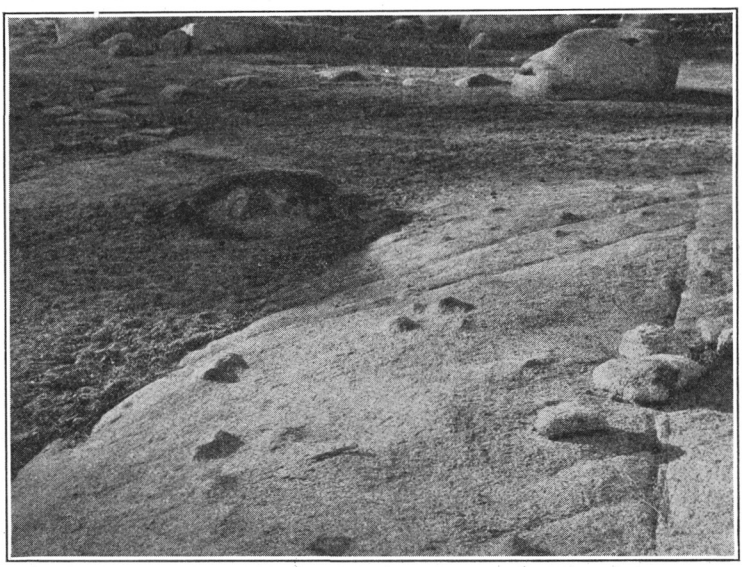
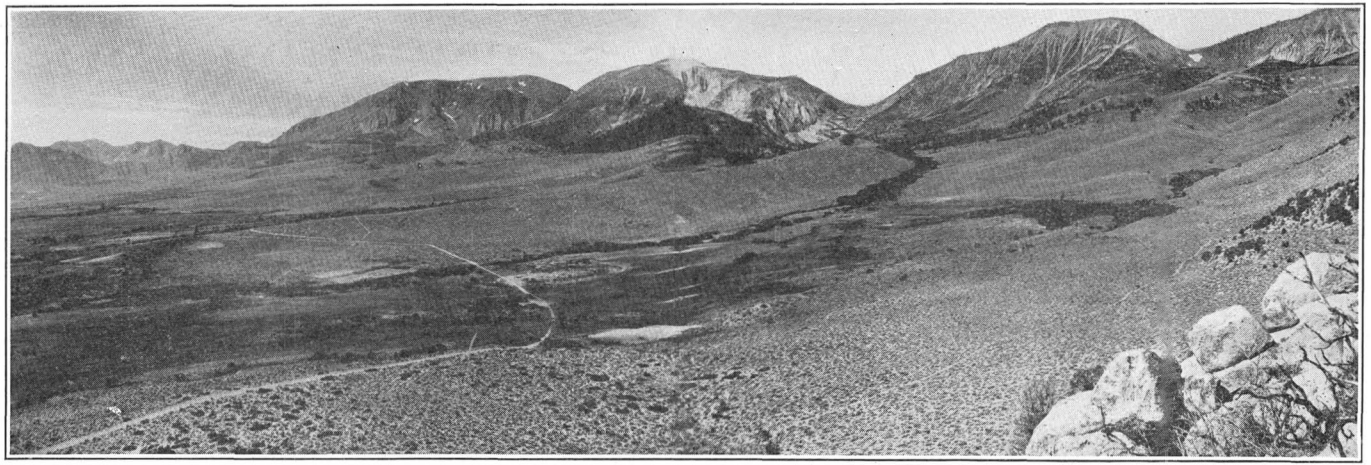


FIGURE 14.—*Glaciated Outcrop of Granite of the Tahoe Stage*

Weathering has destroyed the original striated surface, except on the dense resistant xenoliths which now stand out about 1 inch in relief. Near Blood's ranch, Big Trees quadrangle.

In the bottoms of the glacial troughs old roches moutonnées are easily recognizable by their rounded forms, but when they are examined for glacial polish and striations it is found that such surfaces have almost entirely disappeared. In the areas where granite is the bed rock, one finds only scattered traces of the original surface, except beneath a protective covering of earth or sod. Here and there, however, striæ may be found on quartz or aplite veins that have resisted weathering. Many of these protrude several inches from the general surface, thus affording a measure of the depth to which the granite has wasted away. Where dense resistant rocks such as hornfels or quartzite occur, large areas of glaciated surface may still be found, although usually they are dull and much shattered by the action of fire and frost.



MORAINES ALONG THE EAST BASE OF THE SIERRA NEVADA SOUTHWEST OF MONO LAKE

In the center of the view a large smooth lateral moraine of the Tahoe stage extends out from Bloody Canyon. The scarcity of boulders and the absence of a terminal moraine are typical. To the right, in front of Mount Dana, is a maturely eroded mass of till of the Sherwin stage resting upon granite; the white line marks the contact. The Tioga stage moraines of Bloody Canyon are scarcely visible.

The moraines of the Tahoe stage are commonly so large and massive that they overshadow the rather diminutive moraines of the Tioga stage. Old lateral moraines standing 500 to 1,000 feet high are not uncommon, as at Fallen Leaf Lake and west of Bridgeport. In most cases the terminal part of the moraine has been largely removed by the axial stream. The latter has generally reached grade and developed a flood plain of notable width, but its tributaries, most of which are short intermittent streams, have done little more than cut notches in the lateral moraines, leaving the isolated sections still intact. At the mouth of Laurel Canyon, in the Mammoth Basin, the huge glacial embankment which stands nearly 1,300 feet above the plain has been breached in the middle and the opening is now occupied by a small moraine lobe belonging to the Tioga stage.

Deep ravines 2 miles long have been eroded back into the large moraines of the Tahoe stage southwest of Bishop and southeast of Mammoth.[5]

The original knob-and-kettle features of the moraines are still preserved here and there, but around the margins the growth of ravines has locally obscured them.

Two imposing moraine loops were built on the west side of the Mono Lake basin by large glaciers of the Tahoe age. Subsequently, erosion destroyed most of the terminal part and left only the lateral ridges. When the lake afterward rose to its maximum height, its waves carved well-defined terraces on the ends of these two sets of moraines (Leevining and Lundy canyons). This rise of the lake was probably brought about by the more favorable climate during the Tioga glacial epoch, but at that time the glaciers were shorter and did not reach the shore of the lake.

Nearly all of the glacial lakes of the Tahoe epoch have disappeared. A few of them not entered by streams are still represented by marshy ponds. The majority have been converted into delta plains, now meadows, through which the axial streams meander. Some of these lake plains have since been intrenched by the streams, as the encircling moraines were cleared away.

Boulders are much less common on the Tahoe than on the younger moraines; the average of many careful estimates is about 70 boulders (more than 1 foot in diameter) per acre. Seldom are there more than 200 per acre over any considerable area. This may be due partly to the disappearance of boulders by decay, but in the writer's opinion is probably due to the accumulation of wind-blown dust, concealing most of the

[5] Mount Morrison Quadrangle, U. S. Geol. Survey.

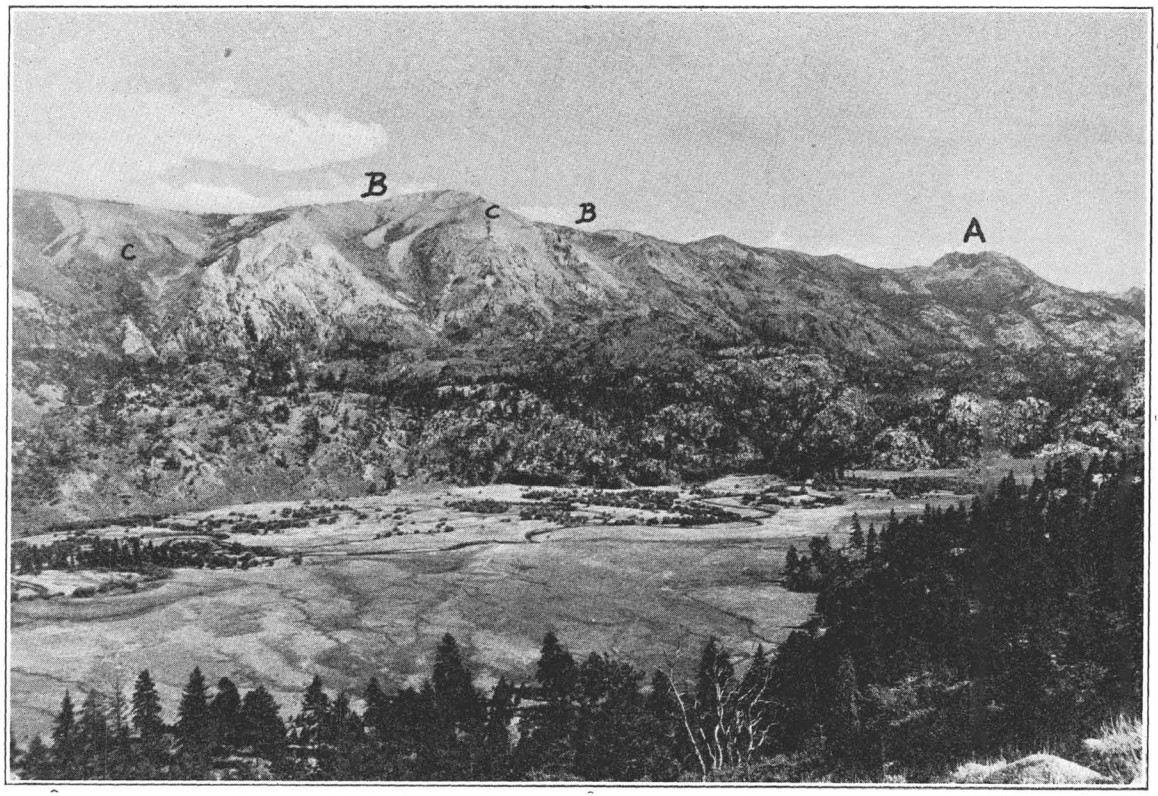


FIGURE 15.—*A filled Lake of the Tahoe Stage*

The locality is Leavitt Meadow in West Walker Canyon. Other glacial features shown in this view are a fresh cirque of the Tioga stage (*A*), old cirques of the Tahoe stage now partly filled with talus (*B*), and remnants of a very old (Sherwin) lateral moraine (*C*).

smaller or partly embedded boulders. Fresh road cuts near June Lake show this to be the fact at least in that locality.

Nearly all of the granitic boulders are considerably discolored and decayed, and some of them are decidedly rotten. The granite weathering ratio [6] on the Tahoe stage till is commonly about 20–70–10. Only very rarely do any of the "granites" retain glacial striæ unless the boulders have been buried, but many of the resistant siliceous rocks still show them distinctly.

In fresh road cuts the Tahoe till generally has a light buff color which is rather characteristic in contrast with the distinctly ash-gray color of the youngest moraines. Commonly a tawny brown oxidized zone extends downward 2–3 feet.

In the Mono Lake and Mammoth basins the moraines of the Tahoe stage are distinguished by a rather thick coating (1 to 10 inches) of rhyolitic ash and pumice lapilli that appears to have been ejected by the neighboring Mono volcanoes. Very little such material is to be found on the younger moraines of the Tioga stage except locally near June Lake.

Northeast of June Lake five or more small cones of red cinders and bombs rise in the midst of the Tahoe stage moraine. Russell (1889, p. 345) regarded them as separate volcanoes built upon the moraine by eruptions penetrating from below at each point. Recently, however, Mayo [7] has found good evidence that the cones are spatter cones built upon a rather broad lava flow which had been poured out over the moraine after the Tahoe age but before the Tioga age. It is a very regrettable fact that all but two of these interesting little cinder cones have recently been almost destroyed by the local roadmakers in search of road metal. As described by Russell (1889, pp. 345 and 376), one of the large viscous obsidian flows poured down over the edge of this same Tahoe moraine from the Mono volcanoes on the east side.

The moraines of the Tahoe stage were much more extensive than those of the Tioga stage and they terminated at elevations averaging about 500 feet lower. West of Truckee the earlier glacier extended down the valley to about 5,800 feet and, as Knopf (1918) has reported, the Big Pine Glacier of the same age descended to about 4,700 feet above sealevel. On

[6] This is a percentage comparison of boulders of three classes: (*a*) those that are substantially unweathered, (*b*) those which are notably weathered externally but are still comparatively sound, and (*c*) those which are more or less completely rotted. The comparison is made exclusively on the common types of rather coarse-grained granitic rock. See page 877.

[7] Evans B. Mayo, personal communication.

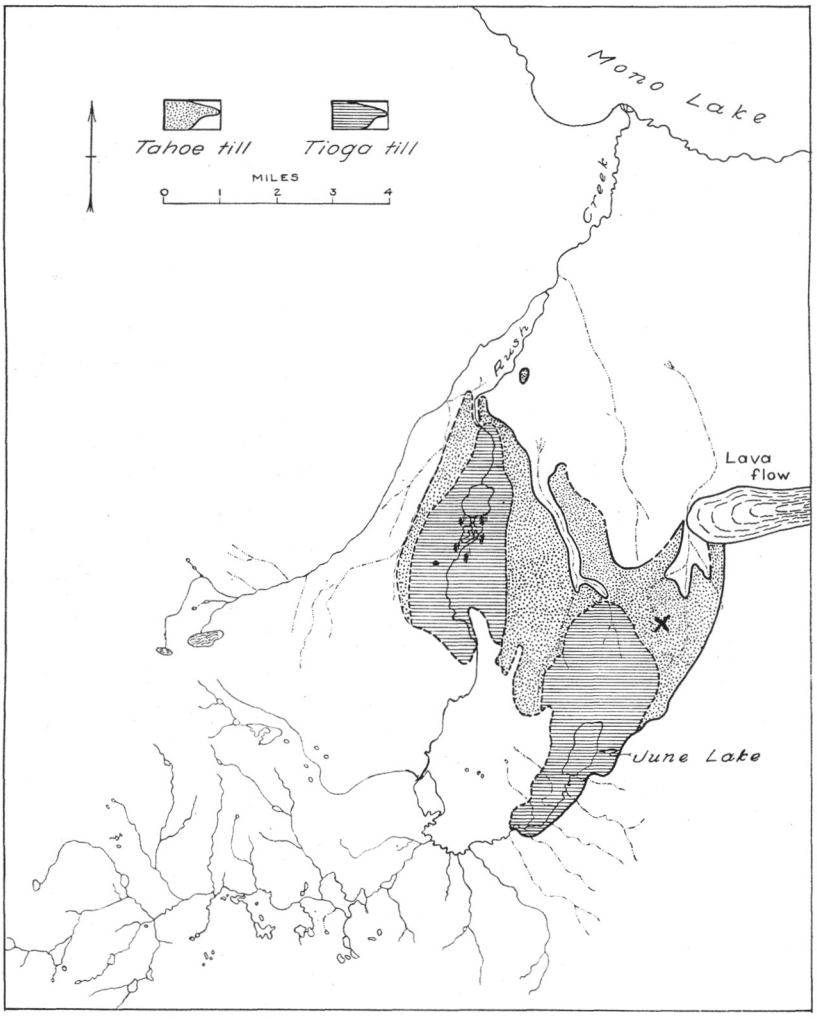


FIGURE 16.—*Moraines near June Lake in the Mono Basin*

The greater effects of stream erosion on the Tahoe moraines, as compared with the Tioga moraines, is well shown. The obsidian flow from the Mono volcanoes on the east covered a bit of the older lateral moraine. The basic flow and spatter cones are in the area marked X.

the western slope of the Sierra Nevada the Merced Glacier terminated near Bridal Veil Falls at an elevation of 3,900 feet.

In spite of the degree to which they have suffered from erosion, it is still possible to map these moraines in considerable detail and to trace them to

the cirques from which the glaciers came. The moraines were deposited within the major valleys of the region after the latter had been excavated to their present general dimensions. Nevertheless, the principal streams have cut through the frontal moraines and in some cases from 20 to 125 feet down into the underlying rock. Where the rock is much jointed, and the gradients steep, one finds the deepest postglacial trenches. An excellent example is the gorge 75–100 feet deep in jointed rhyolite about 1 mile east of Webber Lake (Truckee Quadrangle). Another defile, that has been cut 35 feet down into moderately jointed granite, may be seen along the

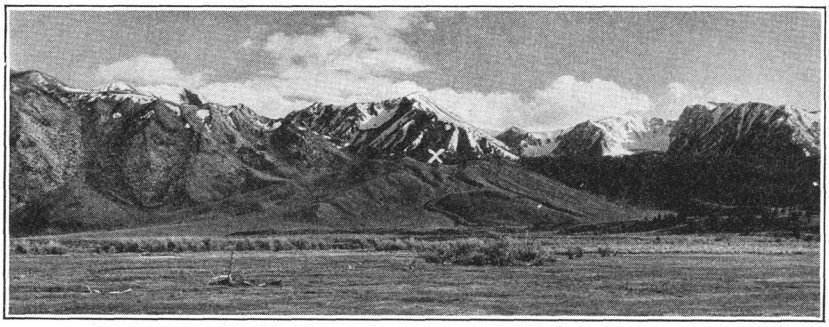


FIGURE 17.—*High morainal Embankment*

This embankment is at the mouth of Laurel Canyon, near Mammoth. Most of the mass is of Tahoe age. Many small ravines have been eroded in its slopes. The breach in the rim is now partly filled by a smaller moraine lobe (X) of the Tioga stage. Fresh cirques appear in the rear.

Sonora Pass highway about 3.6 miles east of the pass. There is a similar trench in the bottom of the canyon 14 miles west of the pass. One of the deepest gorges of this kind is situated just west of Pickle Meadow (Dardanelles Quadrangle), where the west fork of Walker River has cut 125 to 150 feet into andesitic pyroclastics and flows veneered with till of the Tahoe stage.

Glacial terraces pertaining to the Tahoe stage have been studied in the Truckee Valley on the eastern slope and in the Merced Valley on the west. At the town of Truckee the remnants of the valley train coalesce with the Tahoe stage moraine and extend northeastward down the river nearly 40 miles to the city of Reno. Beyond that they disappear and it has not been found possible to trace them farther. The Tahoe terraces, of which there are two distinct levels, now stand 75 and 60 feet above the river just below Truckee, 75 and 60 feet at Verdi, and 60 feet on the west edge of Reno. The gravel contains many boulders 1 to 3 feet in diameter and a

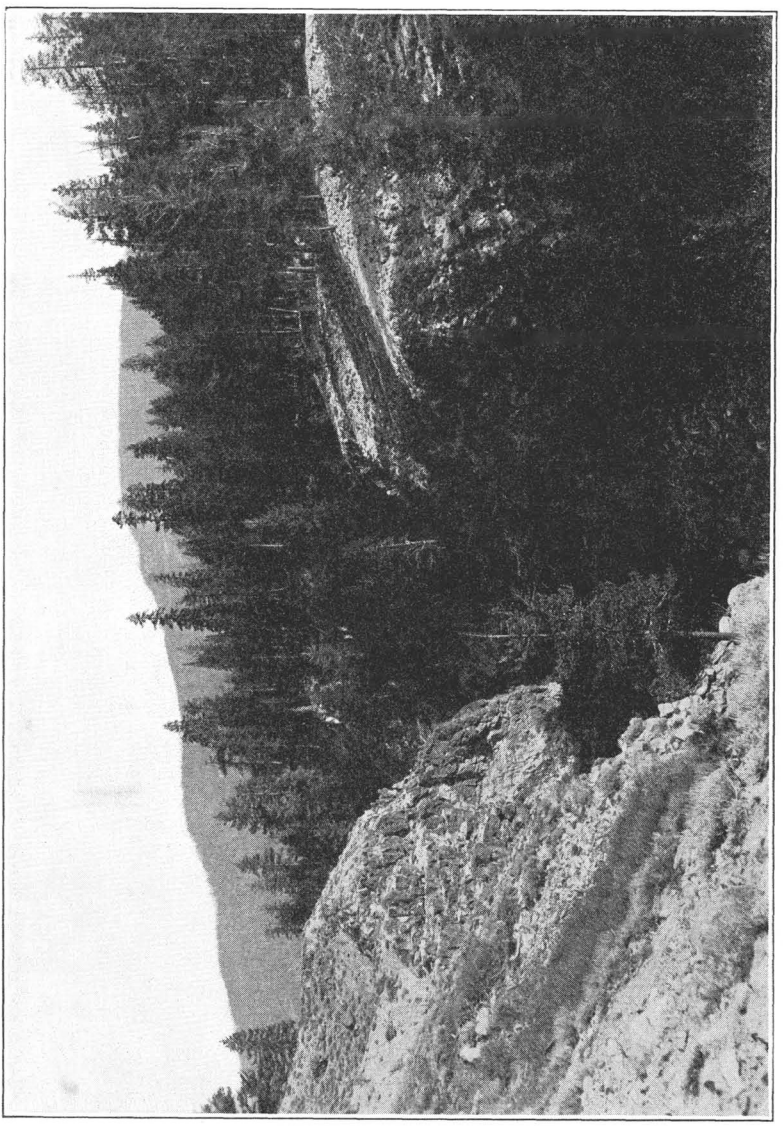


FIGURE 18.—*Gorge eroded through a Moraine*

This gorge has been eroded through the moraine and down into the underlying lava to a depth of 90 feet since the Tahoe age. The locality is east of Webber Lake, Little Truckee River.

few as much as 6 feet. They are notably decayed, but few are rotten to their cores. In color the deposits are buff near the surface but ash gray below. Similar terraces less favorably developed were observed east of Webber Lake, on the Carson River, and on the West Walker River.

Sherwin stage.—There is a considerable body of evidence suggesting a glacial stage intermediate between the Sherwin and the Tahoe stages, but

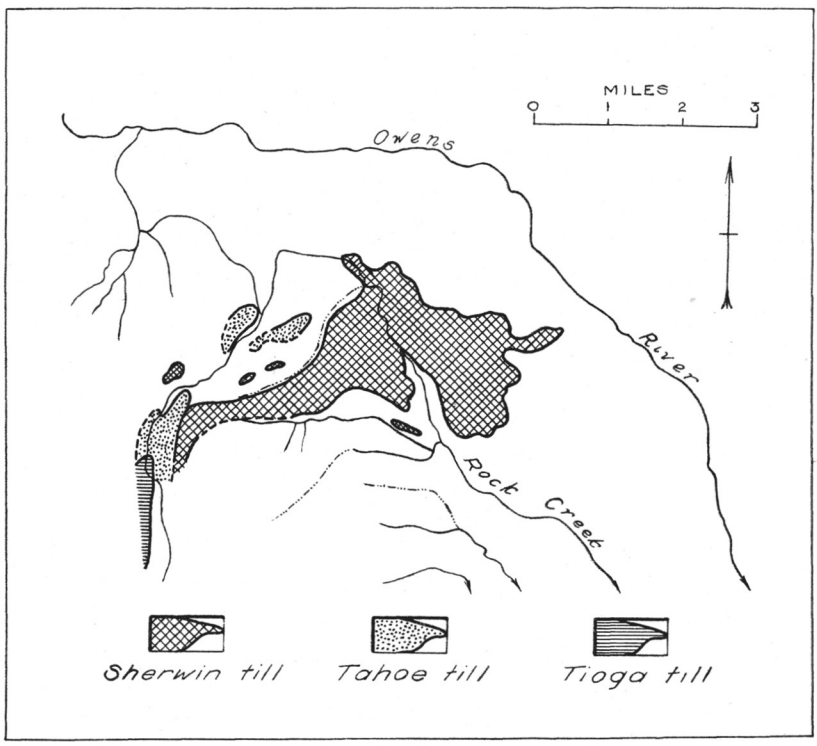


FIGURE 19.—*Sherwin Hill Locality*

The map shows the relations of the moraines of the three youngest stages. The deep transverse ravine of Rock Creek is clearly indicated. See also Figure 20.

the writer prefers to leave the discussion of this question until subsequent field studies shall have furnished a surer basis for interpretation.

One of the best localities for the recognition of the Sherwin (or second) glacial stage is the area north of Sherwin Hill[8] northwest of Bishop. Other good opportunities may be found on mountain spurs southwest of

[8] Mount Morrison Quadrangle, U. S. Geol. Survey, topographic map of the United States.

Mono Lake, on the Mono-Virginia Creek divide south of Bridgeport and especially around the forks of West Walker River.

In general, the original glacial topographic features of this stage have been almost entirely destroyed by advancing stream erosion. No lakes, cirques, or roches moutonnées of this age have been recognized and only occasional remnants of morainic forms. The terminal moraines are entirely gone, but occasional traces of lateral moraines are suggested by sections of old bouldery terraces along the mountain sides. In general, the till has been eroded to the stage of maturity and the main streams have cut deeply into the underlying rocks. North of Sherwin Hill, Rock Creek has incised its valley 600 feet into the granite below the till. Near the forks of West Walker River [9] remnants of the Sherwin till lie upon rock buttresses 800–1,000 feet above the river. Relations of this sort are governed by the physiographic history and lithology of the various localities, and hence uniformity is not to be expected.

The Sherwin stage is now clearly represented by little except large bodies of unmistakable till. Upon these patches of glacial drift the boulders of igneous rock are all much weathered, most of them notably exfoliated and many quite rotten. Only the siliceous rocks retain striæ. The surviving boulders are sparsely distributed over a smooth grassy soil-clad slope, but fresh excavations show that they are abundant only a few feet below the surface. This indicates that the actual decay of the boulders has had more to do with their disappearance than the burial of them by windblown and rain-washed soil. Decay has penetrated deeply into the till. Boulders 3 feet thick have been readily cut through by the jaws of the steam shovels at depths of at least 20 feet below the surface. Nevertheless, the writer has found little to indicate that a definite soil profile has been developed here, as described by Kay (1929), Leighton, McClintock (1930), and others regarding the old tills of the Iowa-Illinois region. No doubt the cold semiarid climate is unfavorable to thorough chemical decomposition.

That windblown material has covered the Sherwin till deeply in some places is indicated by conditions between June Lake and Mammoth. The whole area is buried in ash and pumice lapilli to depths of 3 to 10 feet or more, but occasional road cuts and ravines have discovered beneath this volcanic deposit erratic boulders of granite and metamorphic rocks 5 to 15 feet in diameter traceable to the Sierra Nevada some miles farther west. If glacial, they are probably of Sherwin age.

[9] Bridgeport Quadrangle, U. S. Geol. Survey.

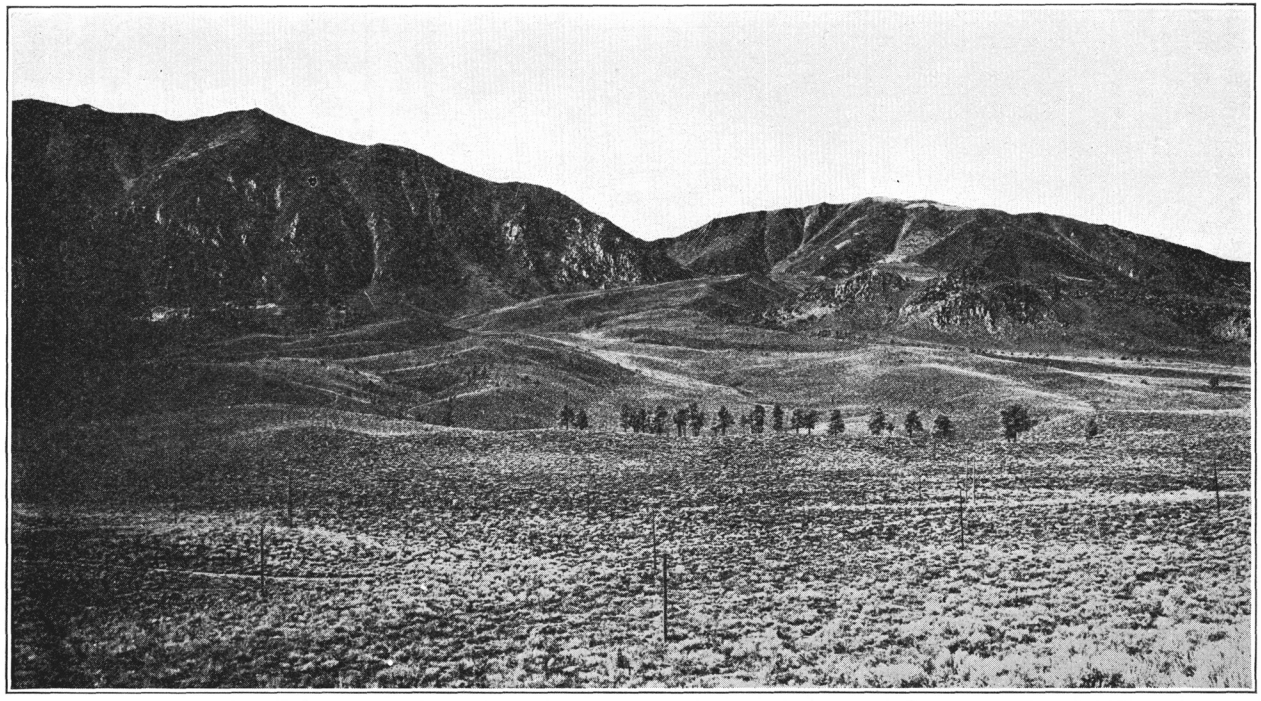


FIGURE 20.—*Maturely eroded Mass of Till of the Sherwin Stage*

The locality is along the base of the Sierra Nevada east of Rock Creek. The original morainic features have been wholly obliterated. The deep postglacial ravine of Rock Creek crosses the center of the view just beyond the line of pine trees. See Figure 22 for cross-section of this locality.

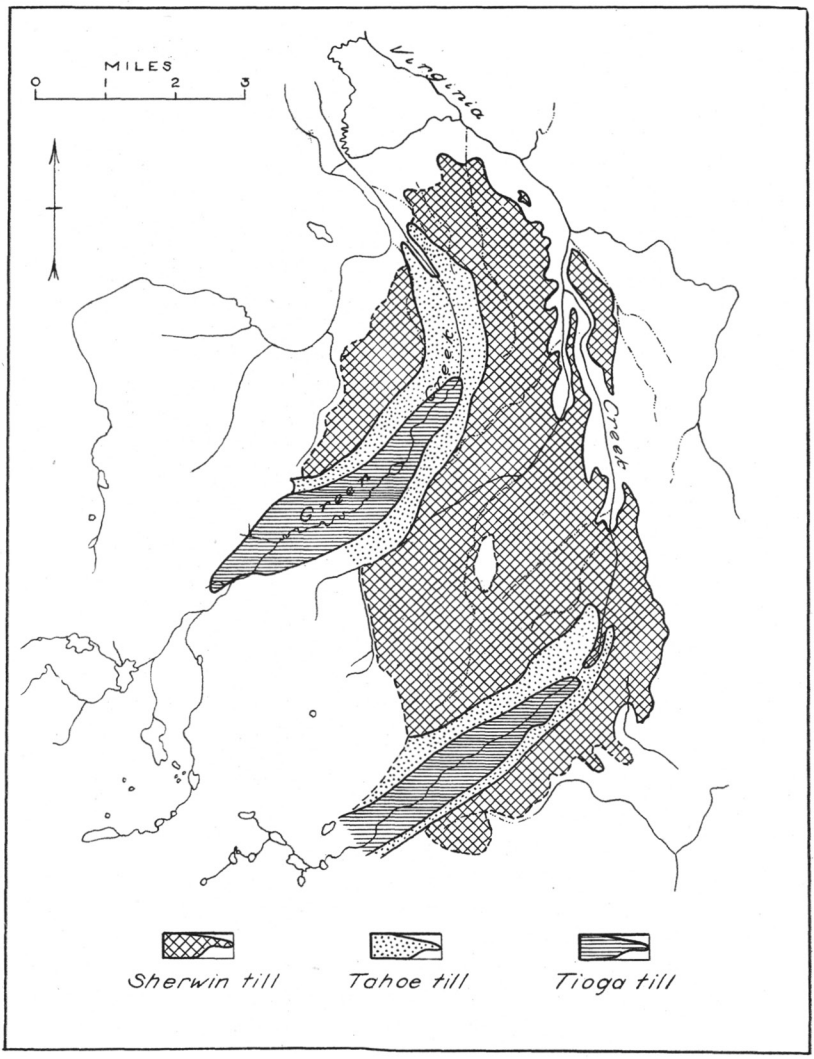


FIGURE 21.—*Virginia Creek Moraine System*

The original outline of the Sherwin moraines has been obliterated by the advance of erosion. South of Bridgeport.

Boulders are much less frequent on the surface of the Sherwin till than on either of the younger sets of moraines. In many places the number is less than one per acre and in but few does it exceed 100 per acre; the average is less than 20. They are generally more abundant on

ridge tops and on the edges of terraces where the till is exposed to excessive deflation and rain erosion. They are correspondingly rare in depressions, where slope wash tends to deposit around them the sediment from adjacent hillocks.

It would be difficult to recognize the glacial origin of the Sherwin till if it were not for the excellent exposures in fresh road excavations. There the wholly unstratified nature of the deposits is clearly revealed and one may readily find many stones scratched and facetted in the characteristic glacial manner.

It is no longer possible to map the moraines of the Sherwin epoch fully, although locally one may trace their original outlines rather indefinitely. Generally, it is difficult to detect any distinct margin around one of the patches of old till, and one may often find beyond the till itself scattered boulders, foreign to the locality, which strongly suggest that they are the sole remnants of a thin layer of till of which all else has wasted away.

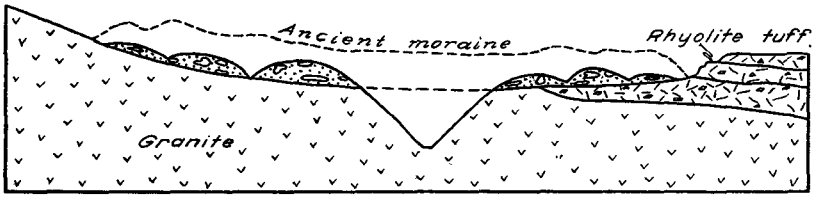


FIGURE 22.—*Transverse Section of Rock Creek Canyon North of Sherwin Hill*
Showing the position of existing remnants of the Sherwin till and the probable original surface of the moraine.

The present distribution of their remnants indicates that the Sherwin moraines were formerly much more extensive than those of either the Tahoe or the Tioga epoch. It also shows plainly that the major topographic features of the district have been notably changed since the till was deposited. That a relatively large part of the morainic tongues has been wasted away by erosion and deflation is indicated not only by the frayed and patchy distribution of the deposits but also by the ragged salient outcrops of solid rock that protrude through the till in many places. As such rocky knolls are the very kind of feature that is readily destroyed by glaciers, one may safely conclude that they have weathered out into relief upon the sites of smoother rounded hills of rock that had been duly shaped by the ice. Good examples may be seen near Dog Creek in the region south of Bridgeport. (See figure 6.)

Glacio-fluvial terraces of Sherwin age beyond the area of glaciation have not been surely identified, although it seems possible that they are pres-

ent along Truckee River southwest of Reno. The terraces in question stand 180 feet above the river. Fresh road cuts show that they are underlain by gravel varying in thickness from 30 feet to more than 150 feet and containing boulders as much as 15 feet in diameter, derived from the head of the Donner Lake valley. The deposits are not mudflow materials, but are well sorted and stratified sand and gravel such as are normally deposited by rivers. In contrast to the river terrace gravels of Tioga and Tahoe ages, these gravels are somewhat rusty in color, as though they had been subjected to a climate warmer and moister than

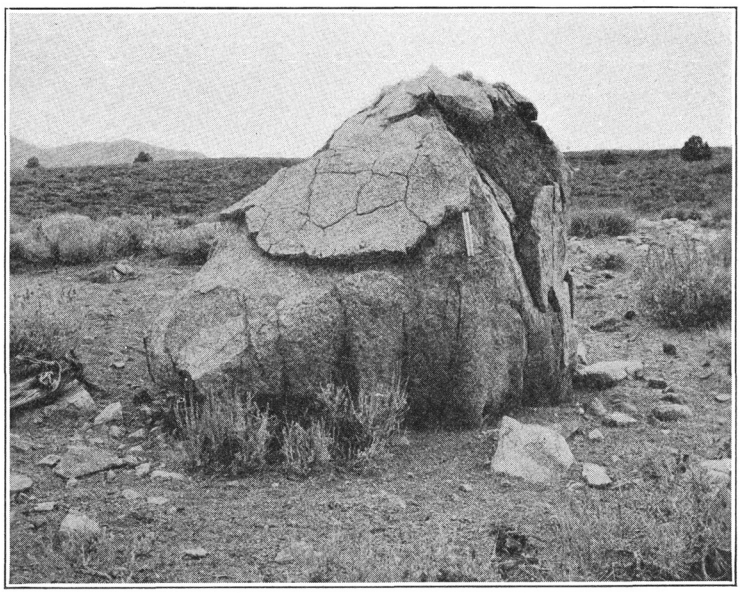


FIGURE 23.—*Typical isolated granitic Boulder on the Sherwin Till, Rock Creek Plateau*

The rock is cavernous and crumbly (rule 6 inches long indicates size of boulder).

today. Unfortunately these terraces have not been traced into connection with any body of Sherwin till. Possibly they belong to a glacial stage intermediate between Sherwin and Tahoe.

In spite of the fact that the Sherwin glaciation was much more extensive than either of the subsequent ones, the topographic changes due to erosion and perhaps diastrophism since its day are so large that the lower edges of the old till remnants now stand at an average elevation of more than 7,100 feet.

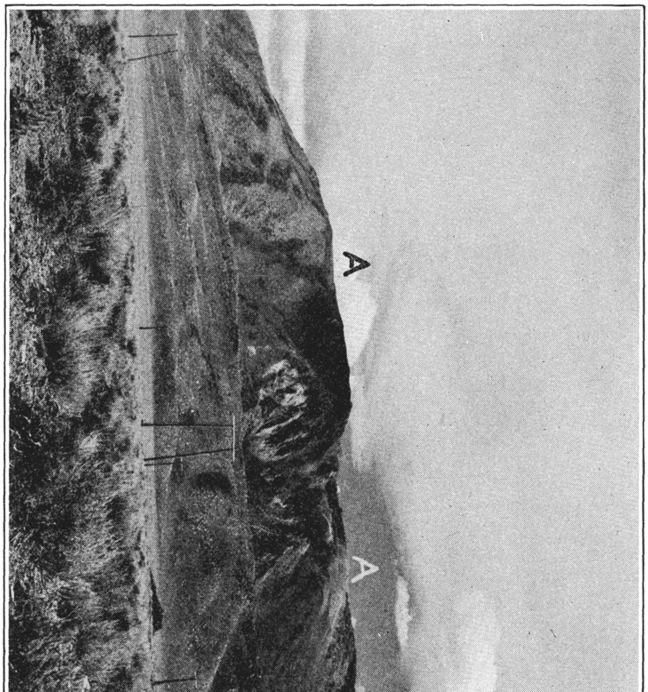


FIGURE 24.—*Mount McGee as seen from the North*

In the foreground the ravine-scarred terminal moraine of the Tahoe stage rises to a height of 400 feet. A lobe of similar age occupies the tributary canyon at (*B*). On the top of the ridge (*AA*) the isolated bodies of the oldest till (?) of the McGee stage stand at elevations of 3,000 to 3,300 above the plain. Mount Morrison is at the extreme right.

McGee stage.—The earliest of the four stages now recognized in the Sierra Nevada is represented only by isolated bodies of boulder earth, the original relations of which are now problematic. On the high ridge west of McGee Peak [10] several thick patches of a deposit strongly resembling till and consisting largely of granite débris rest upon a foundation of Paleozoic slate and marble.

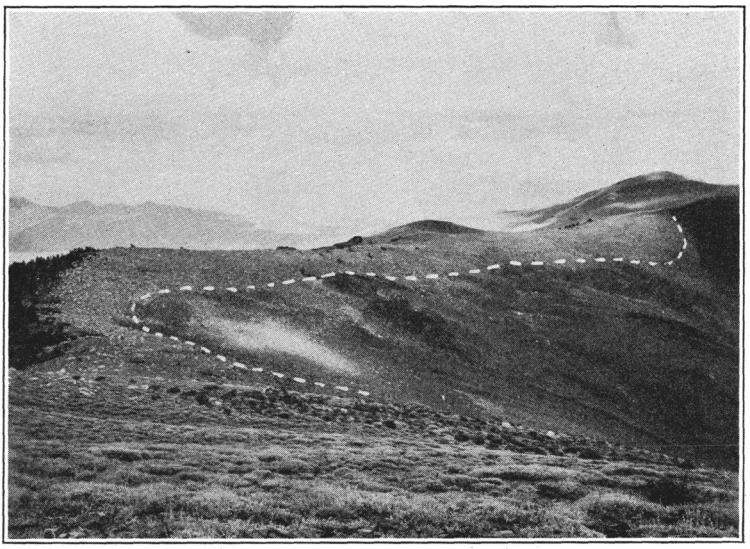


FIGURE 25.—*Crest of high Ridge Southwest of Mount McGee*

Showing the largest patch of ancient till (?) resting on black slate. The white line marks the contact. Camera faced north.

Regarding these deposits it is important to inquire whether they are surely of glacial origin and also to determine their geologic age.

Since the material consists largely of granitic rock and yet rests upon metamorphic sedimentaries it must be a transported deposit. Hence its boulders can not be due to exfoliation and decay in place. It is estimated that 10 to 30 per cent of the material consists of boulders. Many of the blocks exceed 10 feet, some 15, and a few even 20 feet in length. The dimensions of the largest are 28 by 16 by 9 feet. Transported material of these characteristics seems possible only in the deposits of mudflows, landslides, or glaciers. To differentiate these three, under the circum-

[10] Mount Morrison Quadrangle, U. S. Geol. Survey. Topographic map of the United States. See also geologic map of the district by E. B. Mayo, soon to be published by the California State Division of Mines.

stances of this case, is difficult because most of the essential criteria are lacking. Topographic forms and physiographic relations have been wholly destroyed by erosion. There are no large excavations available, and a search of the deposit during two visits to the mountain did not yield any boulders that show definite glacial scratches, although a few showed forms and vague grooves that are suggestive of glacial action. A single striated cobble of quartz slate was later found by Mr. Matthes in the course of a visit to the crest of Mount McGee. The scarcity of striated stones may be explained by several considerations. About 95 per cent

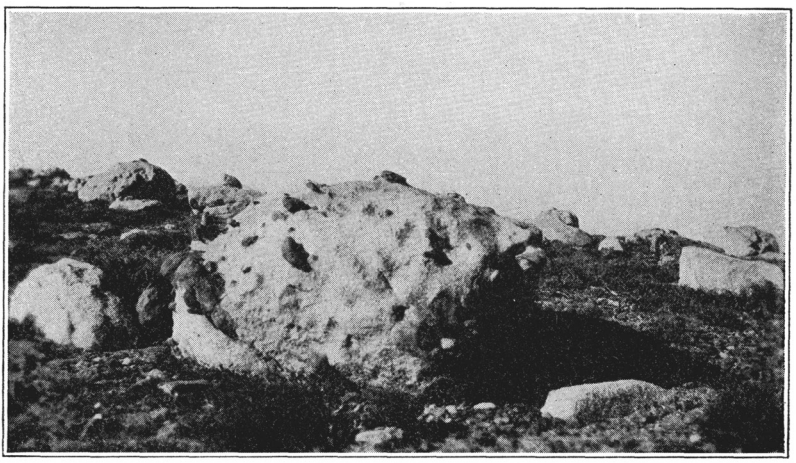


FIGURE 26.—*Detail of eroded Surface of the ancient Till (?) on Mount McGee*

Showing dark xenoliths weathered out in relief on the granitic boulders. Photograph by E. B. Mayo.

of the boulders consist of granite and a little marble—rocks that are so susceptible to decay that none of them show any trace of their original surfaces. Most of them are deeply cavernous and crumbling. The remaining quartzite, hornfels, and slate fragments should retain any markings they may have had, but it is significant that, on descending over the moraine of the Tahoe stage, where such dense rocks form more than two-thirds of the boulders, the writer found only six striated fragments, all of which were rather obscure. It is common observation that glaciated stones are much less plentiful upon alpine moraines than in ice-sheet till. For these reasons the scarcity of striated stones in the McGee tilloid [11] need not be given undue weight.

[11] Meaning a till-like deposit of doubtful origin.

It is perhaps significant that the McGee deposits can be proved to have been transported as much as 3½ miles from the parent outcrops. This is rather a long distance for landslides, but not for mudflows and glaciers. Their position close to the main divide of the Sierra Nevada, where glaciers have reigned in successive epochs, reinforces the writer's inference that they too are of glacial origin, but the opinion is not established beyond reasonable doubt.

The great age of the McGee tilloid is indicated by its position and its relations to physiographic history.

The original moraine (?) has been reduced by erosion to a few small patches that represent only a minute fraction of the whole. In that respect it offers a marked contrast to even the deeply eroded Sherwin till.

It is also significant that these remnants now lie on the tops of divides, in situations where neither mudflown or glacier could possibly emplace them, with topographic conditions as they are now. If at the time these deposits were formed, the eastern front of the Sierra Nevada had stood 3,500 feet above the plain, as it now does, there must inevitably have been valleys of appropriate depth incised in that front. Any glaciers or mudflows of that age must have been diverted down such canyons. The distribution of rock outcrops in the vicinity is such that the old tilloid, consisting almost entirely of granitic débris, could have been derived only from the large outcrop of granite near the head of McGee Creek, for all the adjacent mountains consist of metamorphic sedimentary formations. Under existing conditions a glacier from that locality would have to climb a steep mountainside 2,000 feet high to reach the present site of the ancient tilloid remnants. From these facts it is concluded that the deposits on Mount McGee antedate the present eastern front of the range with its deep canyons. It is reasonable to suppose that while such great topographic changes were being brought about, the mountain peaks of that day were largely demolished and have been succeeded by the others that now adorn the landscape.

Most other localities where the existence of till belonging to the McGee stage is strongly suspected are less satisfactory for study. At such places as Minaret Pass (northwest of Mammoth) and near Ebbitts Pass, large erratic boulders of hornfels and granite, as much as 22 feet long, have been found on the level beds of andesite that form the crest of the main Sierra Nevada divide, in situations which indicate that they must have been emplaced at a time when the topography was entirely different from that of today.

One of the most important areas for the study of ancient glacial deposits is around the forks of West Walker River, northwest of Bridgeport. The moraines of the Tahoe stage are well developed and typical. Above and beyond them are copious deposits of till and stratified drift of the Sherwin stage, greatly eroded and somewhat indefinite of outline, but unmistakable. The Sherwin moraine remnants rise to about 7,800 feet elevation near the forks. Above and beyond them, to the north and east, the maturely dissected slopes of bedded andesitic flows and

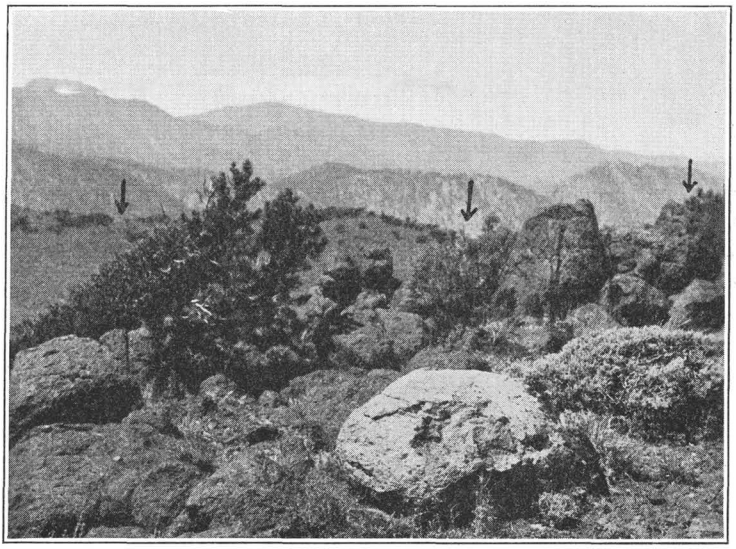


FIGURE 27.—*One of the isolated granite Erratics*

These erratics, on the andesitic crags at the summit of a mountain southeast of West Walker Canyon, are suspected of belonging to the McGee stage. Position of the canyon 2,300 feet deep shown by arrows.

pyroclastics are strewn rather sparingly with erratic boulders up to elevations of about 8,700 feet and probably higher. The boulders comprise epidotic hornfels and granitic rocks, including some of the giant porphyry (Cathedral Peak granite) of the Sierra Nevada crest. Some of these rocks can be traced to exposures at least 15 miles up the valley to the southwest. The blocks are of all sizes up to 20 feet in length. The granites are deeply decayed, exfoliate, and cavernous. It is difficult to understand how such large blocks could be transported on a gradient of only 50–100 feet per mile for 15 miles or more except by the action of a

large glacier. The conditions of this case seem to be too severe for the mudflow hypothesis.

That the deposits are very old is shown by their position far above and beyond the Sherwin moraine remnants, by the fact that the ancient tilloid has wasted away, leaving only scattered boulders, and especially by the fact that West Walker River has since cut a V-shaped canyon more than 2,000 feet deep below the base of the ancient glacial deposit. A comparison of the weathering of the oldest boulder deposits of this area with those on Mount McGee also suggests that they are of similar age.

In 1906 Willard D. Johnson found a bouldery deposit on the side of Rickey Peak [12] at an altitude of about 9,700 feet, but he was not sure that it was of glacial origin. He also noted other boulder deposits at high levels at various points farther north in the West Walker River drainage area, and suspected that they belong to a glacial stage much older than the certainly recognized (Sherwin) till at lower levels.

Other ancient boulder deposits of this stage will doubtless be found upon high spurs along the Sierra Nevada, but the land surface of that age has been so largely consumed by the growth of deep canyon systems that there can be little hope of finding many or large remnants of this drift.

CORRELATION

FOREWORD

For purposes of correlating the glacial phenomena on the eastern side of the Sierra Nevada with those in certain parts of the western United States the writer has examined several districts in California, Nevada, Utah, and Wyoming, applying there the same criteria and comparing his results with the findings already published by Atwood, Alden, Matthes, and others. He has previously studied in some detail the glacial phenomena of the Bighorn (1903), Wind River, Gros Ventre, Teton (1915), and Wasatch Mountains, but most of the information thus derived has never been published.

WESTERN SLOPE OF THE SIERRA NEVADA

The climate of the western slope is moist, the forest thick, and the rate of rock decay doubtless more rapid than on the east side. These differences introduce some factors that the student should keep in mind while comparing the glacial features of the two slopes. In general, the forest conceals distinctive glacial topography and in other ways hinders the study of physiographic history on the western slope.

[12] Bridgeport map.

In September, 1930, the writer had a field conference with Mr. Matthes in the Yosemite Valley, and at that time certain correlations and interpretations were agreed upon. These were later supplemented by a reexamination by the writer in March, 1931. As a result, the following are offered as being the most reasonable tentative conclusions, but they are solely the writer's and are accepted only in part by Mr. Matthes.

The Tioga stage is evidenced by the freshly glaciated rock slopes in Tenaya Valley above the gorge and in Merced Valley above the Nevada Falls, by the unfilled lakes such as Tenaya and Merced Lakes, by the lack of notable intrenchment of the granite by the creeks, and by the fresh condition of the glacial boulders. At that time neither the Tenaya nor the Merced glaciers descended into the Yosemite Valley proper and only small glaciers existed in the valleys of such tributaries as Yosemite Creek and Illilouette Creek. Moraines of this stage are small and inconspicuous. The writer does not yet know which of them marks the farthest advance of the ice of the Tioga age.

The identification of the Tahoe stage has been less confidently made in the Yosemite region than in almost any other part of the range and the writer is still unable to reconcile some of the conflicts in testimony of the observed facts. However, the weight of evidence indicates that the glacier of that age advanced into Yosemite Valley and built the moraines below El Capitan and Bridal Veil Falls. Like the Tahoe moraines of other valleys in the Sierra Nevada, these occupy the bottom of the canyon and are the largest and most advanced of the moraines so situated. The till is somewhat buff in color, most of its constituents are notably weathered and some of the boulders are crumbly. The large lake impounded by the moraine loop has not only been completely filled by the delta, but the river has since consumed most of the lake plain in excavating a flood plain about 15 feet lower. The rocks along the canyon wall are rather crumbly and retain the original glacial surface in only a few places. The altitude of the terminal moraine (3,950 feet above sealevel) corresponds closely with that of other Tahoe stage moraines [13] on the western slope and is much lower than that of any Tioga stage moraine known in the entire range. During the Tahoe stage, glaciers in the Yosemite Creek, Illilouette, and Snow Creek Valleys failed to reach the Merced Canyon. Below El Portal there are remnants of a gravel valley train resting upon rock terraces about 30 feet above the Merced River. The top of this valley train once stood about 55 feet above the river, but it is now generally covered by talus and mudflow débris from the slopes above and is exposed

[13] Yuba River 4,000 feet, and Kings River 4,150 feet.

only in the road cuts and canyon walls. The decay and color of the pebbles and the depth of trenching suggest that this is the valley train of the Tahoe stage. It resembles that east of Truckee.

Till of much older aspect, almost wholly devoid of glacial topography, appears in isolated but numerous patches here and there in the Yosemite region. This is the older till (El Portal stage) of Matthes (1931). Among the best places to study it are south of Glacier Point, at Old Fort Monroe, in Big Meadow, and especially north of Gentry checking station. In all cases it lies on slopes or shoulders 1,000–3,500 feet above the present river. The till is decayed to depths of over 10 feet and is covered with an orange-buff soil that conceals nearly all of the boulders. Even in fresh road excavations it is very rare to find distinctly striated stones. Where the subjacent rock surface has been recently exposed by removal of the till, glaciated surfaces have been observed at only one or two places, because the bed rock is itself deeply decayed. Many of the boulders in this till are characterized by a decided reddening of the decayed exteriors—a trait not found in either of the two younger tills, but common on Sherwin till elsewhere in the range. The granite weathering ratio is about 0–15–85 and the frequency about one per acre. The western limit of the old rusty (El Portal) till has never been ascertained. It is now agreed between the writer and Mr. Matthes that the supposed moraine in the valley bottom at El Portal is really a local deposit of mudflow or landslide material. The writer suspects that the ancient glacier formerly extended a few miles west of El Portal and that the cutting of the inner canyon and its deep tributary ravines has destroyed all trace of the terminal moraine and valley-train terraces that once extended west of it. In general, the various characteristics of the El Portal till indicate that it belongs to the Sherwin stage.

Evidence of the McGee stage on the western slope of the Sierra Nevada is scanty and unconvincing. On the north slope of Sentinel Dome and in other similar positions there are large isolated boulders regarded by Matthes as glacial erratics left by the wastage of a moraine much older than the (Sherwin?) till remnants below it near Glacier Point. Since Matthes and Calkins seem to have proved that the Sentinel Dome blocks were transported hundreds of feet up the adjacent slope, it seems probable that they are glacial erratics. The writer is not convinced, however, that they are older than the ancient till (Sherwin?) that covers the slope below. Thin till on a mountainside may easily be washed away, leaving only a few resistant blocks. In fact, the boulders may originally have

been isolated on the rock surface, as were the thousands which now adorn the most recent "glacial gardens" of the Tenaya Lake basin.

In summary, it appears to the writer that (*a*) the Wisconsin stage of Matthes includes both the Tioga and the Tahoe stages, (*b*) the El Portal stage is the same as the Sherwin, (*c*) the Glacier Point stage is probably not distinct from the latter, and (*d*) there is, as yet, insufficient evidence of the McGee stage in the Merced River basin.

Along Yuba River[14] (also the Southern Pacific Railroad) the three youngest glacial stages were found by the writer to be consistently developed. The Tioga stage is represented by weak cirques, a nearly filled marshy lake at Soda Springs Station, and some very low moraine loops at an altitude of 6,500 feet a few miles farther west. The glacier was only about 200 feet thick and 5 miles long.

The Tahoe stage glacier was much larger and more vigorous. To this stage are ascribed most of the great expanses of barren granite in the névé region of the old glacier. The ice descended the Yuba Valley to Emigrant Gap and projected a lobe on through Bear Valley to an altitude of 4,000 feet, thus corresponding closely with that in the Yosemite Valley. The glacier was 2 miles broad in its central portion and over 24 miles long. At Cisco it was more than 600 feet thick, and it exceeded 1,000 feet in depth at Emigrant Gap where its south lateral moraine now forms the crest of the divide. The till on this moraine has a G. W. R. of 15–77–8 and a boulder frequency of about 80 per acre, and the soil is buff. The moraine has not been badly marred by erosion, but a large lake that once existed north of Emigrant Gap has been filled and converted into a level meadow.

Till corresponding to the Sherwin stage was found in road cuts and along the railroad 2 miles northwest and 1 mile northeast of Blue Canyon Station, several hundred feet above the creeks. Its glacial origin is inferred from its unsorted structure and from the great size of the erratic boulders (10 to 20 feet). Striated surfaces are retained on only a few of the boulders. As in the Yosemite region, the boulders are not only well rotted, but are distinctly rusty in color. Since the topography is now maturely erosional, the geologist has only the rather infrequent excavations for a guide in mapping the till. Hence its actual distribution may never be determined. When the distribution of bedrock formations becomes more accurately known, it may be possible to distinguish more certainly between old till with erratic boulders and residual soil inclosing boulders of decay.

[14] Colfax and Truckee quadrangles, U. S. Geol. Survey. Topographic map of the United States.

Ancient till, here referred to the Sherwin stage but possibly in part of greater age, occupies ridge tops in many places between Yuba and Merced canyons. Long ago Turner, observing their advanced state of decay and greatly eroded condition, concluded that they must represent an earlier glacial epoch. The glacial phenomena of the western side of the Sierra Nevada have been closely studied in only a few localities. Many interest-

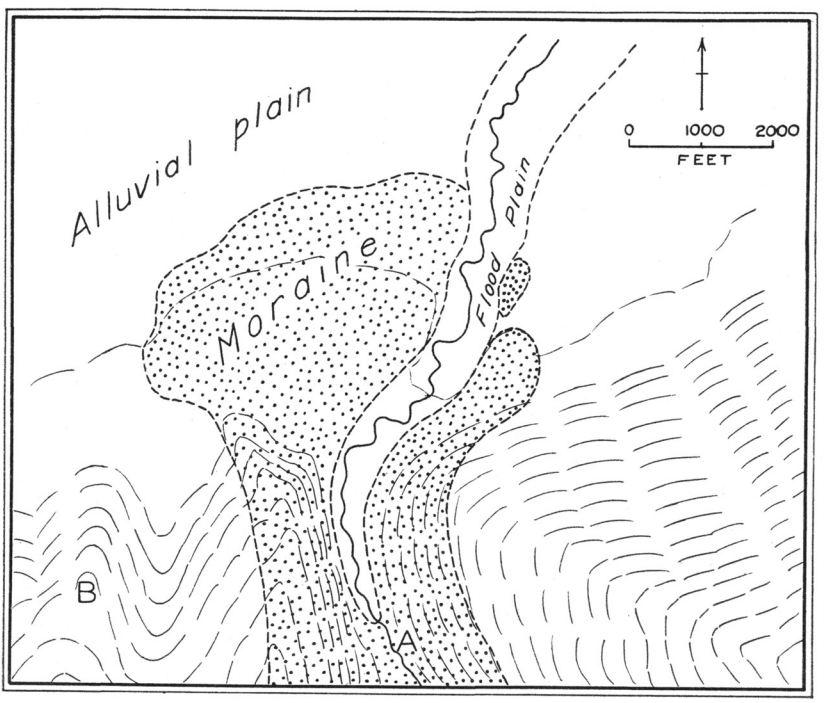


FIGURE 28.—*Location of the old Moraine (Tahoe Stage) at the Mouth of Lamoille Canyon in the Ruby Mountains of Nevada*

Possible older till (Sherwin stage) is indicated at B. The rock gorge is situated at A.

ing facts await those who will eventually give this region the attention it merits. As yet, however, no satisfactory evidence of the McGee stage has been found anywhere on the western slope.

RUBY MOUNTAINS, NEVADA

The Ruby Mountains (formerly called the East Humboldt Range), southeast of Elko, Nevada, reveal ample evidence of former glaciation, as reported by Hague.[15] By applying there the methods developed on the

[15] U. S. Geol. Expl. 40th Par., vol. 2, pt. II, pp. 620-621, 1877.

dry eastern slope of the Sierra Nevada, the writer found it easy to recognize the two latest glacial stages, and he found suggestions of another, still older.

The Tioga stage is represented by small fresh moraine loops, usually inclosing clear lakes, behind which rise the wild crags of the freshly torn cirques. None of these glaciers reached the lower parts of the canyons and but few of them descended below an altitude of 8,000 feet. The moraines are very bouldery and the rocks are but little decayed. A typical and relatively accessible locality in which to study these features is at Angel Lake, southwest of Wells.

To the Tahoe stage belong the larger and more conspicuous moraines that are visible along the flanks of the range. The largest glacier of that age, about 15 miles long, issued from Lamoille Canyon and built a low bulbous moraine upon the plain. Above the mouth of the canyon the stream has cut a gorge 40 feet deep in the gneissic rock below the till and it has excavated a flood plain 500–1,000 feet wide across the terminal moraine. Several other glaciers of the same age farther south reached the base of the range, and some of the glaciers around Mount Bonpland were nearly as large. In most cases only the lateral moraines are now preserved. Even they have been distinctly marred by ravines and have been subdued to smooth rounded forms. The boulders are somewhat more decayed than is usual on moraines of this age, but the value of the comparison is diminished because the rocks observed in the Ruby Range were gneisses of sedimentary origin rather than granodiorites. Ice-worn outcrops are much broken and rarely retain even traces of the glaciated surface. Boulder frequency averages about 65 per acre and the gravel terraces beyond the moraine at Lamoille are about 50 feet high. These and the other conditions indicate the Tahoe stage.

In the rather hasty examination of the range made by the writer no sure evidence of pre-Tahoe glaciation was found. However, there is till-like bouldery material outside of and somewhat above the high southwest lateral moraine at the mouth of Lamoille Canyon. Its boulders are much weathered and sparsely distributed (3 or 4 per acre). If this material is till, its relations and condition suggest that it is a remnant of a moraine of the Sherwin stage. A careful inspection of rocky shoulders several hundred feet above the base of the range may well reveal more decisive evidence.

The Snake Range in southeast Nevada harbored several glaciers in late Pleistocene time. A bulky moraine probably of the Tahoe epoch extends from Wheeler Peak out upon the plain near the village of Baker, and the

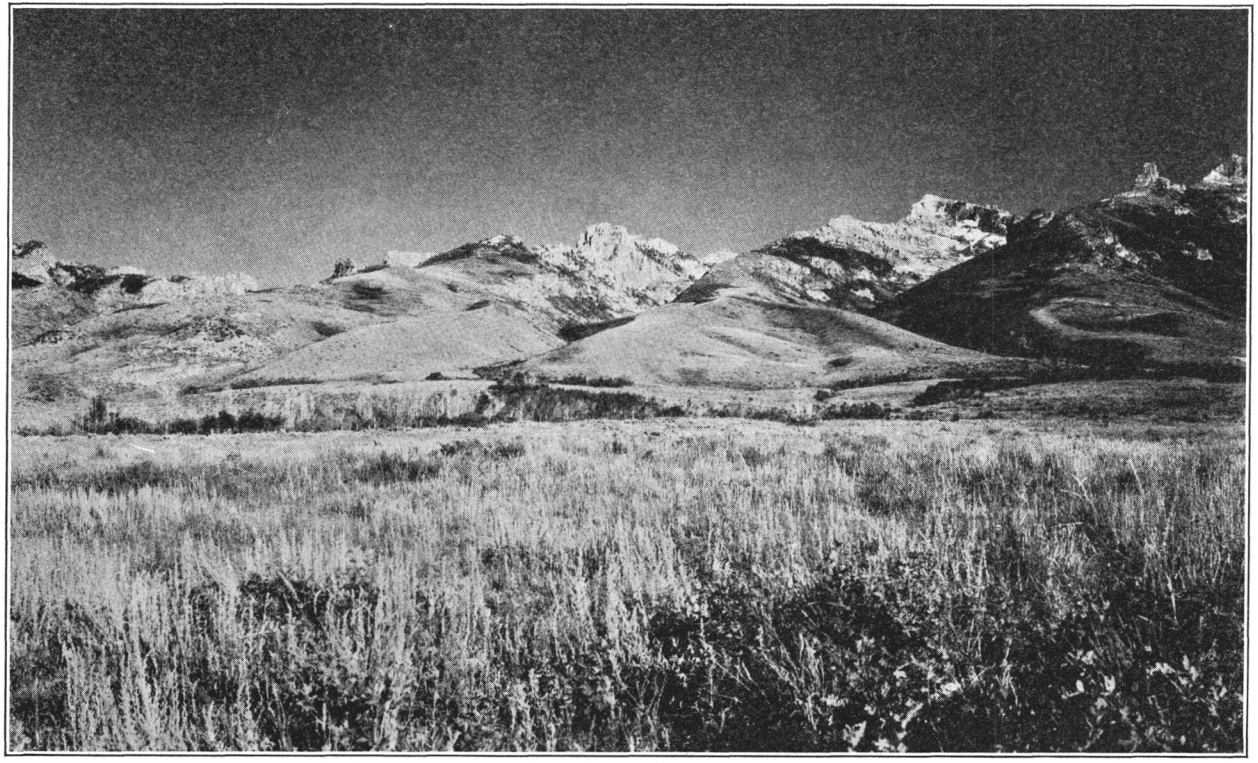


FIGURE 29.—*Old lateral Moraines of the Tahoe Stage*

The locality is along the west slope of Lamoille Peak in the Ruby Mountains. The cirques were refreshed during the Tioga stage but the moraines of that age are scarcely discernible in the photograph.

raggedness of the cirques on the eastern slope indicates glacial action also in the Tioga age.

There are similar but weaker evidences of glaciation in the White Mountains northeast of Bishop, the Carson Range near Carson City, and the Independence Range north of Elko, in Nevada.

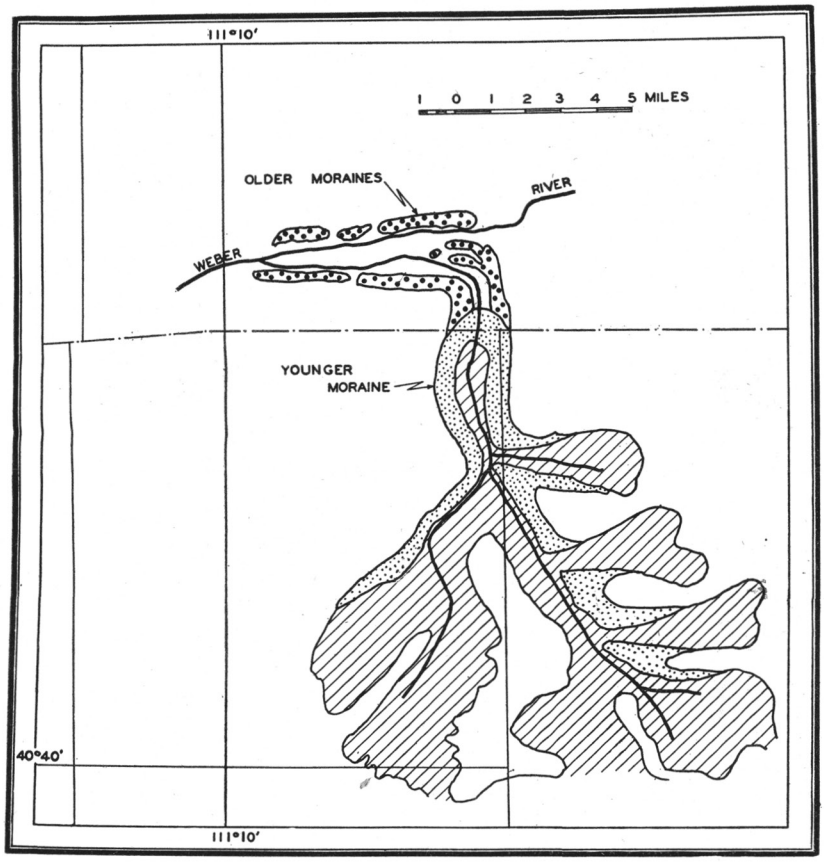


FIGURE 30.—*Moraines on Weber River in the Uinta Mountains of Utah*

The more eroded condition and greater extent of the earlier stage is well shown. (After Atwood.)

W. D. Smith (1927) has reported glaciated valleys on the west slope of Stein Mountain in southern Oregon. Much more obscure and doubtful indications of glacial action, probably of the Tahoe age, have been observed by the writer in the Sweetwater, Spring Mountain, Schell Creek, Toyabe, Humboldt, Onequi, and Beaver ranges of Nevada and Utah. Apparently none of these have been closely examined by glacialists.

WASATCH RANGE, UTAH

In his report on the glaciation of the Wasatch and Uinta ranges of northern Utah, Atwood (1909) demonstrated that two distinct episodes of glaciation may be recognized. His evidence has been reviewed in the field by several geologists, including the writer of this paper, and in general they have verified his conclusions. The moraines that were assigned by Atwood to his "later epoch" are essentially like those of the Tioga stage in the Sierra Nevada. In both places they are but little eroded, very slightly decayed, retain unfilled lakes and are of small extent. The granite weathering ratio on a frontal moraine of this age in Big Cottonwood Canyon [16] proved to be 96–4–0 and the boulder frequency 750 per acre. These are highly typical of the Tioga stage. The axial creek has not reached grade in its notch through this moraine.

The moraines of Atwood's "earlier epoch" are more extensive and much more bulky. The granite weathering ratio averages about 7–76–17 and the frequency less than 200 per acre. The granitic boulders are partly exfoliated and some of them display cavities several inches deep. Fresh exposures of the till show a yellowish and even rusty discoloration to a depth of as much as 6 feet, indicative of notable progress in the postglacial weathering processes. The creeks have rather generally cut through the moraines and 25–100 feet into the underlying rock. In nearly all cases the terminal moraines have been largely washed away by the graded axial streams, leaving only the lateral moraines. All of these conditions point directly to the Tahoe stage as recognized in California.

The moraines of both of these stages lie in the bottoms of the canyons and thus indicate that the amount of postglacial erosion has been relatively small. As yet no one has found in the Wasatch Range any patches of greatly eroded till lying upon high terraces and shoulders. As they have been reported from other districts to the north and east it seems probable that they exist also in the Wasatch region, but the dense growth of scrub-oaks and aspens effectually hides the mountain slopes and makes the search for such deposits very difficult. As roads are extended in the canyons, fresh excavations may reveal them by chance.

One of the most important questions regarding the glacial history of Utah is the relations of the glacial stages to those of Lake Bonneville. The crucial localities in which this relation can be determined are at the mouths of Little Cottonwood, Bell, and Alpine canyons, all southeast of

[16] Thirteen and a half miles by road east of the mouth of the canyon.

Salt Lake City. Only there do the lake terraces and deposits touch the moraines at the mouths of the canyons.

In his study of Lake Bonneville, Gilbert (1890) observed that there is no terminal moraine at the mouth of Little Cottonwood Canyon and that the highest wave-cut terrace of the old lake was not engraved across the ends of the lateral moraine ridges. From these facts he concluded

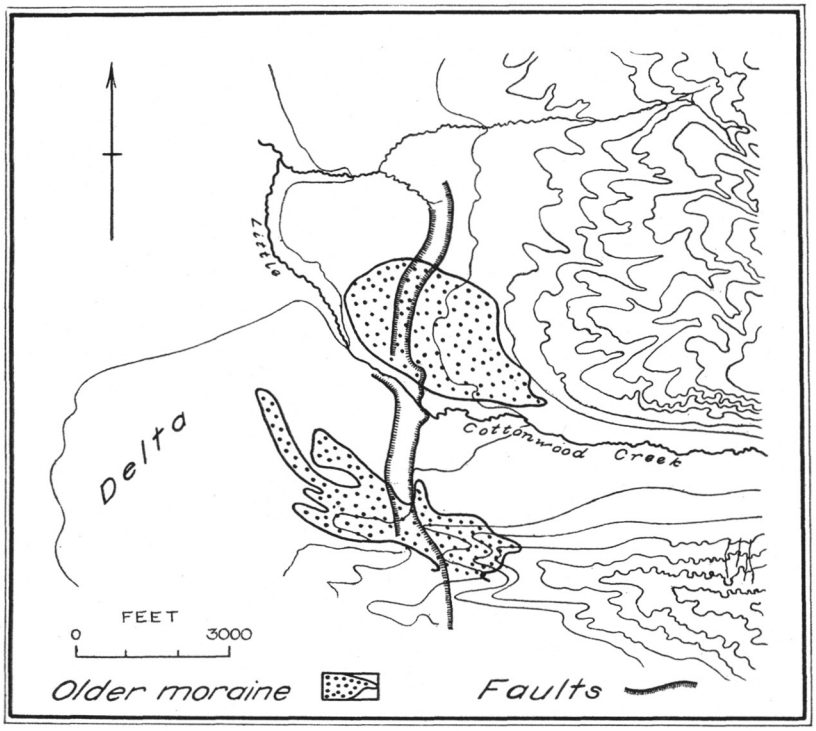


FIGURE 31.—*Map of the Mouth of Little Cottonwood Canyon, Wasatch Mountains, Utah*

Showing the relations of the moraines and terraces. (After Gilbert.)

that the glacier discharged directly into the lake and hence made no frontal moraine. On this inference the maximum rise of the lake was contemporaneous with the glaciers, and the latter belonged to the second expansion of Lake Bonneville. Later Atwood (1909) concurred in this opinion.

The present writer has carefully examined these localities. He found the delta deposits of the Bonneville substage covering the lower part of the Little Cottonwood moraines and continuing as a terrace up into the

wide breach between the gaping lateral moraines. Matters are locally complicated by postglacial faults, for which due allowance must be made. It was observed that the wave-cut terrace along the mountain front becomes steadily fainter as it approaches the great deltas and finally disappears before reaching the canyons. It is suggested that the prograding of the deltas warded off wave attack and thus prevented it from notching the ends of the moraines. This hypothesis would remove the chief objection noted by Gilbert and would permit the acceptance of the general evidence that the moraines are older than the Bonneville shore substage and that the latter is of Tioga age.

The glaciers of the Tioga age did not reach the mouths of the canyons, but river-borne detritus issuing from them entered Lake Bonneville, built deltas, and buried the ends of the longest lateral moraines. As the level of the lake went down, the original deltas were intrenched, but were enlarged in area at lower levels. Remnants of the earlier delta surfaces exist as gravel terraces that extend up the canyons.

In a cursory examination of the west end of the Uinta Mountains, the writer was able to verify Atwood's opinion that the two glacial stages there mapped by him are the same as the two in the Wasatch Range.

OTHER RANGES IN THE ROCKY MOUNTAINS

San Juan Mountains of Colorado.—In their last report on the glacial history of the San Juan region, Atwood and Mather (1931) distinguish three stages, which they name the Cerro, the Durango, and the Wisconsin.

The Cerro glaciers were of piedmont form and more extensive than the others. Only remnants of the maturely eroded till now remain and a network of canyons 500 to 2,000 feet deep has been carved subsequently. The facts strongly suggest the Sherwin stage of California.

The Durango stage is represented by large moraines inside the canyons and by gravel valley-train terraces 150–250 feet above the creeks. This indicates the Tahoe stage.

The Wisconsin moraines are lower, lie within the Durango moraines, and are connected with gravel terraces only 20–30 feet high, thus conforming closely to the Tioga stage of the Far West.

Mountains of western Wyoming.—The glacial history of the Teton, Gros Ventre, and Wind River mountains, as elaborated by the present writer (1915), includes the Buffalo, the Bull Lake, and the Pinedale stages. Although some of the criteria used in the Sierra Nevada have never been applied in this region, there is an obvious parallelism between the three stages of Wyoming and the Sherwin, Tahoe, and Tioga stages

in California. The decay of boulders, the extent and depth of postglacial stream erosion, and the relations of moraines to valleys all support this opinion. Fryxell (1930), who has recently made a detailed study of the glaciation of Jackson Hole, Wyoming, readily identified the same stages.

Mountains of western Montana.—Alden has studied the effects of Pleistocene glaciation over a large part of Montana and extended his comparisons to Wyoming, Idaho, and Washington. He concurs (1926) in the view that three stages may be distinguished and that they are essentially the same as those previously worked out in the Teton region. The Kennedy till of Montana is correlated by him with the Buffalo till of the Snake River headwaters. Two younger sets of moraines lie inside the modern canyons, but of these the earlier ones are much bulkier and more eroded than the later.

CORRELATION WITH THE STANDARD SECTION

For the United States the standard section of the Pleistocene glacial deposits is that of Iowa, Wisconsin, and Illinois. The work of many glacialists, such as T. C. Chamberlin, W J McGee, Calvin, and Leverett, culminating in recent studies by Kay, Leighton, and Alden has resulted in substantial agreement and the recognition of five distinct glacial stages: (1) the Nebraskan, (2) the Kansan, (3) the Illinoisan, (4) the Iowan, and (5) the Wisconsin. The last is divided into Early and Late Wisconsin.

Recently there has sprung up sentiment in favor of reducing the five or six stages to four by bracketing the Iowan and Wisconsin together as subdivisions of one stage. Thus Kay (1931) proposes the Eldoran epoch to include (*a*) Iowan glacial, (*b*) Peorian interglacial, and (*c*) Wisconsin glacial ages. Leighton (1931) offers a somewhat different plan to represent similar ideas; he retains the Wisconsin epoch and divides it into (*a*) Manitoban (= Iowan), (*b*) Quebecan (= Early Wisconsin), and (*c*) Hudsonian (= Late Wisconsin)—all glacial advances. The glacialists of other regions hope that these differences of usage will soon be harmonized. Meanwhile, the writer will employ the older terms in their usual meanings.

Conditions of topography, climate, and lithology change to such a degree between Wyoming and Iowa that to extend correlations across the gap would be hazardous. Fortunately, Alden,[17] who was already familiar with the glacial formations of the prairie states, has traced them more or less continuously from Iowa across Nebraska, South Dakota, and Mon-

[17] Personal communication.

tana to the Rocky Mountains, noting the gradual slight changes in character along the entire glacial margin. As a result of this research he concludes that the Pinedale stage of Wyoming is identical with the Wisconsin, and the Bull Lake stage with the Iowan. The Buffalo stage resembles the Kansan, more than either the Illinoisan or the Nebraskan, but the correlation is uncertain, since the older tills have not yet been traced across the Great Plains.

Although realizing the liability of error, especially regarding the older deposits, the writer ventures to present the following table of correlations for western United States as a tentative scheme for continuing studies. The views embodied have been reached partly in the course of field conferences with Kay and Matthes, but they are not responsible for the opinions here expressed.

The absence of stages equivalent to the Illinoisan stands out in this table as a challenge. It is reasonable to suspect that there is such a stage in the West, and indeed the writer has found some rather definite evidence of it along the eastern slope of the Sierra Nevada. The present doubt regarding its existence is probably due in part to the obliteration of the

Tentative Correlation Table of Glacial Stages in Western United States

Iowa and Illinois	Montana	Wyoming (Wind River)	Colorado (San Juan)	Utah (Wasatch)	Nevada (Ruby Mts.)	Sierra Nevada	
						East	Yosemite Matthes
Wisconsin	Wisconsin	Pinedale	Wisconsin	"Younger"	Angel Lake	Tioga	Wisconsin
Iowan	Iowan (?)	Bull Lake	Durango	"Older"	Lamoille	Tahoe	
Illinoisan	.....	.....	.....	.....	.....	—?—	
Kansan	Kennedy	Buffalo	Cerro	.....	—?—	Sherwin	El Portal
Nebraskan	.....	.....	.....	.....	.....	McGee	Glacier Pt.

phenomena by glaciers of the next later age, but largely to the inherent difficulty of making, between tills of greater age than Iowan, such nice distinctions as are possible among the younger moraines. It is therefore not unlikely that glacial deposits of Illinoisan age are present but are as yet undifferentiated from those of the typical Sherwin stage. The writer hopes to pursue this problem in the near future.

PURPOSE OF THE CORRELATIONS

The writer is interested in the glacial stages of the West, not so much for their own sakes as for their utility in reconstructing the Pleistocene history of the Cordilleran region. Many individual events in that history have been determined, but serious difficulties are encountered when the attempt is made to arrange these in consecutive historical order and still more when one tries to fit such a sequence into the general scheme of the period. Fossils are rare, and even when found they give but little comfort, because the evolutionary changes among organisms were too slow to bring about very distinct faunas within the Pleistocene period—especially in the later part.

The best and most convenient criteria at present available for working out the sequence of Pleistocene events are physiographic. For general correlations there seems to be no basis as good as that afforded by the climatic pulsations for which the Pleistocene period is noted. Such climatic variations, if due to general atmospheric or perhaps astronomic causes, must have affected all parts of the region and impressed their record upon its topographic forms and deposits. Basins held fresh lakes during the cooler epochs, but only playas or salinas in the intervening dry times. Alluvial fans grew larger in the more arid ages and were intrenched under the influence of the next cool moister régime. Such illustrations serve to indicate how the establishment of a series of climatic ages may facilitate the integration of a continuous history of the Pleistocene period in western United States.

Already tentative correlations have been extended out from the glacial area of the Sierra Nevada to the desert basins eastward as far as Death Valley and thence to the Colorado River. The great pediments and alluvial fans as well as the lake terraces and salt beds can thus be assigned to approximate geologic dates and still older features referred to them in turn.

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Notes