

ART. XXII.—*Certain River Terraces of the Klamath Region, California*; By OSCAR H. HERSHEY.

REMNANTS of terraces occur in all the principal valleys of the Klamath Mountains. Heretofore, the writer has not considered them of any particular significance as they appeared not to constitute a definite system. In the down-cutting of the deep Pleistocene valleys, remnants of the old valley floor were left at various levels above the present streams and do not necessarily indicate an uplift of the region by stages. On a recent trip between the coast at Humboldt Bay and the high mountains near the head of the South Fork of Salmon River, the writer had the opportunity of observing a more definite system of river terraces than are developed farther east in the Klamath region and they seem to tell a story worthy of consideration, especially through its bearing on the problem of the cause of glaciation of the high mountains.

These terraces are situated on the Trinity River below the mouth of New River, on the Klamath River below the mouth of Salmon River, and on the Salmon River and its South Fork as far up as Summerville. These streams in this region flow in Pleistocene cañons which have an average depth of 3,000 feet. They are trenched into comparatively resistant metamorphic rocks such as schists and slates, intruded by batholites and dikes of gabbro, diabase, diorite and allied igneous rocks. There is considerable diversity in the resistant properties of the different formations and in consequence the cañons vary greatly in width. Throughout the greater portion of their courses they are extremely narrow at the bottom, usually no wider than the streams, and for miles in places are practically impassable except high up on the slopes. The rivers are superimposed on the structure and traverse indifferently hard and soft belts. The downward progression of the valley floor is controlled by the rate of erosion of the hard rock barriers in the gorges. In the soft belts, the streams exert their energies on the walls of the valley rather than its floor and excavate small basin-like valleys with flat floors from ten to twenty-five times as wide as the gorges in the hard rocks.

Through the gorges the streams flow straight and swift and hurry along the gravel and boulders. In the basins, the streams until recently wound about in meanders, here and there touching and undermining the valley walls. The gravel carried out of the gorges was spread over the flat floors of the basins in sheets from 5 to 20 feet in depth, constituting ordinary gravelly alluvial plains. As the rock barriers in the gorges

were eroded, the basin floors were cut down, remnants of the alluvial plains left as terraces, and a new gravel plain formed. That is the explanation of the terraces but it is not by any means the whole of the story.

The terraces are confined almost exclusively to the basins. The system is chiefly developed below a height of three or four hundred feet above the streams. Occasional alluvial remnants occur higher but there is nothing definite about them. Three fairly persistent levels may be traced out in the different basins, although intermediate terraces are occasionally detected. The lower is the most prominent, stands from 20 to 75 feet above the present streams at low water, and in reality forms the flat floor of the basins. After a terrace level is abandoned by the streams, the rock debris from the neighboring steep mountain slopes works down and builds up talus deposits, giving the older terraces a sloping surface. Hydraulic mining demonstrates that the river deposits extend to the inner edge of the terraces under the talus debris. The lower terrace level has been abandoned so recently that talus deposits and alluvial fans on it are not conspicuous, so that its evenness of surface is a marked feature.

Above Hawkin's Bar, the Trinity River issues from a gorge cut largely in gabbro, and enters upon a belt of Bragdon slate, the least resistant of all the pre-Cretaceous formations of the Klamath region, and has eroded in it a valley from one-fourth to over one-half mile in width. The stream now flows in a narrow cañon trenched from 50 to 75 feet below the flat valley floor. The walls of the cañon consist of highly inclined slates capped by gravel.

From the mouth of Willow Creek to Waterman, three miles, the valley is wide and the terrace system well developed. Several hills of rock rise like islands, centrally on the valley floor. The stream flows in its usual very narrow cañon trenched 30 to 40 feet below the lower terrace which forms the flat valley floor.

The river passes out of the Bragdon slate belt, for several miles traverses a narrow gorge and then returns to the slate belt and enters Hoopa valley. This is about seven miles in length and one mile in average width. Its altitude is about 350 feet above sea level.* The floor is even enough to constitute a fine body of agricultural land. The river traverses it in a meandering course, touching each side alternately, but the meanders are trenched 20 to 30 feet below the flat valley floor.

* Altitudes given in this paper are derived largely from aneroid determinations by J. S. Diller. The figures of the height of terraces are mainly estimates drawn from memory, but are sufficiently accurate not to vitiate the arguments.

The tiny cañon is no wider than the stream and is cut into the rock below the gravel. The valley also preserves splendid remnants of the higher terraces up to several hundred feet, especially at the upper end where there is a beautiful display of three sharp terraces, each a rock bench capped with gravel. Opposite the village of Hoopa, each side of the valley has a well marked remnant of the principal upper terrace, several hundred feet above the stream and other remnants indicate strongly that at that level the valley once had a flat floor of similar shape and size as the present.

At the lower end of Hoopa valley, the river leaves the Bragdon slate belt and to its mouth traverses a gorge in Paleozoic schists. In ascending the Klamath River from Weitchpec, traces of the terrace system are observed in the cañon at various places, particularly at the mouths of Bluff and Red Cap Creeks, but there is no prominent development of them until Orleans is reached. Here for several miles the river is traversing a comparatively soft belt of schist and has eroded a basin over one-fourth mile in average width, the slopes of which are finely terraced. The broad lower terrace, on which is built the village of Orleans, is the valley floor proper and has a level about 30 feet above the ordinary stage of the river. The stream flows through the basin in a rock cañon no wider than the river. Gravel-capped rock benches rise behind each other to a level of 400 or 500 feet above the river and are extensively mined. The main one at several hundred feet seems to correspond in degree of preservation with the main upper terrace on the Trinity River. The altitude of Orleans is nearly 800 feet.

Continuing up the Klamath River and then up the Salmon River traces of the terrace system are encountered at many places in the cañon, particularly at the mouths of tributary streams, but there is no pronounced development of them until Nordheimer is reached. From here to the Forks of Salmon, the valley is wide enough to have a well-marked flat bottom, which is traversed by the river in a narrow rock cañon cut down from 30 to 60 feet. Discontinuous remnants of the higher terraces up to several hundred feet are present all along the river for many miles. The altitude of the river at the Forks of Salmon is about 1700 feet.

Up the South Fork of Salmon River, traces of the lower terrace are hardly anywhere absent; except in a few of the narrowest gorges. Wherever the rocks are soft this lower terrace spreads out to a broad, flat gravel bar, always elevated above the present river level. It is well developed at Cecilville, altitude about 2650 feet, where the village is built on it. The present cañon has a depth of about 25 feet and its usual

extreme narrowness. At several points from here upstream there are in the small cañon, where the rock is excessively soft, traces of a lower terrace whose rock floor is usually 5 to 10 feet above the stream. They are indefinite, are due to a shifting of the stream meanders and do not necessarily indicate renewed uplift. From Cecilville downstream they are weakly developed at a number of points, but nowhere are conspicuous and will be ignored in the following discussion.

In the vicinity of the old town-site of Petersburg, several miles above Cecilville, the river was able to excavate a basin in the area of the Salmon hornblende schist because of its local shearing and partial alteration into chlorite schist. Here the terrace system is typically developed with three main levels, the lower trenched by the river to a depth of 30 to 40 feet. The lower terrace may be traced through the next gorge upstream. At its level there is a slight bench with gravel deposits along both sides of the gorge, and the present cañon, with nearly perpendicular rock walls, has a depth below them of 30 to 50 feet. This leads us into the Summerville basin, excavated largely into an area of non-resistant granite.

The altitude of the river at Summerville is about 3100 feet above the sea. It flows in a rather wide cañon (because the rock is unusually soft), and 30 to 40 feet deep. From its edges, before mining operations were begun, a gravel terrace extended back several hundred feet and then the basin floor rose in successive benches to a level of 300 feet above the stream. Indeed, the entire terrace system was developed here in unmistakable form. This is the farthest point up the river at which it reaches a prominent development, as above here the rocks are nearly uniformly hard, the cañon narrow, and the stream very high grade. Glacial deposits occur within five miles upstream. Within the cañon at many points there are benches, by which the terrace system may be traced into connection with the glacial series. This has been done. However, it deserves treatment as a separate subject, but some of the conclusions will be used in this paper.

The most important features described in the preceding paragraphs are, that each basin throughout the area discussed contains a broad, flat, gravel floor, and that the streams no longer flow at this level, but in a tiny cañon trenched mostly from 30 to 50 feet beneath it into the hard rock below. The contrast between the broad valley floor and the narrow cañon winding about in it is extremely prominent and certainly indicates a change of conditions. The size of the cañons relative to that of the streams is everywhere so nearly alike as to point indubitably to a like age for the flat valley floor in each basin. Now, the development of the flat valley floor

required a long period of comparative stability during which down-cutting in the basins was practically nothing and the streams devoted their attention to widening their valleys. The streams were low grade, at least in the basins, and had meandering courses. Suddenly conditions changed and the streams universally in this area began to trench the valley floor, in many cases retaining the meandering courses. Several hypotheses as to the nature of this change in conditions will be examined briefly:

1. That the down-cutting of the barriers in the gorges was intermittent because of some peculiarity in their structure. This position is untenable. The hypothesis would be worthy of serious consideration if the strata were at a low angle and hard and soft layers alternated. The strata throughout the region are practically vertical and the igneous rocks rise vertically through them. Each barrier belt is essentially uniform in structure and resistant properties in any given 500 feet of depth. All other conditions remaining equal, the down-cutting in the gorges will be practically uniform and the lowering of the basin floors equally as regular. The tiny cañons in the basins are rarely any wider than the streams. Down-cutting in the gorges must proceed as rapidly as in these cañons in the basins. There is not nearly the contrast in the size of the cañons in the basins and the equivalent portion of the gorges, as between the broad valleys and their equivalent portion of the gorges. In this I see evidence that the broad valley floors are not due solely to the barriers, but to the barriers in combination with a past general low-grade condition of the main streams of the entire area. Further it appears evident that the down-cutting from the level of each main terrace, and especially from the last, was due to causes independent of the structure of the barriers.

2. In some regions, particularly those of semi-arid climatic conditions, an increased and better distributed rainfall sometimes causes a dissection of alluvial plains. In this region precipitation is now, and apparently always has been abundant. The streams have been able to remove the rock debris to the sea about as fast as weathering produced it, so that it nowhere accumulated to great depth. Therefore, widening of the valleys occurred only under low-grade conditions of the main streams. Suddenly increased rainfall would hardly result in dissection, but rather, for a time at least, in aggradation. I am going to connect the lower terrace with the later stages of glaciation in the high mountains, and on the generally accepted principle that the Glacial Period was one of excessive precipitation, we must presume that the rainfall is now less than when the broad valley floors were formed.

3. That decreased rainfall caused the erosion of the tiny cañons has in its favor the probability as derived from other sources of such a lessening in the precipitation during their development, but hardly explains the sudden trenching without even destroying the meanders. Further, a lessened precipitation would yield smaller streams which would be less able to carry away the products of weathering and would reach a stable grade with a higher angle of slope and aggradation would result.

4. That the tiny cañons are the result of a general uplift, without tilting, of the entire region is vitally defective for the reason that dissection should begin at the coast line and advance inland. The cañons would be older and consequently larger near the sea than far up on the streams. Now, it is a characteristic of these cañons that they are equally developed proportionate to the streams far up on Salmon River as low down on the Trinity and Klamath Rivers. The recency of the beginning of the cañon erosion low down on the streams as clearly shown by their small size, implies that with uplift without tilting, in order to abrade the stream-bed at all, there should be such an increase of grade near the coast that the cañons would soon run out and the middle and upper courses of the streams retain their low-grade condition.

5. The hypothesis which I can unreservedly accept, is that along with general uplift there has been a tilting of the region toward the coast. The main rivers have been converted from low-grade to high-grade streams. They began to erode their beds at the same time throughout the area and the cañons resulting are everywhere approximately equal. The present high-grade character of the streams is evident. They flow swiftly in the cañons within the basins as well as in the gorges. They move considerable bowlders with ease and there is little more tendency for the debris to lodge in the cañons in the basins than in the gorges. The bottoms of these cañons will be reduced far below their present level before the energy of the streams will be largely devoted to widening of the basins as it once was. Indeed, I am of the impression that this uplift and tilting of the region was one of the most pronounced which has effected it in Quaternary time, but has been so recent that its products are yet insignificant and likely to be overlooked.

In the absence of accurate surveys, distances on these rivers may be roughly determined by the trails. The Klamath River at Weitchpec, about 45 miles from the sea, has an altitude of scarcely 300 feet. Taking this point as a base, the Salmon and Klamath Rivers fall from Summerville to Weitchpec (a distance of about 80 miles), 2,800 feet or 35 feet per mile.

The upper Trinity River between Trinity Center and Bragdon falls about 10 feet per mile. This is so nearly a stable grade for that stream that it has not in recent times materially trenched the floor of its comparatively broad valley, but, on the contrary, it is able to build alluvial plains of coarse gravel which it floods nearly every year. This portion of the Trinity River is a larger stream than the Salmon River above Forks of Salmon, and a smaller stream than the Klamath River from the mouth of the Salmon River to Weitchpec, but it is about the equivalent of the average of those two streams. It is encumbered with gravel of similar coarseness to that on the Salmon and Klamath Rivers. I wish to derive from this comparison the suggestion that while the streams were forming the flat valley floor in the basins, the fall from Summerville to Weitchpec was probably no greater than 10 feet per mile. Indeed, on the lower Trinity where the tiny cañon is well developed, the fall now scarcely exceeds that amount and at the time of the development of the broad valley floor must have been considerably less.

The difference between the theoretical 10 feet per mile and the present fall of 35 feet per mile or 25 feet per mile, may be the differential amount of the uplift, which would mean an absolute elevation of the Summerville basin exceeding 2,000 feet (which, in reality, is probably a minimum). This implies that the central portion of the Klamath region, particularly that area which is occupied by the high mountains which were once extensively glaciated, has suffered an elevation relative to the present coast-line, late in the Quaternary Era, of several thousand feet.

The higher terraces seem also to indicate uplift, but not of such a pronounced differential character, as a stable grade was resumed without great depth of cutting. This series of disturbances occurred within the last one-fifth and probably the last one-tenth of the Quaternary Era. Similar uplifts may have occurred earlier in the era, but their effects inland have been mostly destroyed.

The terrace system is developed on Redwood Creek and on the lower Mad River, where it connects with the lower marine terraces along the coast. Opposite Korbel the flat-topped hills mark the floor of an ancient valley a number of miles wide, as described by Mr. J. S. Diller.* It is traceable as the principal upper terrace to the mouth of the valley where the latter enters on the lowland of the Humboldt Bay region. The river has trenched it to the depth of several hundred feet, excavating a broad valley in soft Tertiary strata but a narrow gorge

* "Topographic Development of the Klamath Mountains." U. S. Geol. Sur. Bull., No. 196, p. 54.

in the hard Franciscan sandstone just below Korbel. The degree of preservation of this terrace, and its relation to lower terraces in the same valley, constrain me to consider it practically the equivalent of the main upper terrace (that occurring so persistently at several hundred feet above the streams) on the Trinity, Klamath and Salmon Rivers. The Mad River terrace seems to slope toward the sea at a rate which was certainly not original. It may connect with a marine terrace back of Eureka.

Near Bay View station, on the railway between Eureka and Arcata, there is a much eroded terrace rising probably 75 or 100 feet above the bay. An extensive railway cutting exposes false-bedded brown sand and silt, evidently marine. This terrace I consider the equivalent of one of the upper river terraces inland. It is developed in the town of Arcata where it consists largely of a yellowish, non-pebbly silt resembling weathered loess. North of Arcata there is developed a lower terrace which consists of a bed of irregularly stratified gravel overlaid by silt. Its outer edge rises probably 15 to 20 feet above the Humboldt Bay lowland or alluvial plain. This terrace I correlate with the lower terrace (the broad valley floors) of the Trinity, Klamath and Salmon Rivers. The town of Eureka is largely built on a low, flat terrace of brown sand, whose outer edge rises probably 15 to 20 feet above the bay and may be of the same age as the lower river terrace inland.

The main upper terrace, occurring so persistently at several hundred feet above the Trinity, Klamath and Salmon Rivers in the area herein discussed, seems to be approximately of the age of the Red Bluff formation. The cañons excavated by the Sacramento River and Clear Creek since the uplift of the Red Bluff formation, are fairly comparable with those eroded on the western slope of the Klamath Mountains since the streams began to cut below the main upper terrace. I should say that throughout the Klamath region the post-Red Bluff erosion nowhere exceeded a depth of 500 feet, unless in a few limited areas which were exceptionally tilted, areas which have not yet come to light. It has been prevailing from 200 to 300 feet in depth, reaching 400 feet locally. The post-Red Bluff erosion constitutes at least the last one-fifth and probably the last one-tenth of the erosion of the Sierran or Pleistocene cañons.

The low terrace at Eureka and the low gravel terrace at Arcata I attribute to the San Pedran subsidence which seems to have been quite persistent along the coast of California. The development of the broad valley floor, constituting the lower terrace on the Trinity, Klamath and Salmon Rivers, I

also consider to have been approximately San Pedran in age. At the close of the San Pedran epoch there seems to have been a land disturbance practically co-extensive with the State. The coast line and Great Valley were slightly uplifted and some of the main mountain masses, as the Klamath, were distinctly bowed. In the incoherent strata of the Great Valley, broad, shallow cañon-shaped valleys were excavated, but in the hard rocks of the Klamath region tiny cañons were eroded. With the exception of a more recent local subsidence on the coast and west of the center of the Great Valley, this first post-San Pedran orogenic activity is the last of which we have any record in California.

After studying the small present cañon of the lower Trinity, Klamath and Salmon Rivers as far up as Summerville, one is able to arrive at a fairly definite conclusion as to what would be the character and amount of the erosion of the same period in the glaciated valleys had not glaciation intervened to complicate matters. Recently the writer has recognized evidence of glacial deposits earlier in age than those usually described from the California mountains. Part of the evidence of age consists of certain rock gorges on Coffee Creek and the South Fork of Salmon River. Higher in the glaciated valleys are much smaller rock gorges (tiny cañons) which have been eroded practically since the complete disappearance of the Quaternary glaciers. It is not possible at the present time to accurately fix upon the time relation of the erosion of the cañon from Summerville downstream and the different stages of the glaciation. But comparison, and the connection by direct tracing of one of the upper terraces in the Summerville basin with the product of one of the earlier stages of the glaciation, make it fairly certain that the inception of the cañon cutting from Summerville downstream considerably antedated the close of the glaciation, but certainly did not occur earlier than its beginning. If there were no inter-glacial stages, the uplift which inaugurated the last cañon cutting from Summerville downstream, was contemporary with some stage of the glaciation, probably a later one. At any rate, it is safe to assert that the uplift did not occur before the beginning of glaciation and apparently has not occurred since its close.

The axis of deformation or line of greatest elevation, is somewhere centrally situated between Summerville in the Salmon River valley and Trinity Center in the upper Trinity valley. Between these points is the group of high mountains which were most extensively glaciated. These mountains apparently rose to the extent of between 2,000 and 3,000 feet at some time between the beginning and close of the glacia-

tion. The elevation may have contributed to the glaciation, but to accepting it as the sole cause of the glaciation there is one serious objection. That is that the glaciated areas in these mountains are now probably as high above sea-level as they ever have been, yet the existing glaciers, three in number, are insignificant.

The supposed submerged river valleys in the border of the continental plateau off the coast of California have been accepted by certain writers as evidence of a former much higher elevation of the California mountains, a probable cause of Quaternary glaciation. For some time, the writer has doubted the pertinence of the argument. In the first place, it is not certain, as pointed out by Lawson,* that all or any of these long, narrow depressions are submerged valleys of erosion. But, accepting the general opinion that they are such, it is not certain that they were eroded as late as any part of the Glacial Period. Further, it is not certain that they indicate an uplift of the mountains of California above their present altitudes.

The sub-marine border of the continental plateau west of the Klamath region was depressed, not by a general epeirogenic subsidence but by a sea-ward tilting of the land. Such differential movements of this region have characterized it throughout the late Tertiary and Quaternary times, an opinion fully accepted and enlarged on by Mr. Diller in the paper before cited. The land has been swinging on an axis approximately corresponding to the present shore-line. By its not exactly coinciding with the present shore-line have been produced the various elevations and subsidences along the coast. But west of this axis the dominating movements were depressions, sinking the plateau border deeper and deeper beneath the sea. East of the axis we have evidence chiefly of a succession of differential uplifts. The supposed submerged river valleys off shore are probably an extension of the upper portion of the deep Pleistocene cañons. They were first submerged by a sea-ward tilting of the country long before the earliest glaciation of which we have any record in the California mountains. This statement I base on the fact that, since the submergence, the sea near the present shore-line has cut away so much of the land as that it must have been at work long before the earliest glaciation in the California mountains. The larger topographic features of the present coast line had been developed before the close of the Red Bluff epoch. The present coast line yields no evidence whatever of a marked elevation above the present at any time as late as the Red Bluff epoch.

In short, it is in the submergence and not the erosion of the

* Bull. Dept. Geol., Univ. Calif., vol. i, pp. 57-59.

supposed sub-marine river channels that I see corroborate evidence of elevation inland. Each tilting to which is due the river terraces described in this paper, served only the more effectually to depress the drowned valleys. Even the recent drowning of the mouths of the modern rivers west of the Klamath region tells the story of tilting, as the tide runs up them only a few miles.

The writer long accepted elevation as the direct cause of the great Quaternary glaciations, but that theory of late has seemed very questionable. The uplifts and the glaciations should connect more closely than they do. Further, the disappearance of the glaciers should have been brought about by depression of the land. In the Klamath region, the glaciated valleys, as already mentioned, appear to be at present as high above sea-level as they were at any time during the Glacial Period; therefore, the theory of elevation as the sole cause of glaciation seems inadequate.

Berkeley, California.