Pleistocene Glaciation in the Ruby-East Humboldt Range, Northeastern Nevada

ROBERT P. SHARP
University of Illinois, Urbana, Illinois

INTRODUCTION

Any Quaternary chronology developed in continental areas far from the sea must be, in large part, based on the succession of glacial stages. Long continued study of the glaciation of the central United States has produced a standard chronology for that region, but glacial studies in the western United States have been less intensive and, furthermore, suffer from the lack of extensive and continuous glaciated areas. The glaciated mountain ranges of western United States are mere dots in a vast expanse of unglaciated country, and as much information as possible must be gathered from these ranges before a satisfactory Pleistocene glacial succession, consistent with that of the central United States, can be established. In recent years, Blackwelder[1] has done much to emphasize this problem in the Great Basin and his work serves as an inspiration to others.

FIGURE 1: Location of the Ruby-East Humboldt Range (in black) and the intermittent lakes on the east side of the range.

Glacial studies in western mountain ranges acquire significance because of the need for a chronology with which to date and correlate

1. Eliot Blackwelder, "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges." *Bull. Geol. Soc. Am.*, Vol. 42, pp. 865-922, 1931. "Glacial and Associated Stream Deposits of the Sierra Nevada." *Mining in California*, Vol. 28, pp. 303-310, 1932. *Sixteenth International Geological Congress Guidebook*, No. 16, pp. 84-86, 1934. "Supplementary Notes on Pleistocene Glaciation in the Great Basin. *Jour. Wash. Acad. Sciences*, Vol. 24, pp. 217-222, 1934.

Pleistocene and Recent geologic features, geomorphic forms, pluvial and interpluvial periods, and deposits containing evidence of early man. Such studies are further important for the information gained on meterological condition during the Pleistocene.

The Ruby-East Humboldt Range[2] is approximately midway between the Sierra Nevada on the west and the Wasatch Mountain on the east

FIGURE 2: Looking south into the upper part of Lamoille Canyon which has been occupied by ice in the Angel Lake substage of glaciation (later Wisconsin). The well-defined, U-shaped aspect of the canyon is apparent, and post-glacial erosion of the canyon walls and building of detrital cones on the floor of the canyon, though noticeable, are relatively insignificant compared to the amount of post-glacial erosion and detrital filling in the canyon below the terminal moraines of the Angel Lake substage. Lamoille Canyon contained a glacier twelve miles long in the Lamoille substage of glaciation, the largest glacier in the range. August 24, 1937.

(Figure 1). Detailed studies of the glaciation in a range of intermediate location, such as this, offer a possible means of relating the Pleistocene glacial succession worked out by Blackwelder in the Sierra Nevada with that developed in the central United States. The criteria developed in the course of such studies may have value for students of mountain glaciation in other parts of the world.

2. Not to be confused with the Humboldt Range of west-central Nevada described by Louderback (*Bull. Geol. Soc. Am.*, Vol. 15, 289-346, 1904).

LOCATION AND PHYSICAL FEATURES

The Ruby-East Humboldt Range is a narrow, fault-block mountain mass, approximately one hundred miles long, in Elko County, northeastern Nevada (Figure 1). The range trends north twenty degrees east and is divided by Secret Pass into a northern part, the East Humboldt Mountains, and a southern part, the Ruby Mountains.

FIGURE 3: Looking northwestward into the upper part of Moore Creek on the east side of the central Ruby Mountains. This view illustrates the irregular, ill-formed type of moraine (AL) common to many of the canyons on the east side of the range. Moore Creek cascades down the front of this moraine, which belongs to the Angel Lake substage, in a gully (G) not over twenty-five to thirty feet deep, indicating the slight extent of stream dissection since the last glaciation. A nivation depression (N) at the right side of the picture is still occupied by a small patch of snow. June 22, 1937.

The range has a steep, rugged, eastern face and a less steep western slope, and in all places the crest is much nearer the eastern than the western foot. The topography of the interior of the mountains is rugged, and the relief is between 4000 and 5000 feet at maximum. The crest of the range has an average altitude of about 10,000 feet, although the higher peaks are between 11,300 and 11,400 feet high.

King[3] and his associates first recorded glaciation in the Ruby-East Humboldt Range. Blackwelder[4] has published two papers which describe its glacial features briefly.

Nearly perfect U-shaped canyons such as Lamoille and Rattlesnake (Figure 2); lateral and terminal moraines, twenty-five to 250 feet high and one-quarter to three-quarters of a mile long; outwash de-

FIGURE 4: Looking eastward from the crest of the northern Ruby Mountains down to the Robinson Lake basin, at an elevation of 9200 feet, which was occupied by a moderately large, flat, cliff glacier, three and one-half to four square miles in area. Robinson Lake in the mid-foreground occupies a shallow depression in glacial drift which mantles nearly the entire basin.

posits; glacial polish and striations; cirques; glacial tarns; horns; and glacial steps all offer indisputable testimony that the Ruby-East Humboldt Range has been extensively glaciated by ice during the Pleistocene. Evidence of glaciation has been observed only in the northern sixty-five miles of the range.

3. Clarence King, "Geological Exploration of the Fortieth Parallel." Prof. Paper No. 18, *Engineer Dept., U. S. Army,* Vol. 1, pp. 475-476, 1878; and Vol 2, pp. 537-538, 1877.
4. Eliot Blackwelder, "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges." *Bull. Geol. Soc. Am.,* Vol. 42, pp. 910-911, 1931. "Supplementary Notes on Pleistocene Glaciation in the Great Basin," *Jour. Wash. Acad. Sciences,* Vol. 24, pp. 218-219, 1934.

NATURE OF THE GLACIERS

The glaciers in the larger canyons on the west slope formed long sinuous streams of ice. Shorter steeper canyons with open theater heads, mostly on the east side were filled with broad, ill-defined ice masses, only a few of which possessed well-defined ice tongues projecting down into the lower, confined part of the canyon. Many of these glaciers built large, irregular, poorly-defined, morainal embankments (Figure 3) which are notably different from the well-formed moraines in the larger canyons on the west slope. Small piedmont glaciers were formed at the foot of the range by the ice streams debouching from certain canyons (Rattlesnake, Lamoille, Willow, Clover, Angel, South Fork of Angel, and Schoer Creeks). In a few localities (e.g. near Schoer Creek and the South Fork of Angel Creek on the east side of the East Humboldt Mountains, and Robinson Lake basin, shown in Figure 4, at the head of Soldier Creek near the crest of the Ruby Mountains) a number of glaciers from adjoining canyons coalesced to form small integrated ice masses or cliff glaciers covering areas of two to four square miles on the mountain slope.

CRITERIA USED FOR DIFFERENTIATING GLACIATIONS

Evidence of two separate glaciations has been found in the Ruby-East Humboldt Range. The first, or earlier, has been named the "Lamoille" and the second, or later, the "Angel Lake" by Blackwelder.[5] These names will be retained in this paper, but, as both glaciations appear to be Wisconsin, they will be referred to as substages and not stages in order to be consistent with the current practice in the central United States.[6]

Topographic Condition of Moraines. Moraines of the Angel Lake substage (Figure 5) possess a topography more typically glacial than moraines of the Lamoille substage. The Lamoille substage moraines are more subdued and rounded, are not so hummocky, are more deeply dissected by the streams, and lack the fresh, well-defined glacial topography so characteristic of the moraines of the Angel Lake substage.

Type of Moraine. Within the canyons, the Lamoille substage is represented only by lateral moraines. The terminal moraines of this substage have been entirely removed by erosion. The terminal moraines of the Angel Lake substage are well preserved and are merely notched by the streams, as clearly shown in Figure 3.

Boulder Frequency on Surfaces of Moraines. Figure 5 shows a moraine of the Angel Lake substage (AL) resting upon a moraine of the Lamoille substage (L). The contrast in frequency of boulders on the surfaces of these two moraines is immediately apparent. The surface of the Lamoille substage moraine is sparsely dotted with large boulders of resistant rocks which have been able to withstand weathering and disintegration. In contrast, the surface of the Angel Lake substage moraine

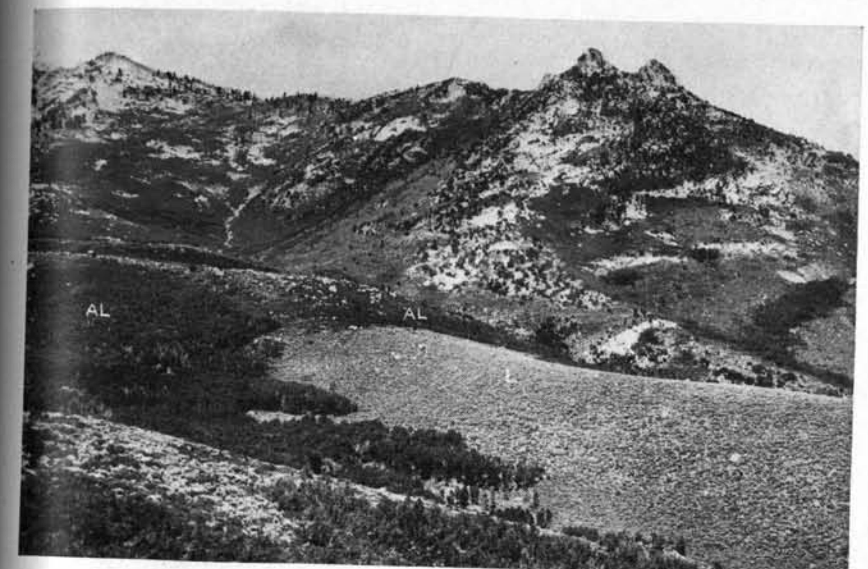

FIGURE 5: Looking northwestward to Wines Creek on the east side of the central Ruby Mountains. The smooth, rounded sage-brush covered ridge (L) extending from the center of the picture to the right edge is a lateral moraine of the Lamoille substage. The bouldery mass (AL) resting on top of this ridge, just to the left of the center of the picture and extending to the left edge, is a combination terminal and lateral moraine of the Angel Lake substage. The subdued topography of the Lamoille substage moraine presents a strong contrast to the sharp, fresh, glacial topography of the Angel Lake moraine. Of further note is the contrast in boulder frequency on the surfaces of the two moraines.

5. Eliot Blackwelder, "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges." *Bull. Geol. Soc. Am.*, Vol. 42, p. 918, 1931.
6. F. T. Thwaites, *Outlines of Glacial Geology*. Edwards Bros. Inc., Ann Arbor, Michigan, 1935. See pp. 71-72.

is covered with a profusion of boulders large and small. The contact between the two moraines near the center of the picture, Figure 5, is particularly sharp.

Weathering and Staining of Drift. The till composing the moraines contains fragments of fine- to medium-grained granitic rocks, pegmatite, quartzite, diopside granulite, schist, and gneiss. These fragments range in size from an inch or two, to huge boulders many feet in diameter. They are embedded in a sandy to gravelly matrix which makes up only a small part, ten to twenty per cent, of the mass. These deposits resemble more the tills of New England than those of the central United States. Only boulders of granulite, mica schist, and some of the granitic rocks show noticeable effects of weathering and disintegration. In moraines of the Lamoille substage many such boulders are so soft that the pick end of a geological hammer can be driven into them up to the shank. The same rock types in moraines of the Angel Lake substage are relatively fresh.

Drift of the Lamoille substage has a yellowish tinge for several feet below the surface, owing to oxidation and iron staining, which is distinct from the drab, gray color of the drift of the Angel Lake substage. Weathering and staining of drift have been useful for distinguishing deposits of different glaciations only locally in this area owing to the lack of suitable exposures in which such phenomena could be observed.

Composition of Residual Boulders on Moraines. Careful inspection of the moraines of the Ruby-East Humboldt Range shows that the relative frequency of boulders of the various rock types is about the same on the surface of moraines of the Angel Lake substage as in fresh cuts of the same moraines. If the fresh till contains twenty per cent quartzite boulders, it has approximately twenty per cent quartzite boulders on the surface, and correspondingly for the other rock types. The boulders on the surface of a moraine of the Lamoille substage are largely quartzite, regardless of the composition of the moraine as displayed in a fresh cut. Granulite, mica schist, and granitic boulders are rare on the surface, though they may be present in fairly large quantities in the unweathered drift. In an exposure of the moraine of the Lamoille substage at the mouth of Lamoille Canyon, quartzite boulders make up only fifteen to twenty per cent of the till. On the surface of this same moraine, seventy-five to eighty per cent of the boulders are quartzite. The less resistant rock types have been largely eliminated by weathering and decomposition. This clearly demonstrates the fallacy of determining the composition of a moraine of the Lamoille substage from the composition of the boulders exposed on its surface. Mackin[7] has noted the same relation in the terrace and pediment gravels of the Big Horn Basin. The elimination of the less resistant rock types by weathering and decomposition suggests a considerable interval of time between the deposition of the moraines of the Lamoille and Angel Lake substage. An abundance of residual quartzite boulders on the surface of a moraine identifies the moraine as belonging to the Lamoille substage and has proved a useful criterion for differentiating the moraines of the two glaciations. Naturally, the criterion cannot be applied without regard for the composition of the fresh till.

Modification of Glaciated Canyons by Post-Glacial Erosion and Detrital Filling. Post-glacial erosion of the walls and detrital filling of the bottoms of canyons or parts of canyons glaciated only in the Lamoille substage are so extensive as to destroy or mask in large part the U-shape and glacial aspects of the troughs. Canyons or parts of canyons glaciated in the Angel Lake substage show only small-scale post-glacial gullying and detrital filling and have well-defined U-shapes (Figure 2). This contrast in appearance of parts of canyons glaciated in the Lamoille and in the Angel Lake substage is particularly well show in Lamoille Canyon. Here, the glacier of the Lamoille substage extended to the mouth of the canyon and spread out on the piedmont slope to the west. In the Angel Lake substage, the Lamoille Canyon glacier moved down only as far as the mouth of the Right Fork, but the Right Fork glacier moved into Lamoille Canyon and down it for a quarter of a mile, as indicated by its terminal moraines. Below this point the canyon is filled with large alluvial cones and is notably different from the well-defined, U-shaped, upper part of the canyon. The contrast between the part of the canyon glaciated in the Angel Lake substage and the part glaciated only in the Lamoille substage is striking, and the change is sharp. The difference cannot be accounted for by a difference in rocks because the rocks are essentially the same, and where different, show no relation to the amount of erosion or detritus filling the canyon. In the Ruby-East Humboldt Range, at least, parts of a canyon glaciated at different times can be distinguished by the amount of post-glacial erosion of the canyon

7. J. H. Mackin, "Erosional History of the Big Horn Basin, Wyoming." *Bull. Geol. Soc. Am.*, Vol. 48, pp. 838-839, 1937.

walls and the detrital fill on the canyon floors. Moraines located downstream from the parts of the canyon showing evidence of considerable post-glacial modification more likely belong to the older than to the younger glaciation.

Position of Moraines. The position of the moraines, though possibly not a true criterion for differentiating separate glaciations, has proved useful in field mapping. Moraines of the Lamoille substage are located

FIGURE 6: Looking east to the west slope of the Ruby Mountains just south of Lamoille. Seitz Creek is in the first large canyon from the left side of the picture, and Heenan Creek is in the second canyon to the right of Seitz Creek. Lateral moraines (L) of the Lamoille substage (Iowan Wisconsin) and terminal moraines (AL) of the Angel Lake substage (Later Wisconsin) are easily distinguished on both creeks. July 3, 1937.

farther down the canyons and higher up on the canyon walls than the moraines of the Angel Lake substage. In some cases, lateral and terminal moraines of the Angel Lake substage lie inside the lateral moraines of the Lamoille substage. Figure 6 shows this relation on Seitz Creek where the lateral moraines of the Lamoille substage (L) form long smooth ridges inside of which, and more or less blocking the canyon, is the terminal moraine of the Angel Lake substage (AL).

NUMBER OF GLACIATIONS

Lamoille and Angel Lake Substages. By use of the criteria listed above, the moraines of two glaciations, the Lamoille and Angel Lake substages of the Wisconsin, have been mapped in the Ruby-East Humboldt Range (Figure 11). The best places for observing the relations between moraines of the two substages are on Leach, Weeks, Steels, Pole, Wines, Heenan, Seitz, and Lamoille Creeks.

No certain evidence of glaciation earlier than the Lamoille has been found in the Ruby-East Humboldt Range. The large boulders on the ridge south of Lamoille Canyon mentioned by Blackwelder,[8] and similar deposits elsewhere in the range have been examined carefully but are not considered convincing. It is possible that traces of earlier glaciations in this range have been destroyed or have been modified to such an extent as to be unrecognizable. The question might be asked, is it possible that this range was not high enough during the early glacial stages to support glaciers of any size? This is possible, for the uplift of the range has been in progress from the Miocene to the late Pleistocene or Recent, and the mountains may have reached their present altitude only in late Pleistocene time. If such were the case, the range need not have been glaciated extensively prior to the Wisconsin.

PHASES WITHIN THE ANGEL LAKE SUBSTAGE

Moraines in several canyons (particularly Pole, Boulder, and Segunda) give all appearances of being retreatal moraines of the Angel Lake substage. These moraines are irregular, hummocky piles of detritus on the canyon floors, some distance up the canyons from the terminal moraines of the Angel Lake substage. They are not well-formed, arc-shaped terminal moraines, and their general appearance suggests that they were deposited during an equilibrium phase in which ice supply and ice wastage were balanced. They may indicate a phase in the retreat of the last ice, but this study has not been detailed enough to prove a corresponding mountain-wide pause in the retreat of the glaciers of the Angel Lake substage.

Many of the sharp, ragged cirques occupied by ice during the last glaciation are blocked at the mouth by embankments of large angular blocks resembling talus. However, the embankment-like construction shows that these are not talus deposits. In most cirques, the embankments are one-half to three-quarters of a mile from the head of the cirque. This seems too great a distance for material to slide over the ice

8. Eliot Blackwelder, "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges." *Bull. Geol. Soc. Am.*, Vol. 42, p. 911, 1931.

to form the embankments as has been suggested for other localities by Richter,[9] Goldthwait,[10] and Von Engeln.[11] Likewise, the embankments are too far from the cirque walls to be pro-talus[12] ramparts. True pro-talus ramparts have been noted in other places, particularly at the head of Rattlesnake Canyon and on Moore Creek. The embankments at the cirque mouths have been formed either during a period of equilibrium when ice supply and ice wastage were balanced, or they have been formed by a slight readvance of the ice. Regardless of the exact mode of origin, they probably represent another phase in the retreat of the last glacial ice.

CORRELATION AND AGE OF GLACIATIONS

The following table shows how Blackwelder[13] has correlated the glaciations in the Ruby-East Humboldt Range with those he recognizes in the Sierra Nevada.

Ruby-East Humboldt Range	Sierra-Nevada	Age
Angel Lake	Tioga Stage	Wisconsin
Lamoille	Tahoe Stage	Iowan

The recent consensus of opinion seems to be that the Iowan should be considered a substage of the Wisconsin[14] and not a separate stage coming between the Illinoian and Wisconsin. If such is the case, the Lamoille and Angel Lake glaciations are merely substages of the Wisconsin, and the retreatal phases of the Angel Lake substage, described above, may correspond to other substages of the Wisconsin.

The post-glacial modification of that part of Lamoille Canyon glaciated only in the Lamoille substage, by erosion of its walls and detrital filling of its bottom, has been described and contrasted with the relatively slight post-glacial gullying and detrital filling of the part of Lamoille Canyon glaciated in the Angel Lake substage. The evaluation of the amount of time required to produce such modifications is difficult. Certainly the interval between the Lamoille and Angel Lake glaciations is longer than the time between the Angel Lake glaciation and the present, and the question immediately arises as to whether or not it is long enough to justify correlating the Lamoille substage with the Illinoian.

Other canyons, for example Seitz and Heenan immediately to the south, show moraines (Figure 6) of the two substages in relations which are almost exact duplications of the relations of moraines of the Tioga and Tahoe stages in the Sierra Nevada. This strongly suggests that moraines correlative of the Tioga and Tahoe moraines of the Sierra Nevada are present in the Ruby-East Humboldt Range. If the moraine at the mouth of Lamoille Canyon is Illinoian, the moraines correlative of the Tioga and Tahoe stages, both younger than the Illinoian, should also be found in the canyon. Such is not the case. Only moraines of the last glaciation, correlative of the Tioga stage, are found. This in itself suggests that the moraine at the mouth of the canyon is not Illinoian, but that it is to be correlated with the Tahoe stage (Iowan) of the Sierra Nevada. In addition, the moraine at the mouth of Lamoille Canyon has a typical hummocky, glacial topography. This distinct glacial topography, plus depth of weathering, staining, disintegration of boulders and such criteria in no way suggests an age as great as Illinoian. Unfortunately, Blackwelder[15] has not recognized an Illinoian stage in the Sierra Nevada, though he has some evidence for this stage, so no direct comparison can be made there. Blackwelder's[16] Sherwin stage in the Sierra Nevada is correlated with the Kansan. The Sherwin till is deeply weathered and stained, boulders are soft and disintegrated at great depths, and all traces of a glacial topography have been removed by post-glacial erosion. The moraine at the mouth of Lamoille Canyon possesses no features which would suggest that it is old enough to be correlated with the Sherwin stage of the Sierra Nevada.

In short, no good evidence has been found for correlating the moraine at the mouth of Lamoille Canyon with the Illinoian, and Blackwelder's

9. E. Richter, "Geomorphologishe Beobachtungen aus Norwegen." *Sitzungsber Wiener Akad. Math. Naturw.*, Kl. Vol. 105, Abt. 1, pp. 154-164, Quoted by W. H. Hobbs, *Characteristics of Existing Glaciers.* 1911, 1922, see p. 14.
10. J. W. Goldthwait, "Geology of New Hampshire." *New Hampshire Acad. of Science,* Handbook No. 1, p. 12, 1925.
11. O. D. Von Engeln, "Palisade Glacier of the High Sierra Nevada, California." *Bull. Geol. Soc. Am.*, Vol 44, p. 584, 1933.
12. William S. Cooper, "Plant Successions in the Mount Robson Region, British Columbia." *The Plant World,* Vol. 19, p. 220, 1916.
C. H. Behre, Jr., "Talus Behavior above Timber in the Rocky Mountains." *Jour. Geol.*, Vol. 41, p. 630, 1933.
Kirk Bryan, "Geomorphic Processes at High Altitudes." *Geographical Review,* Vol. 24, pp. 655-656, 1934.
13. Eliot Blackwelder, "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges." *Bull. Geol. Soc. Am.*, Vol. 42, p. 918, 1931.
14. F. T. Thwaites, *Outlines of Glacial Geology.* Edwards Bros. Inc., Ann Arbor, Michigan, pp. 71-72, 1935.

15. Blackwelder, op. cit., pp. 895, 918.
16. Blackwelder, op. cit., pp. 895-900, 918.

original correlation of the Lamoille substage with the Tahoe stage of the Sierra Nevada seems justified. Furthermore, it appears entirely likely that Blackwelder is right in correlating the Tahoe stage with the Iowan and not with the Illinoian; for in the Ruby-East Humboldt Range the features of the Lamoille substage are relatively so fresh that they cannot be correlated with the Illinoian. The features of the Angel Lake sub-

FIGURE 7: Morainic loop (M) in the Angel Lake substage moraine on Pole Creek. The remarkable freshness of features such as this, which shows only minor post-glacial modification, indicates a relatively late Wisconsin age for the Angel Lake substage of glaciation. This loop is near the point of maximum extent of the Angel Lake substage glacier and is not merely a feature of a late retreatal phase within that substage.

stage correspond remarkably well with similar features of the Tioga stage in the Sierra Nevada, and Blackwelder's correlation of the two seems justified. The freshness of the various features of the Angel Lake substage and the relatively long interval of time between it and the Lamoille substage show that the Angel Lake glaciation is certainly post-Iowan Wisconsin and not merely a retreatal phase of the Lamoille substage. Figure 7 serves to illustrate the remarkable freshness of the features of the Angel Lake glaciation on Pole Creek. The arc-shaped loop in the center of the picture shows remarkably little post-glacial modification and indicates a relatively short post-glacial period compared to

the length of the post-glacial period indicated by the features of the Lamoille glaciation. The possibility that the Angel Lake glaciation is middle Wisconsin and that its retreatal phases are later Wisconsin must be considered, but in our present state of knowledge just which substages of the post-Iowan Wisconsin are represented by the moraines, here called Angel Lake, is indeterminate. The tentative correlations proposed are outlined in the following table.

Angel Lake substage (including retreatal phases)	Later Wisconsin	Wisconsin
Lamoille substage	Iowan substage	

EXTENT OF GLACIERS

The glaciers of the Lamoille substage were the more extensive; for the moraines of this substage lie farther down the canyons and higher up on the canyon walls than the moraines of the Angel Lake substage.

Lamoille Canyon contained the longest glacier of the range. This glacier was twelve miles long in the Lamoille substage and eight miles long in the Angel Lake substage. Rattlesnake Canyon contained a glacier which was eight miles long in the Lamoille substage and three and three quarters miles long in the Angel Lake substage. The glaciers of the two substages had corresponding proportional lengths in many other canyons on the west slope of the range. The glaciers on the east side of the mountains, and even in a few canyons on the west side, were much shorter. The longest glaciers on the east side of the mountains were in Leach, Weeks, Steels, and Pole Canyons. Weeks Canyon contained a glacier which was two and five-tenths miles long in the Lamoille substage and one and nine-tenths miles long in the Angel Lake substage. Pole Canyon contained a glacier which was two and four-tenths miles long in the Lamoille substage and two and one-tenths miles long in the Angel Lake substage.

In the Lamoille substage only the glaciers in Rattlesnake, Seitz, and Lamoille Canyons on the west side of the range emerged from the mountain block on the piedmont slope. The glaciers of Schoer, Angel, South Fork of Angel, Willow, and Clover Creeks at the north end of the East Humboldt Mountains moved down on the slope east of the principal scarp, but in this area a subsidiary fault block lies east of the main scarp, and these glaciers can hardly be said to have emerged on the piedmont slope. In the Lamoille substage, glaciers reached the foot of the mountains but did not emerge on the piedmont slope on Greys and Heenan Creeks on the west side of the mountains, and on Winchell, Leach, Weeks, and Steels Creeks on the east side. In the Angel Lake substage only the glaciers of Clover and Willow Creeks reached the base of the range. The others were confined entirely to the mountain block.

ALTITUDES TO WHICH GLACIERS DESCENDED

The moraines of the Lamoille substage in Lamoille and Seitz Canyons, on the west side, at an altitude of 6100 feet, are the lowest of any in the range. The Lamoille substage glaciers descended to an average altitude of 7300 feet on the west side and 7200 feet on the east side of the range. The Angel Lake substage glaciers descended to an average altitude of 7800 feet on the west side and 7600 feet on the east side of the range. The fact that the ice descended to an average altitude somewhat lower on the east side than on the west is probably to be attributed to the steeper gradients of the east side canyons and possibly to a lower snow-line on that side, a matter to be considered shortly.

The centers of heaviest glaciation have been the highest parts of the range, more specifically the north end of the East Humboldt Mountains and the central Ruby Mountains immediately south of Lamoille Canyon. In the East Humboldt Mountains about seventeen per cent of the mountain area was covered by glaciers in the Lamoille substage and approximately fourteen per cent in the Angel Lake substage. In the central Ruby Mountains approximately thirty-four per cent of the mountain area was covered by glaciers in the Lamoille substage and about twenty-seven per cent in the Angel Lake substage. In both areas the glaciers of the Angel Lake substage occupied about eighty per cent of the area covered by the Lamoille substage glaciers. Figure 8 shows the relation between glaciated and unglaciated surfaces in one of the more heavily glaciated parts of the range.

Blackwelder[17] observed no evidence of glaciation in the Ruby Mountains south of Harrison Pass, but in the present study, well-defined moraines have been mapped in the vicinity of Pearl Peak, five miles south of Harrison Pass.

17. Eliot Blackwelder, "Supplementary Notes on Pleistocene Glaciation in the Great Basin." *Jour. Wash. Acad. Sciences,* Vol. 24, p. 219, 1934.

LATE PLEISTOCENE SNOW-LINE IN THE RUBY-EAST-HUMBOLDT RANGE

The exact position of the present snow-line in this range is not known. In particularly favorable years snow lasts from year to year in shaded cirques, and it is not impossible that the crest of the range would be capped by perennial snow if its topographic configuration were favorable for the preservation of the snow that falls each winter. On the other hand, it is entirely possible that the present snow-line lies at an altitude of a few hundred to a thousand feet above the crest of the range.

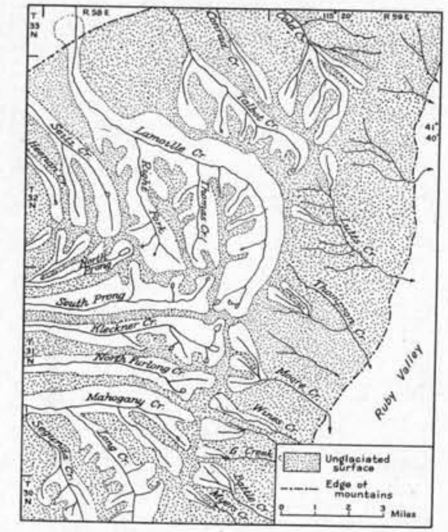

FIGURE 8: Glaciated and unglaciated areas in the central part of the Ruby Mountains. Thirty-four per cent of the total mountain area represented in this map has been glaciated.

In the Pleistocene glacial periods the snow-line must have been considerably lower. The glacial snow-line in a range such as this can be determined in two ways. First, the snow-line may be determined approximately by the altitude of the crest at the transition from the glaciated to the unglaciated parts of the range. In these mountains, the crest ranges in altitude from 11,000 to 8,000 feet. That part of the range in which the crest is below 9800 feet is unglaciated, and that part in which the crest is above 9800 feet is glaciated. On this basis, the snow-line during the Wisconsin glaciation was at an altitude of about 9800 feet.

The second method is based upon the principle that the altitude of the cirque floors is governed in a broad way by the height of the glacial snow-line, and that the altitude of the cirque floors may be used as the glacial snow-line, a method advocated by Penck and Brückner.[18] The average altitude of all the cirques in this range, as determined from the existing 100-foot contour map, is approximately 9100 feet. If the data on which this determination is based are analysed more closely, it be-

18. Albrecht Penck, and Eduard Brückner, *Die Alpen im Eiszeitalter.* Erster Band, Leipzig, 1909, p. 266.

comes apparent that the snow-line on the east side of the range, at about 8800 to 8900 feet, is roughly 500 feet lower than the snow-line on the west side at about 9300 feet. This difference in altitude of the snow-line on opposite sides of the range is probably to be attributed largely to wind drifting of snow and to the fact that the east side of the range is in a mid-afternoon shadow when the sun's heat is most effective for melting snow. No consistent data were obtained to show that the snow-line rose southward in the range.

The discrepancy between the altitude of glacial snow-line as determined by the two methods may possibly be attributed to the fact that excavation of cirques, though initiated at or above snow-line, if long enough continued, can produce a cirque, the floor of which may be some distance below snow-line. For this reason, the altitude of the floors of the smaller cirques may more accurately indicate the glacial snow-line. The altitude of the floors of the smaller cirques is two to three hundred feet higher than the average altitude of all the cirque floors. An average snow-line for the range at about 9400 feet is obtained by using only the floors of the smaller cirques, and this figure may be more nearly correct than that obtained by using the altitude of all the cirque floors.

The exact amount of lowering of snow-line in the late Pleistocene is indeterminate because the position of the present snow-line in this range is unknown. Klute[19] reports a lowering of the snow-line in the Rocky Mountains during the last glaciation of approximately 2000 feet and in the Sierra Nevada of approximately 3600 feet at this latitude. It appears to be something of a general rule that the Pleistocene snow-line was depressed a smaller amount in regions which have at present a light precipitation than in regions of heavy rainfall. On this basis it is possible that the glacial snow-line in the Ruby-East Humboldt Range was depressed a smaller amount than the snow-line in either the Rocky Mountains or the Sierra Nevada. If this is true, the present snow-line may be only a short distance above the crest of the range.

On the whole, it seems best to state that the average Wisconsin snow-line in the Ruby-East Humboldt Range may have been at an altitude ranging from 9300 to 9800 feet on the west side of the range, and perhaps as much as 500 feet lower, 9300 to 8800 feet, on the east side, favor being placed on the higher figures in both cases. The methods of

19. Fritz Klute, "Die Bedeutung der Depression der Schneegrenze für eiszeitliche Probleme." *Zeitschrift für Gletscherkunde,* Vol. 16, p. 75, 1928.

determining glacial snow-line are not precise enough to permit a separation of the figures given above into two sets corresponding to the two glaciations recognized in the range. Furthermore, it must be admitted that the figures given are probably affected considerably by local conditions which can be eliminated only by regional studies on a larger scale. The positions of glacial snow-line are of significance for the light they may throw on Pleistocene environment and meteorological conditions.

WIND DIRECTION IN THE LATE PLEISTOCENE

Figure 8 shows that the upper part of Lamoille Canyon trends nearly north-south and lies immediately west of the head of Lutts Canyon on the east side of the range. Lutts Canyon has a large area for catchment and storage of snow at its head, but it has been less extensively glaciated than much smaller canyons, notably Moore and Wines, not far away to the south. If the late Pleistocene storms came from the east no explanation for this anomalous condition is forthcoming, even after differences of size, exposure, and altitude have been considered. If the storms came from the west, the reason for the small size of the Lutts Canyon glacier is immediately apparent. The upper, north-south part of Lamoille Canyon immediately to the west acted as a trap for wind-blown snow from the west. Lutts Canyon was thus deprived of its share of wind-blown snow, whereas the smaller canyons to the south, lacking the snow trap to the west, received relatively large quantities of wind-blown snow.

This same relation is also demonstrated by the north and south forks of Thompson Creek as can be seen in Figure 8; and, in this case, the conditions of exposure, location, size, and altitude are so nearly the same that no other explanation seems acceptable. The south fork of Thompson Creek contained a glacier because the head of Lamoille Canyon is too shallow to act as a snow trap. The north fork of Thompson Creek in the shadow of a deeper part of Lamoille Canyon was deprived of wind-blown snow and contained only a very small glacier or none at all.

Another feature suggesting late Pleistocene wind from the west is the fact that the largest glaciers on the west slope of the range, notably the Lamoille and Rattlesnake Canyon glaciers, headed in areas which were in wind shadows for storms coming from the west. The head of Pole Canyon has a southern exposure, but Pole Canyon has contained a relatively large glacier because its head lies in a wind shadow for storms from the west.

In short, the available evidence strongly suggests that most of the late Pleisocene storms of this region came from the west.

FACTORS DETERMINING EXTENT OF GLACIERS

The reasons why certain parts of the same mountain range have been more extensively glaciated than other parts have been discussed by a number of workers, more recently by Matthes.[20] It is generally recognized that altitude is a factor of prime importance, not only because of relatively heavier snowfall at higher altitudes, but because the lower temperature and rarefied atmosphere prohibit quick melting of the snow and ice. The relation between altitude and glaciation is well shown in the Ruby-East Humboldt Range, for the areas of heaviest glaciation coincide exactly with the high areas of the range.

Furthermore, it is recognized that wind shadows and sun shadows are places particularly favorable for the collection and preservation of snow. These relations are clearly exemplified in the Ruby-East Humboldt Range, for Lamoille and Rattlesnake Canyons, which contained the longest glaciers of the range, have northerly courses in their upper parts so that the heads of both canyons are in northerly-exposed and sun-shadowed cirques. They are further protected by a high ridge immediately to the west, which puts them in a wind shadow; for, as noted above, the storms which brought precipitation to this area came from the west. In addition, both canyons head in areas of high altitude.

The relatively small size of the glaciers on the east side of the range as compared to those on the west may be accounted for largely by three factors. First, the east side of the range lies in a precipitation shadow cast by the high crest of the range. The storms which came from the west dropped the larger part of their moisture on the west side of the range. Second, the steepness of the floors and walls of the upper parts of the canyons on the east side is so great that snow cannot gather to any great depth before it is removed by slides and avalanches. These slides and avalanches moved the snow from high places into or near the zone of wastage where it melted more rapidly. The net effect was to decrease the supply of ice. Third, the glaciers on the west side of the range were

20. François E. Matthes, "Geologic History of the Yosemite Valley." *U. S. Geol. Surv. Prof. Paper* 160, pp. 51-53, 1930.

relatively bigger because they were nourished by more and larger snow fields than those on the east side owing to the contrast in topographic configuration on opposite sides of the range. Not enough snow was blown over the crest of the range to compensate for the natural handicaps of the east side, and the glaciers of the east side were smaller and less powerful than those on the west.

THICKNESS OF ICE

The thickness of ice in the Angel Lake substage in Lamoille Canyon has been determined by mapping the upper limit of the last glaciation on the walls of the canyon. A maximum thickness of 900 feet has been found in this way. This is probably a maximum thickness for the entire range, as Lamoille Canyon contained the largest glacier in the range. The glacier was thickest about three miles from its head and five miles from its lower end. The longitudinal surface slope on this glacier over a distance of five miles was approximately 340 feet per mile. The gradient of the present canyon over the same distance is 260 feet per mile. The glaciers of the Lamoille substage were probably somewhat thicker, as they were larger and more extensive.

POST-GLACIAL EROSION

Within the canyons the terminal moraines of the Lamoille substage have been entirely removed by erosion, and only lateral moraines of that substage are preserved. The terminal moraines of the Angel Lake substage, in contrast, are only notched by the streams to depths ranging from twenty-five to fifty feet. On Heenan Creek on the west side of the range, south of Lamoille, outwash gravels of the Lamoille substage have been dissected to a depth of about twenty feet. On other streams, outwash gravels of the two glaciations have been found at corresponding heights above present stream level.

The amount of post-glacial erosion in bedrock is dependent upon so many factors that figures on depth of such erosion are significant only within wide limits. The maximum depth of bedrock erosion since the Lamoille substage of glaciation is recorded near the mouth of Lamoille Canyon where Lamoille Creek has cut a narrow rock-gorge fifty feet deep. The rocks in which the gorge is cut are fissile quartzite and gneiss, moderately resistant rocks, which dip downstream twenty-five degrees. Faulting later than the Lamoille substage of glaciation along the west base of the range in this vicinity has probably played a part in rejuvenating Lamoille Creek so that it could erode its bed.

Bedrock erosion since the Angel Lake substage amounts to five to seven feet in places. These measurements have been made at the lips of falls or glacial steps and do not mean that the streams have lowered themselves by a depth of five to seven feet for their entire course. In many places, particularly near the heads of the canyons, the streams flow practically on the bedrock floor of the former glacier, dissection amounting to only a few inches.

FIGURE 9: Post-glacial spalling of a rock surface near the head of Thomas Canyon, central Ruby Mountains, covered by ice during the last glaciation (Later Wisconsin). Striated and polished surfaces are still preserved on some of the spalls. The rock is a uniform, medium-grained binary granite. Altitude 10,000 feet. July 25, 1937.

The danger of dogmatically relying on depth of bedrock erosion as a means of distinguishing glacial stages is shown by a forty-five foot gorge, in pegmatite and granitic rock, near the head of Lamoille Canyon in a place which has been covered by ice during the last glaciation. The relatively great depth of this gorge may be due, in part, to subglacial erosion.

Large pot holes, three to seven feet in diameter and four to seven feet deep, have been observed on the Right Fork and on Lamoille Creek near the junction with the Right Fork. These pot holes are probably

subglacial in origin and, hence, give no measure of the amount of post-glacial erosion.

Post-glacial spalling and solifluction have considerably modified the landscape in the higher parts of the range. The glaciated rock surface near the head of Thomas Canyon (Figure 9) is a particularly good example of post-glacial spalling in uniform granitic rock.

FIGURE 10: View, looking northwestward toward the north end of Ruby Valley, showing shore features of the Pleistocene Franklin Lake. Note the lake cliff (AA) and the lake beaches (BB) and (CC). The road follows part way along one of these beaches in the left foreground. The dissection of the cliff (AA) and the surface back of it indicates a moderate antiquity for the cliff.

HIGH LAKE LEVELS

The valleys east of the Ruby-East Humboldt Range form three hydrographically closed basins occupied by the dry or intermittent lakes, Snow Water Lake, Franklin Lake, and Ruby Lake. On the east side of Ruby Valley, in its northern part, marks of former high levels of Franklin Lake are conspicuous. Most of these levels are distinguished by low constructional embankments built by waves on the shores of the lake (Figure 10). The highest level (AA in Figure 10) is a cliff cut largely in alluvium and in two places in Carboniferous limestone. This cliff is fronted by a flat, wave-cut platform. At one point on the east side of Ruby Valley bars have been built on a small limestone island in such a way as to form a double tombolo. Between the bars is a small delta-shaped, land-locked basin much like the basins between the "V" bars described by Gilbert[21] from Lake Bonneville. Similar cliffs and beaches of the same lake are to be seen just north of Harrison Pass on the west side of Ruby Valley. The lake which formed these features was over 100 feet deep.

Ruby Lake lies at the southern end of Ruby Valley south of Harrison Pass. Well-defined beaches, spits, and cliffs of higher levels of Ruby Lake are preserved on both sides of this part of Ruby Valley. In one place on the east side of the valley thirteen beaches have been counted. Ruby Lake is separated at present from Franklin Lake by a low, east-west alluvial ridge, east of Harrison Pass. This alluvial ridge has probably been built by the waves of the lakes with the aid of detritus-laden streams from both sides. At higher stages, Ruby Lake and Franklin Lake submerged this ridge and formed a single lake.

Unfortunately, no evidence has been found which shows the relations of these lakes and the glaciation. It is clear that they are fairly recent; for embankments and cliffs in alluvium and unconsolidated material do not persist for any great length of time. Whether the lakes are contemporaneous with the glaciation or follow it cannot be stated from the data at hand. Time was not available for studies extensive enough to attempt a separation of the various lake features into groups which might have some relation to the two substages of glaciation.

POST-GLACIAL FAULTING

Moraines of the Lamoille substage which lie on the piedmont slope west of the Ruby Mountains at the mouths of Lamoille and Seitz Creeks are broken by fault scarps, thirty to fifty feet high. These scarps indicate faulting later than the Lamoille glaciation in this area. An escarpment, twenty feet high, in outwash material of the Angel Lake substage at the mouth of Heenan Creek may indicate faulting later than the Angel Lake glaciation. This scarp appears only on one side of the creek, and it is possible that the scarp is a feature of stream erosion and not faulting.

The Ruby Mountains have been relatively uplifted by faulting along the west base at least as recently as post-earliest Wisconsin and possibly as recently as post-Later Wisconsin.

21. G. K. Gilbert, "Lake Bonneville." *U. S. Geol. Surv.*, Monograph I, pp. 57-59, 1890.

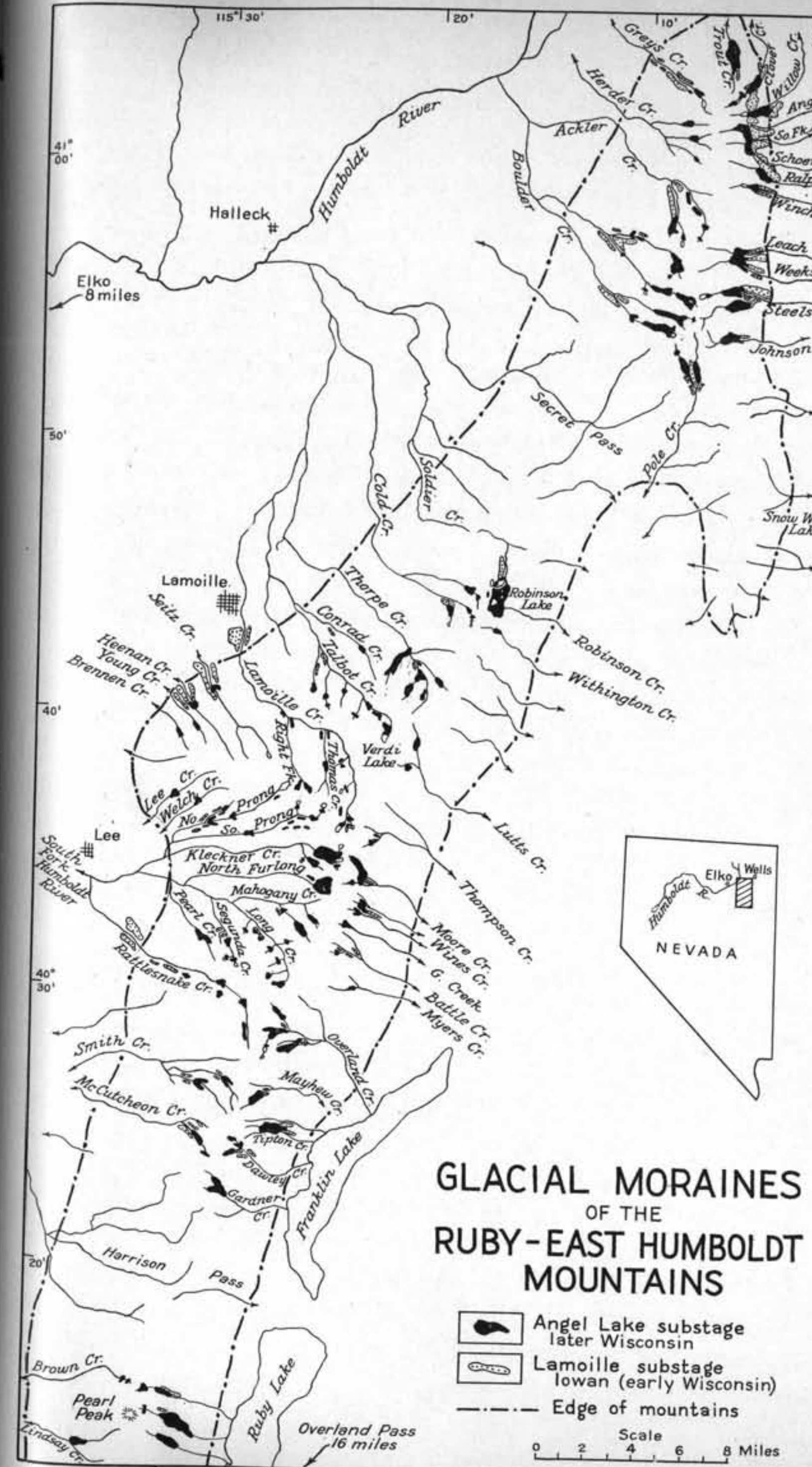

FIGURE 11: Glacial moraines in the Ruby-East Humboldt Range.

SUMMARY

U-shaped valleys, moraines, cirques, lakes, glacial polish, and other features indicate beyond doubt that the Ruby-East Humboldt Range has been extensively glaciated in the Pleistocene.

The criteria useful for differentiating separate glaciations in this range are: the topographic condition, the type, and the location of moraines; the boulder frequency and the composition of residual boulders on the surfaces of moraines; the weathering and staining of drift; and the modification of glaciated canyons by post-glacial erosion and detrital filling.

Application of these criteria shows that the range has been glaciated by two distinct ice advances, both of which appear to be Wisconsin. (Figure 11.) Satisfactory evidence of glaciations earlier than those recognized is lacking, and the suggestion is offered that either the features of earlier glaciations have been entirely destroyed or so far obscured as to be unrecognizable, or the mountains were not high enough before the Wisconsin to be glaciated.

The older glaciation of the Ruby-East Humboldt Range, named the Lamoille substage, is thought to be the same as the Tahoe glaciation in the Sierra Nevada, which in turn is correlated with the Iowan of the central United States. The younger, or Angel Lake substage, is thought to be the same as the Tioga glaciation of the Sierra Nevada. In keeping with the present consensus of opinion in the central United States, the Iowan is considered the earliest substage of the Wisconsin. Thus, the Lamoille substage is considered to be earliest Wisconsin. Weathering and dissection of the Lamoille substage drift and the detrital filling of canyons indicate a considerable time interval between the two substages of glaciation. This interval is thought to be long enough to place the Angel Lake substage in the Later Wisconsin. Pauses in the retreat of the ice of the Angel Lake substage may be related to subdivisions of the Later Wisconsin recognized in the central United States.

The glaciers of the Lamoille substage were the more extensive and descended to an average altitude of 7300 feet on the west side, and 7200 feet on the east side of the range. Glaciers of the Angel Lake substage were shorter, and descended to an average altitude of 7800 feet on the west side and 7600 feet on the east side. Ice descended to its lowest altitude, 6100 feet, on the west side at the mouths of Lamoille and Seitz Canyons in the Lamoille substage, and emerged from the mountains on the piedmont slope in several localities on both sides of the range. In the Angel Lake substage, the glaciers, with two exceptions, were confined entirely to the mountains. Glaciers of the Angel Lake substage occupied roughly eighty per cent of the area occupied by ice in the Lamoille substage.

The Wisconsin snow-line in this range appears to have been at an altitude between 9300 and 9800 feet on the west side of the range and, perhaps, as much as 500 feet lower, 8800 to 9300 feet, on the east side; the higher figure is favored in each case. The glacial features of the range indicate that the late Pleistocene storms, like the present, came largely from the west. Bedrock erosion has been fifty feet at maximum since the Lamoille substage, and five to seven feet at the most since the Angel Lake substage of glaciation.

Uplift of the range later than the Lamoille substage of glaciation is indicated by fault scarps, thirty to fifty feet high, which break the moraines of this stage along the west base of the range.

ACKNOWLEDGMENT

Professors Kirk Bryan and Marland P. Billings of Harvard University have offered many excellent suggestions and criticisms in the field and in the preparation of this paper. Dr. George H. Anderson of the California Institute of Technology has kindly permitted the present writer to study the glaciation of the Ruby-East Humboldt Range, a problem to which he had a prior claim. Dr. Anderson is to make a detailed study of the rocks and internal structure of the range. A debt of gratitude is owed to local residents of Nevada, too numerous to mention, for many kindnesses extended in the course of the field work.

Auszug[22]

Die Ruby-East Humboldt Gebirgskette ist ein schmaler Bergmassivschollen im nordwestlichen Nevada. U-förmige Täler, Moränen, Trogschlüsse, Seen, Gletscherschliffe und andere Merkmale deuten auf die ausgedehnte Vergletcherung des Gebirgszuges im Pleistozän hin. Glazialforschungen in derartigen Gebirgen mögen am Ende zur Entwicklung einer pleistozänen Zeitrechnung für die westlichen Vereinigten Staaten führen, die im Einklang mit den in anderen Teilen der Welt aufgestellten Chronologien stehen würde.

Die folgenden Kennzeichen können im diesem Bergzug zur Unterscheidung der verschiedenen Vereisungsperioden benützt werden: Topographische Beschaffenheit, Wesen und Lage von Moränen; Häufigkeit von Geröllstücken

22. Translated by Kurt E. Lowenstein.