SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 99, NUMBER 2

GEOLOGIC ANTIQUITY OF THE LINDENMEIER SITE IN COLORADO

(With Six Plates)

BY
KIRK BRYAN
AND
LOUIS L. RAY
Harvard University

(Publication 3554)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
FEBRUARY 5, 1940

The Lindenmeier Valley viewed from the west. Piracy by a tributary of Boxelder Creek has beheaded the valley. High Plains escarpment to left, Colorado Piedmont to right.

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CONTENTS

	Page
Introduction	1
Acknowledgments	6
General geology of the Lindenmeier site and adjacent regions	6
General statement	6
The Tertiary beds of the High Plains	7
Character of the Colorado Piedmont	8
Rocks near the Lindenmeier site	8
Springs and their significance	9
Climate and its influence	10
The culture layer and its local setting	11
The Lindenmeier Valley	14
Topography	14
Conclusion	19
Pediments and terraces of the Colorado Piedmont	20
General statement	20
Spottlewood pediment	21
Coalbank pediment	22
Timnath pediment	23
Piracy by the South Platte River	24
The canyon-cutting cycle	24
Alluvial terraces	24
Modern flood plain	26
Summary	27
Glaciation of the Cache la Poudre Valley	27
Prairie Divide glacial stage	28
Other possible pre-Wisconsin glaciations	29
The canyon-cutting cycle	29
Home, and a possible earlier, glacial substage	30
Corral Creek substage of glaciation	33
Long Draw substage of glaciation	34
Protalus substage	35
Summary	35
Terraces of the Cache la Poudre Canyon	36
The canyon	36
Nature of valley trains	38
Methods of terrace study	39
Terrace No. 6	42
Terrace No. 5	43
Terrace No. 4	44
Terrace No. 3	45
Terrace No. 2	46
Terrace No. 1	46
Correlation of the terraces of the Cache la Poudre Canyon with those of the Colorado Piedmont	47
Folsom sites in the region and their bearing on the geologic age of the culture	48

Page
Glaciation as a chronology.... 49
The European glacial chronology.... 50
  The major ice advances.... 50
  Late-glacial chronology.... 52
Geochronology in North America.... 58
  Methods and results.... 58
  Validity of results.... 65
  Glacial substages in Colorado correlated.... 67
Folsom culture of Late-glacial age.... 69
  Summary of evidence.... 69
  Evidence from other Folsom sites.... 70
Geography of the Folsom culture.... 72

ILLUSTRATIONS

PLATES

1. Lindenmeier Valley from the west.
2. 1, Lindenmeier Spring.
  2, Brennigan Spring.
3. 1, Kersey site and terrace.
  2, Prairie Divide, showing slump masses.
4. The Home moraine.
5. 1, View across Home moraine to erratics on south valley wall.
  2, Corral Creek moraine.
6. 1, Outwash plain below Corral Creek cirque.
  2, Protalus rampart of Corral Creek cirque.

TEXT FIGURES

Page
1. Index map.... 4
2. Topographic map of Lindenmeier Valley.... 12
3. Profiles.... 13
4. Block diagram of Spottlewood pediment.... 20
5. Block diagram of Coalbank pediment.... 22
6. Block diagram of Timnath pediment.... 23
7. Block diagram of alluvial terraces.... 25
8. Map of Cache la Poudre Valley at Home Post Office.... 32
9. Generalized profile of Cache la Poudre Canyon, with terraces.... 37
10. Horizontal profile of Cache la Poudre River, with terraces.... 40
11. Antevs' Scandinavian map simplified.... 54
12. Recalculation from Antevs' text (diagram).... 55
13. Antevs' map of ice retreat in New England.... 59

GEOLOGIC ANTIQUITY OF THE LINDENMEIER SITE IN COLORADO

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INTRODUCTION

The antiquity of man in America is a problem of many ramifications which is as yet largely unsolved. The geologic approach is attended with difficulties which arise from the lack of immediate precedent as to method and from the lack of a well-established geologic chronology applicable to the whole world. However, the extensive culture layer at the Lindenmeier site in Colorado, containing a wide variety of stone implements associated with the bones of extinct animals, provides an unparalleled opportunity for an approach to the problem on several lines. The methods evolved and the chronology established during a 4-year campaign are here set forth. The chronology is, however, local, and its correlation with a time sequence of world-wide recognition involves numerous assumptions whose validity requires confirmation. The European chronology is being continually improved and is, as yet, not directly applicable to North America. Only by extensive studies of late Pleistocene time from the geological, paleontological, and archeological standpoints will a thoroughly sound world-wide chronology be attained. By the convergences of lines of evidence derived by these three methods, combined with the results of paleobotany, it will be possible eventually to date events of the Pleistocene in western United States in terms of the chronology already available in northern Europe.

Interest in the later phases of the geologic story in North America has, heretofore, lacked the stimulus provided by archeological finds in deposits of geologic antiquity. Many badly authenticated or even fraudulent discoveries, purporting to have some measure of antiquity, have cast a cloud of suspicion on claims of the presence of any man in North America earlier than the late-neolithic American Indian. However, in 1927, the discovery of the fluted points, now generally called Folsom, in association with extinct bison (Figgins, 1927, and Brown, 1929), led to a veritable revolution in thought among conservative anthropologists. Here, for the first time, implements distinct in type from the ordinary "neolithic" points, characteristic of the American Indian, were indubitably contemporaneous with an extinct animal. The considerable antiquity thus implied was admitted promptly by many leading anthropologists and led to much activity. From the three standpoints of typology, of vertebrate paleontology, and of general geology, further progress appeared possible.

Unfortunately, conditions at the original site were not favorable for geologic dating (Bryan, 1929 and 1937; Roberts, 1935). Furthermore, a reconsideration of the known stratigraphic position of extinct vertebrates indicates that many species may have survived into comparatively recent time (Romer, 1929 and 1933). Mere association with the remains of extinct animals is no longer considered a measure of an antiquity as early as, or earlier than, the climax of the last glaciation. Many extinct species are now thought to have survived into the last few thousands of years. These species are considered to be definitely Late-glacial, or Post-glacial in the European sense.

Many observers, both trained archeologists and a great group of amateurs, have enlarged our knowledge of the distribution of Folsom and Folsom-like points. Many finds of points associated with extinct animals have been reported (Cook, 1927; Schultz, 1932; Figgins, 1933; Sellards, 1938; Bryan and C. N. Ray, 1938). Also, other stone cultures of considerable antiquity have been discovered (E. W. and W. H. Campbell, 1937; Bryan, 1938; C. N. Ray, 1938), so that now we are confronted, not with a single problem of antiquity, but with a group of problems.

In order that the geologic method of attack may be used in dating the increasing number of finds of Folsom and other cultures, it is necessary to establish: 1, that the cultural objects are associated with a definite bed or beds; 2, that these beds are related to some definite geologic event; 3, that this event is related to other events or is of wide geographic extent; 4, that this event and related events are also related to some known geologic chronology. Such a sequence is obviously a rigorous requirement which may not always be met.

The foregoing relations appear to be characteristic of the Lindenmeier site, discovered in 1934, and intensively investigated by Dr. F. H. H. Roberts, Jr., of the Smithsonian Institution, from 1934 to 1938. Here, as described by Roberts (1935, 1936, and 1937), there is a layer of dark earth, containing bones of extinct animals and artifacts, buried in places under material 14 feet thick. This layer has been traced in outcrop and by excavation for more than 2,000 feet east and west, and more than 300 feet in a north and south direction.

Archeologically, the site is the most important find of recent years, because it has yielded over 2,000 stone implements, including, besides the typical fluted points, other points, and a wide variety of scrapers and similar artifacts, sufficient to define the stone culture by typology. Thus, the date of the culture becomes of importance.

The culture layer lies on the floor and southern slope of a valley abnormal in the area. Locally, this valley, because of stream piracy, retains part of its old floor, which is preserved downstream as a mere terrace remnant. Thus the valley and its culture layer may be related to a terrace which commonly occurs also on nearby streams. In this instance there are present the first two requirements mentioned above, the definite culture stratum, which can be related to a geologic event—the formation of the unusual Lindenmeier Valley, and of the contemporaneous terraces in the local streams.

These streams are small and ephemeral tributaries of a perennial river, the Cache la Poudre, which rises in the mountains and flows out onto the plains. The terraces of the tributaries may be traced down their courses and correlated with those of this main river. The Cache la Poudre is in turn a tributary of the master stream of the region, the South Platte River (see map, fig. 1), which drains most of the northern part of the Colorado Front Range and the adjacent Colorado Piedmont. As the present gradient of the South Platte River is a local base level, and as its successive positions in the past have been local base level, it follows that the terraces of all the streams in the region are similar in number and relative age. Thus, the third requirement is fulfilled, that the geologic event be of wide geographic extent.

Furthermore, the Cache la Poudre and other major tributaries of the South Platte, rise in the Rocky Mountains, an area recently glaciated. Some of the terraces, particularly the lower and younger terraces here involved, may be traced upstream and related to the episodes of glaciation in the mountains. Now, glaciation is a phenomenon that is world-wide. In the past the glaciers were not only more extensive than now, but formed and advanced at least four times during the Pleistocene. Although there is no absolute proof that growth and advance of glacial ice was synchronous over the earth, nevertheless, there is much confirmatory evidence, such as an apparent uniformity in the total number of major ice advances, and an equally close similarity in the episodes attending the final retreat of the last great glacial advance. Thus, glacial chronology is, if not a perfect time record, at least a standard chronology.

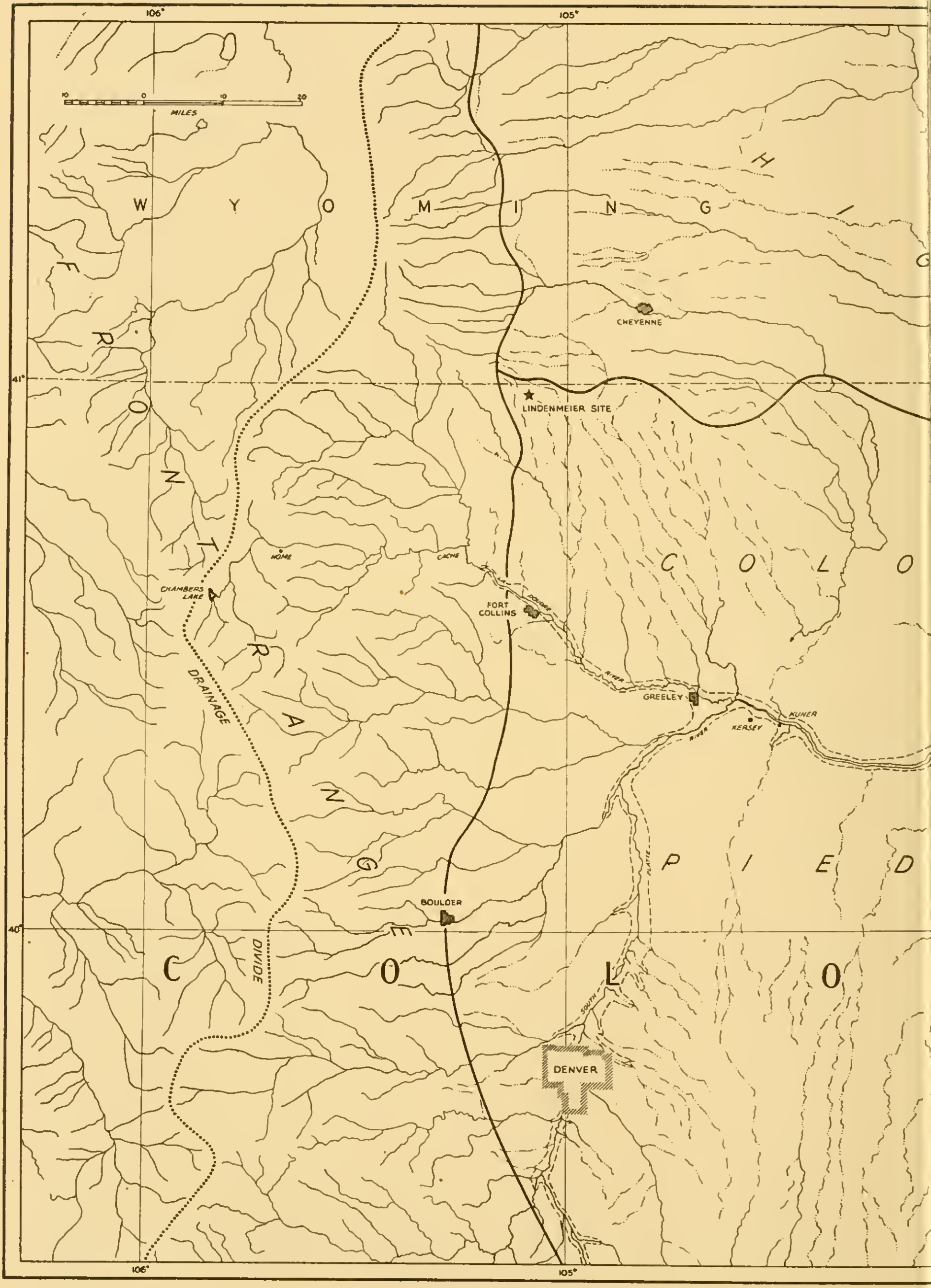
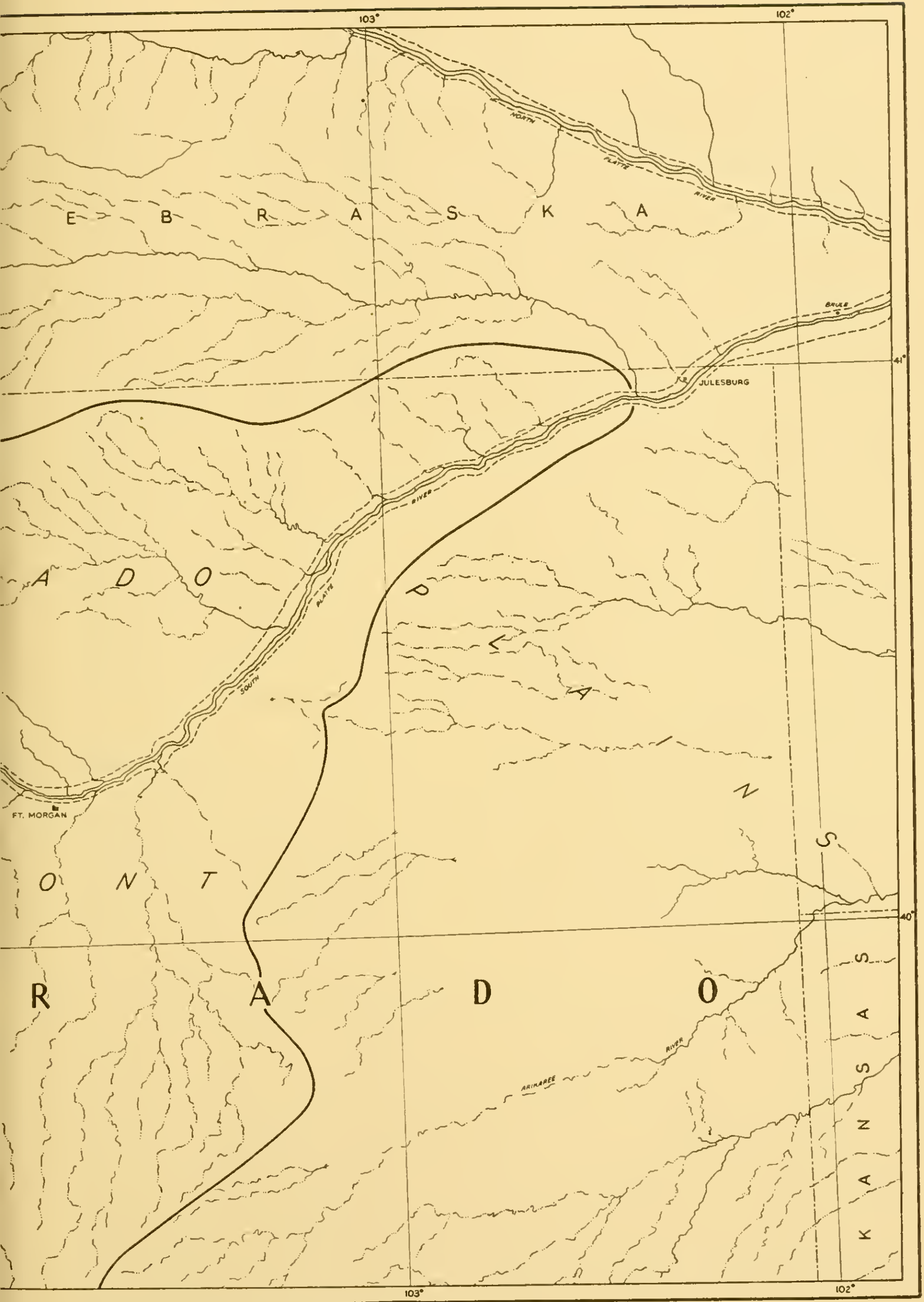


Fig. 1.—Map of the major physiographic subdivisions a



age of northeastern Colorado and adjacent territory.

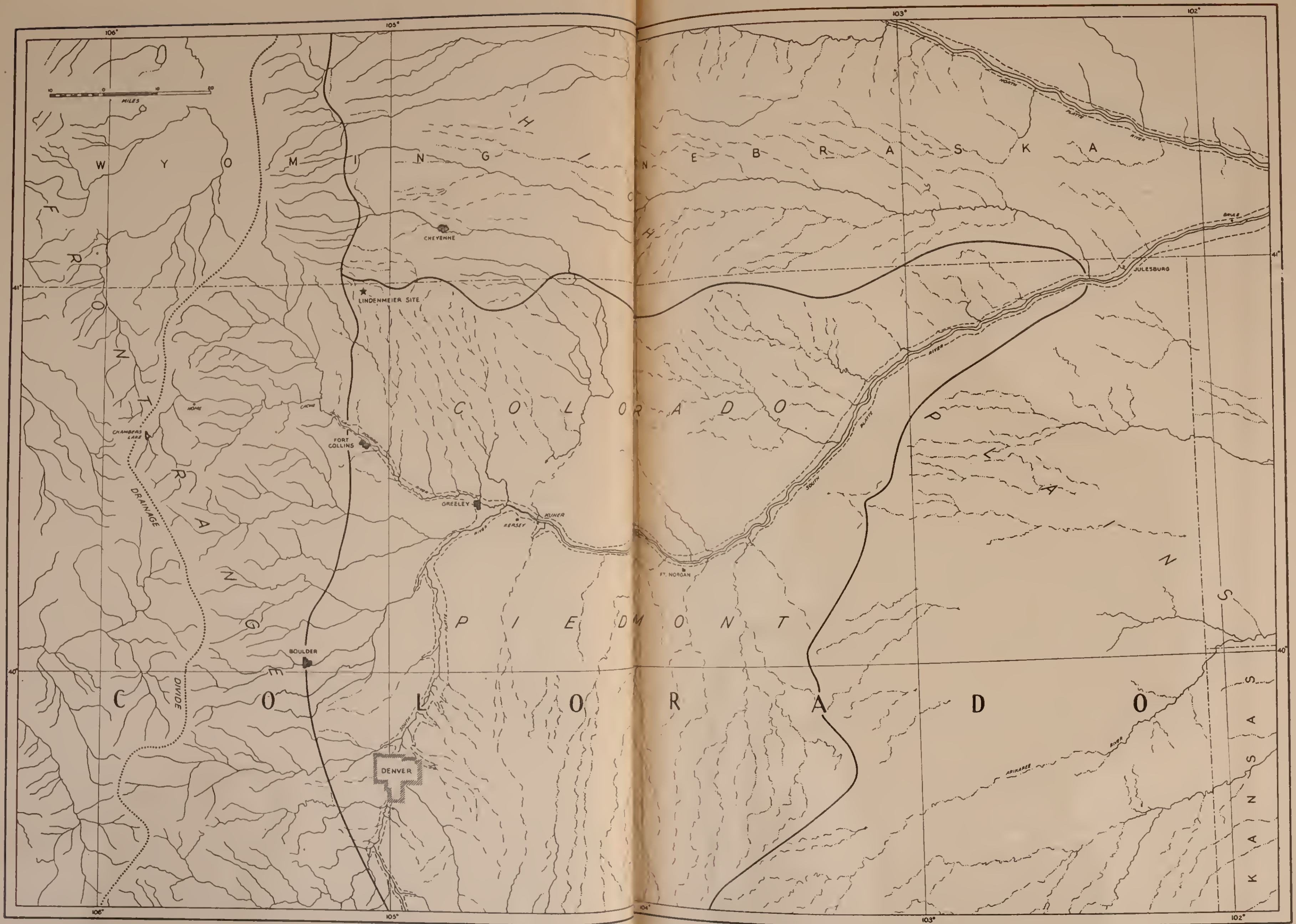


FIG. 1.—Map of the major physiographic subdivisions rainage of northeastern Colorado and adjacent territory.

ACKNOWLEDGMENTS

During the summer of 1935 Bryan spent a month at the Lindenmeier site, studying the geologic chronology and making a topographic map of the Lindenmeier Valley, in which task he had the volunteer assistance of Franklin T. McCann and John T. Hack. The topographic map was later extended by E. G. Cassedy, of the Smithsonian Institution, who has spent several weeks during the following seasons making this and other maps and sketches of the Lindenmeier Valley and adjacent country. During the summers of 1936 and 1937 the geologic work was extended by Ray into the main drainage systems of the South Platte and the Cache la Poudre Rivers and into the glaciated portions of the Cache la Poudre Canyon in the northern Colorado Front Range. He was assisted by Thomas W. Steptoe in 1936, and during the later parts of both the 1936 and 1937 field seasons by Charles R. Scoggin. In both years Bryan spent several days with Ray in conferences at critical places in the field. The cost of the field work was met in large part by grants from the Smithsonian Institution. In the summer of 1938, under a grant from the Milton Fund of Harvard University, Ray extended the study of the glacial sequence and the chronology of the later Pleistocene over a large part of the Southern Rocky Mountains.

The writers wish to thank their assistants and the many local residents, especially Miss Agnes Zimmerman and Mr. and Mrs. Bryan Gladstone, Home, Colo., for their helpful aid in carrying on the field work connected with the project. The interest and enterprise of Dr. F. H. H. Roberts, Jr., initiated the investigation, and his many courtesies have made the Lindenmeier Camp a pleasant memory.

GENERAL GEOLOGY OF THE LINDENMEIER SITE AND ADJACENT REGIONS

GENERAL STATEMENT

The Lindenmeier site is located in an area of complex physiographic expression, immediately east of the Colorado Front Range, and on the break in slope between the High Plains and the Colorado Piedmont (fig. 1). The little valley which contains the site owes its unique topography and availability for the accumulation and preservation of cultural remains to circumstances which can be understood only if the character and origin of these major physiographic divisions are explained.

THE TERTIARY BEDS OF THE HIGH PLAINS

Following the uplift of the Colorado Front Range in the post-Cretaceous period of disturbance, streams flowing from the newly risen mountains reduced the border of the mountains to a smooth plain and thereafter spread a mantle of alluvium eastward over a broad piedmont area. This alluviation with intervening periods of erosion continued through much of Tertiary time. In the region studied, the great apron of Tertiary alluvium forms the High Plains and consists of the Brule tuff-clay (Oligocene), and a body of more or less consolidated sand and gravel, divided into two formations: the Arikaree (Miocene) and the Ogallala (Pliocene). These three formations are separated from one another and from the underlying pre-Tertiary rocks by unconformities. As originally laid down, the Tertiary formations lapped on the lower portions of the present mountain area. Erosion has, however, almost completely stripped the mountains of this mantle of detritus, which persists only as small isolated remnants within the mountain area. Only to the west of Cheyenne, Wyo., do the High Plains and the Tertiary cover rocks now extend as far as the mountain front, in the well-known "gangplank," by which the Union Pacific Railroad reaches the core of the mountains on an easy grade.

Field work indicates that the High Plains surface of southern Wyoming is in part erosional and in part depositional. A restoration of the High Plains surface in the vicinity of Cheyenne shows that it was once a featureless plain, sloping gently eastward at 50 to 100 feet per mile. Streams have now entrenched themselves on this surface so that the original plain is represented only by tabular, eastward-sloping interstream areas. Because of the scant rainfall and the pervious character of the underlying Tertiary Arikaree and Ogallala formations, the streams of the High Plains are mostly intermittent, as shown in figure 1. Only a few of these intermittent streams have succeeded in cutting through the pervious beds to the ground-water table, held up by the underlying impervious Brule tuff-clay. Without this permanent ground-water supply the streams cannot maintain a perennial flow. Nearer the mountains, where the rainfall is greater, the streams have been able to tap the ground-water flow and on this account have been able to excavate great basins from the original High Plains. With the incision of the South Platte, and also its companion stream, the Arkansas River, far to the south, many tributaries attained perennial flow. The Colorado Piedmont was, because of the process thus initiated, excavated as a lowland below the High Plains surface.

CHARACTER OF THE COLORADO PIEDMONT

During the excavation of the Colorado Piedmont, pauses in the downcutting of the Cache la Poudre-South Platte and their tributaries led to the development of a series of gravel-capped erosion surfaces, or pediments. Each surface bevels the underlying rock and slopes gently toward the Cache la Poudre-South Platte Rivers and, when followed downstream, becomes a narrow shelf or terrace. This steplike succession of pediments lies between the mountains on the west and the escarpments of the High Plains to the north and east. During this long period of stream excavation and pediment formation, a complicated series of drainage changes has taken place along both the major and minor streams. The courses of many of the minor streams have become adjusted to the north-south structure of the Cretaceous sandstones and shales of the Piedmont area. The northern tributaries of the Cache la Poudre-South Platte Rivers have worked headward, capturing eastward-flowing streams and diverting them (fig. 1). Furthermore, these tributaries, because of their steeper gradient and greater activity, have pushed back the more or less well-defined scarp which forms the boundary between the Colorado Piedmont and the High Plains.

The topography of the scarp between the Colorado Piedmont and the High Plains has been accentuated by ground-water sapping whereever the spring zone, which marks the perched ground-water table along the upper surface of the impervious Brule formation, has been exposed by the headward erosion of small streams. Because of the location of the Lindenmeier Valley along a portion of this scarp, far from the main drainage streams, the Lindenmeier Valley has been preserved as an unusual topographic feature and archeological site (pl. 1).

ROCKS NEAR THE LINDENMEIER SITE

In the vicinity of the Lindenmeier Valley the rocks exposed in the escarpment consist of the Brule and Arikaree formations, which are here unusually thick and separated by an inconspicuous unconformity. The base of the Brule formation is a coarse conglomerate, which lies in channels on the pre-Tertiary formations. The conglomerate, 5 to 50 feet thick, is a stream-laid deposit which is overlain by clay and tuff having an estimated thickness of 350 to 400 feet. The color of the lower tuffaceous beds ranges from a drab yellow to a reddish buff, and the color of the upper tuff beds is white or slightly pink. The upper tuff is massive, almost without lamination or other evidence of the method of deposition.

Overlying the Brule formation is the Arikaree, which consists of poorly cemented arkosic sand and gravel. The gravel is composed primarily of angular to subrounded fragments of crystalline rock, and pieces of quartz and feldspar. From place to place the thickness of the Arikaree formation varies because of the irregularities of the underlying unconformable contact and of the beveling by erosion of the original upper surface of the formation during the development of the present High Plains. Near the Lindenmeier site there is a remaining uneroded thickness of at least 320 feet.

It is evident from the highly irregular bedding of the Arikaree formation that it was deposited in the channels of streams which during times of flood worked and reworked the material so that nearly all the finer debris was carried downstream and out of the area. The cement of this conglomerate is calcareous, and frequently the interstitial spaces between the small fragments of detritus may form a single calcite crystal. On weathering, the more firmly cemented beds tend to form small cliffs and in places overhanging rock shelters of small size.

SPRINGS AND THEIR SIGNIFICANCE

At and near the contact of the pervious Arikaree and the underlying impervious Brule formation, ground water emerges in a spring zone. Springs along this contact are divisible into two types: 1, definite flows of water, issuing at one or more places, and 2, large swampy areas. The point of issue is usually immediately below the Arikaree-Brule contact, and it appears that the water circulates in, and may be more or less confined to, a single point of issue by joints in the upper part of the Brule. Such a condition is well exemplified in a spring area about 6 miles west of the Lindenmeier site. At this locality, which is now dissected by deep gulches, the joints in the Brule formation are colored by limonite and have obviously served as channels of flow when the spring issued at an altitude somewhat higher than at present. The Brule has a further characteristic in that the fine pores of the tuff will transmit water by capillarity. Thus, water circulating in the joints spreads into the upper part of the formation and, where the overlying Arikaree formation has been removed, may emerge at the surface over a large area.

Whether the ground water emerges in a definite opening or over a large area as a swamp seems to depend on the local topography. If the area has been gullied, the water finds its way to the surface through a joint in the Brule and makes a definite point of issue, or spring. Such a spring is the one below the Lindenmeier Camp, in the gully at the Lindenmeier site (pl. 2, fig. 1). In smoother topography, however, the water is brought to the surface by capillarity, and there broad swampy meadows develop. On Spottlewood Creek, sec. 19, T. 12 N., R. 68 W., there is such a meadow (pl. 2, fig. 2), and in sections 21 and 28 of the same township there is a broad meadow of about 30 acres.

Brennigan Spring, in section 30 of the same township, about 2.5 miles by road from the Lindenmeier site, illustrates both types of emergence of water. Here water pours from definite openings into the adjacent gully to form a small stream. Also, there are areas of a few square feet to as much as an acre, where water seeps to the surface. Swampy ground with a vegetation largely of sedge exists on flat places and also on hillsides with slopes as high as 15 to 20 degrees. A test pit showed, above the white tuff of this swampy tract, about 3 feet of dark earth, containing plant remains and formless humus.

Both the springs and swampy areas are of great economic importance in this region, where most of the land is utilized for grazing purposes. In this semiarid climate, with an average rainfall of about 16 to 20 inches (Martin, 1930), little unirrigated land is tilled. Dry farming is too precarious an occupation to be generally successful. Grazing is the dominant industry, especially in the areas where springs and swampy meadows dot the short grass plains with bovine oases of succulent food and drink. Range cattle limit their grazing according to distance from the springs, to which they can easily return. The Lindenmeier site lies almost surrounded by the winter range of the great Warren Livestock Co., whose sheep are lambed each spring on the green grass of the swampy meadows.

CLIMATE AND ITS INFLUENCE

Although the mean rainfall in the country immediately adjacent to the Lindenmeier site is estimated at from 16 to 20 inches, its effectiveness is limited because of the high rate of evaporation, the permeability of the surface rock and soil zones, and the irregular torrential character of the precipitation. At present this region supports a general vegetative cover of grama grass and mountain sage. Climatic fluctuations of the past may have radically altered the character of this cover. Evidences of such vegetative shifts may be found throughout the Great Plains. For example, stumps of a now extinct coniferous forest are reported along the valley of the Niobrara River in Nebraska (Aughey, 1876, p. 266), and even at the Lindenmeier site the last fringe remnant of an extension of the mountain forest onto the plains was removed by the early settlers and has been unable to readvance over the ground lost through human destruction. Apparently the last climatic shift has been a trend toward greater aridity. If, on the other hand, a climatic swing toward more humid conditions be imagined, there would be an advance of the more humid plant associations into the present dry areas. Reconstructing the climatic conditions when glaciers occupied the mountain valleys, we should find a cooler, more humid climate, with consequent decreased evaporation. However, the region adjacent to the mountain front would be subjected to cold, drying winds, which blew across the mountains from west to east. Descending as cold winds from the mountains, they would be warmed and become drying winds in the plains region. Thus, whereas there might be expected a more humid climate with precipitation rising, in the vicinity of the Lindenmeier site, to twice the present amount, or to 40 inches, it would not follow that the vegetative cover would be a heavy forest such as one would normally expect in areas of similar precipitation in the Mississippi and Ohio Valleys. It is the writers' belief that along the mountain front there were, even in late Pleistocene time, extensive grasslands, with scattered coniferous parklike forests—a region suitable for browsing and grazing animals. Far from the major streams, which maintained a perennial flow, springs and water holes were the only sure water supplies and therefore attracted animals. In dry periods, particularly, the more extensive areas of swampy land proved as attractive then as now. Sheltered valleys such as the Lindenmeier, which contained a swampy area with springs and succulent grasses, were favorable for the congregation of animals and suitable for a camp of men who lived by hunting.

Considering this environment of the past with that of the present, it is necessary to reconstruct the many changes which have taken place since the valley was inhabited. By means of a careful and detailed study of the site itself and its relation to the regional changes which have taken place since the development of the culture layer, some concept may be gained as to the antiquity of the human artifacts.

THE CULTURE LAYER AND ITS LOCAL SETTING

The extent of the culture layer at the Lindenmeier site and its relation to the local topography have been developed by painstaking excavation. The facts lead inevitably to the conclusion that the culture layer was formed under local topographic conditions which no longer exist, and it must, therefore, have considerable antiquity.

A brief review of the results of excavation will make clear the local setting in which the culture is found and will serve as an introduction to those peculiarities of the topography which furnish evidence of the complicated chain of events that led to the formation and preservation of the culture layer. The intricate history of the drainage changes, piracies, periods of erosion and alluviation of the isolated Lindenmeier Valley will be first reviewed. Thereafter the chronological sequence at the Lindenmeier site can be correlated with the contemporary events of the surrounding area.

The culture layer at the Lindenmeier site, as described by Roberts (1935, 1936, and 1937), is a brownish black earth that ranges in thickness from a mere film to 2 feet. It crops out along the southern rim of the Lindenmeier Valley and slopes northward to the relatively recent arroyo. As exposed by trenches and test pits, it extends over a large area between letters S and C on the map (fig. 2). In the admirable sections by Roberts (1936, fig. 1) the position of the culture layer on a slightly irregular floor of the Brule formation is shown. Its dark color is in strong contrast to the white color of the floor. The culture layer is a sandy clay containing scattered pebbles, secondarily derived from the Arikaree. It is overlain by a rubble consisting of more or less rounded fragments of Brule tuff, but containing also fragments of feldspar, quartz, and various crystalline rocks, obviously derived from the conglomerates of the Arikaree. This rubble increases in thickness from south to north, toward the axis of the valley, and at the arroyo is 12 to 14 feet thick, as shown at 1 in profile UV, figure 3. The unequal sizes of the fragments, the irregular bedding and the irregular lenses of this rubble, which dip gently northward with the slope of the surface, all testify to its origin as a slope wash produced by the ephemeral run-off from a hill to the south. In the area where excavations have been made, there is no longer a hill to the south. One must suppose that the hill from which this rubble was derived once existed and that it has since disappeared. Furthermore, the culture layer was formed under a set of conditions during which this suppositious hill furnished little coarse debris, and thereafter conditions changed so that the run-off of rains brought in the rubble.

Not only must these facts be explained, but further, the area north of the gully has as yet yielded no artifacts. If one searches the north banks of the gully, he finds no culture layer. On the Brule tuff, there rests an alluvium, consisting of fairly thin-bedded gravel, composed of fragments of crystalline rock—all obviously reworked from the Arikaree, as shown at 2 in profile UV, figure 3. There are nu-

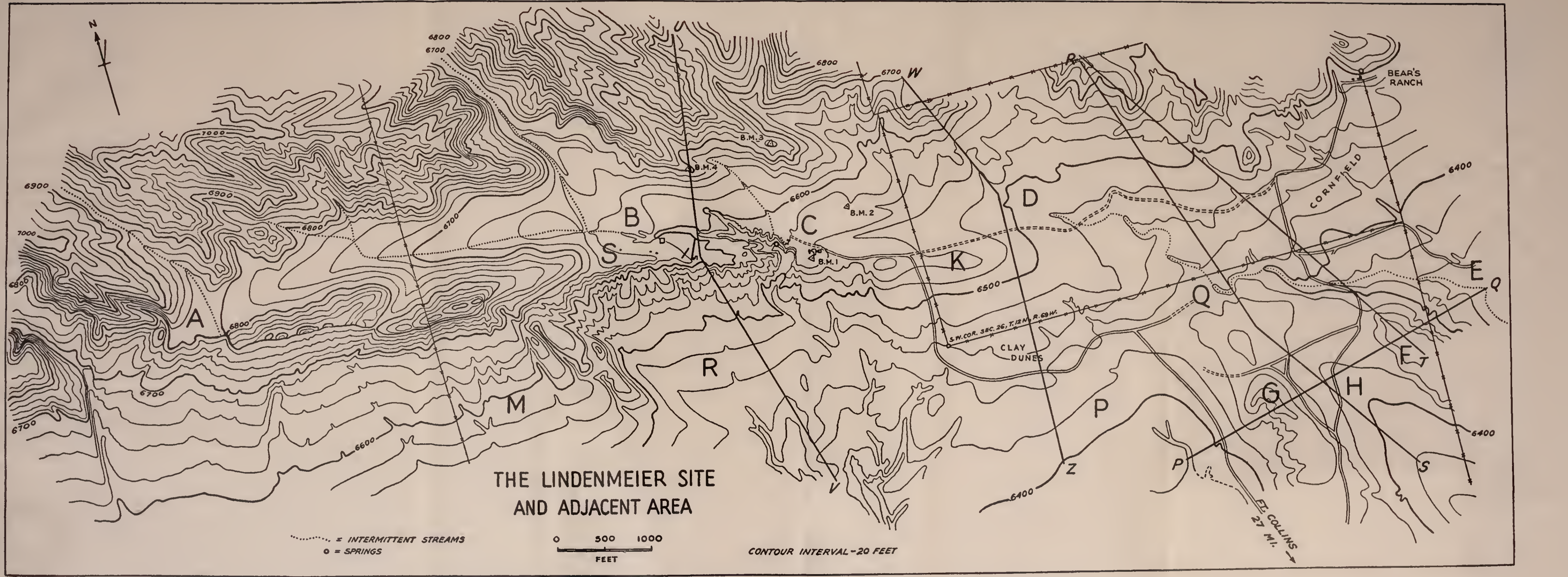


Fig. 2.—Topographic map of the Lindenmeier Valley. Letters indicate topographic features discussed in text and profiles shown in figure 3.

merous bands of dark soil, similar to the soil now underlying the grass roots at the top of the bank. It is obvious that this material was laid down rather slowly by ephemeral streams which had their origin in the areas of the outcrop of the Arikaree to the north and west. At one locality this same gravelly alluvium rests unconformably on a rubble of Brule fragments, similar to that above the culture layer. The gravelly alluvium thus appears to be not only different in origin, but also younger than the culture layer and its overlying rubble.

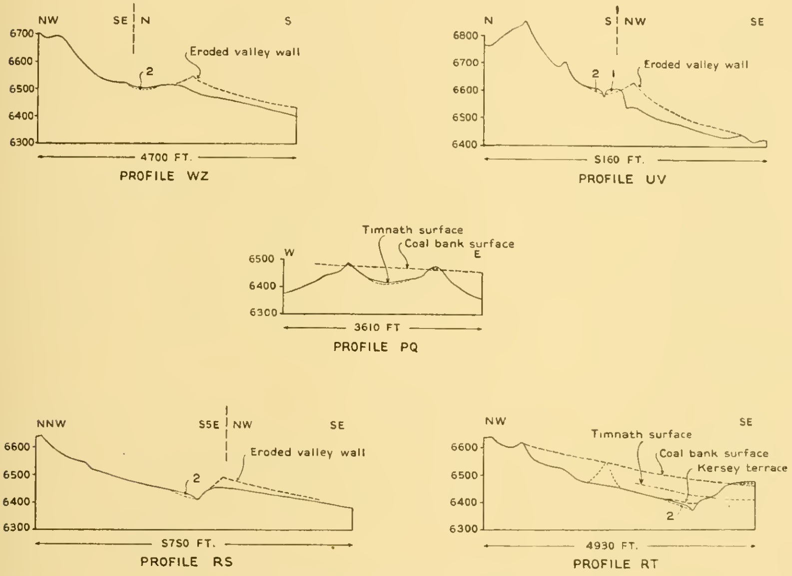


FIG. 3.—Profiles of the Lindenmeier Valley.

These details, proved by Roberts' excavations, present for analysis the following facts:

1. A valley-floor on Brule tuff-clay, with overlying culture layer, containing extinct bison and camel.
2. A rubble of hillside wash, derived from a hill that has now disappeared.
3. A gravelly alluvium, free of cultural remains, which is derived from the west and north and is younger than the foregoing materials.

The history of the Lindenmeier Valley, thus recorded, is unusual. The form of the valley and its topographic details provide, however, a coordinated physiographic history into which these somewhat anomolous facts fit. The detailed topography of the valley becomes critical and must be examined at considerable length.

THE LINDENMEIER VALLEY

TOPOGRAPHY

The Lindenmeier Valley is shown in figure 2 and is also illustrated in the photograph, plate 1. It lies in the present drainage of Boxelder Creek, whose minor tributaries are in a continuous contest for drainage area. It lies also on the edge of the drainage basin of Spottlewood Creek, whose tributaries at one time probably drained the area. In each period of the lowering of grades in the stages of erosion in the Colorado Piedmont, the contest for drainage area was accentuated. Piracies occurred, and one tributary gained the advantage of lower gradient and gained drainage area from the other. At the next stage another tributary had the lower gradient and with this advantage gained territory at the expense of the other.

Immediately north of the Lindenmeier Valley the gravel-capped ridges have a common slope to the southeast. Once this was a smooth plain, graded to the South Platte River, when its bed lay at elevations somewhat more than 200 feet above the grade of the present river at its junction with the Cache la Poudre. This episode in topographic development is the Spottlewood stage,[1] when the whole of the Colorado Piedmont consisted of a single smooth graded plain cut by the Cache la Poudre River and its tributaries.

In the next, or Coalbank stage (see p. 22), the South Platte River lowered its grade about 50 feet at its junction with the Cache la Poudre, and the topography of the Piedmont area became more accentuated. The aspect of the escarpment at the Lindenmeier site was much different from the present. The sloping ridges north of the site were outlined by shallow gulches which drained southeast into a broad plain, whose existing remnants are the flat-topped ridges G and F, figure 2. These ridges are capped by coarse gravel which lies unconformably on the underlying Brule formation and further to the southeast on Cretaceous shale. As shown by the profiles RT and PQ, figure 3, this plain lay 75 feet above the present floor of the Lindenmeier Valley, between points D and E, and about 150 feet above the grade of the present streams in the plain P, west of the ridge G (fig. 2). Remnants of this surface are not detectable in the

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[1] The terms "Spottlewood," "Coalbank," and "Timnath," are defined on pages 21 to 24. They have been introduced by Ray as designations of the topographic surfaces or pediments of the synchronous gravel found on these surfaces, and of the time intervals involved in the production of these surfaces. "Pleasant Valley," "Kersey," and "Kuner" are also introduced as designations of three alluvial terraces, the gravels that compose them, and the corresponding time intervals.

upper end of the Lindenmeier Valley. It seems probable, however, that the existing ridges were outlined by gulches somewhat shallower than those of the present. The Lindenmeier Valley may have been already formed and may also have drained southeastward into the broad, smooth plain represented by the ridges G and F.

As the Coalbank surface lay at considerably higher elevations than the Arikaree-Brule contact, the valleys north and west of points G and F must have been dry. Ground water may have emerged to form broad swampy tracts in the plains represented by the ridges G and F, but no tangible evidence of such a condition is preserved.

In the next, or Timnath stage (page 23), the gradient of the South Platte River was lowered some 70 feet, so that at the junction of the Cache la Poudre it was about 100 feet higher than at present. The streams of the Lindenmeier Valley area were again incised. In the lower part of the valley the drainage was still southeasterly, and most of the area drained through the broad valley at point H, between the two ridges G and F. This valley, as shown in the profile RS, figure 3, lay 50 to 60 feet above the present floor of the Lindenmeier Valley. As shown in profile PQ, it lay at about the same altitude above the plain P, west of ridge G.

At this stage, it seems likely that the upper part of the Lindenmeier Valley, points A-C, was carved into almost its present form. As a well-developed valley with a general course slightly south of east, it may have drained into a broad valley that crossed the southern boundary of the present valley between the points K and Q, in figure 2. There is no proof, however, that it may not have been a tributary of the broad valley H.

The next lowering of grades was substantial, as the South Platte River was cut to a level below its present grade, or a total downward incision of more than 100 feet. This post-Timnath deepening of grade was followed by a refilling of the valley to a height of more than 50 feet above the present grade near the junction of the Cache la Poudre and South Platte Rivers, the Pleasant Valley stage. The river again cut down to, or below, its present grade, and refilled its valley to a height 30 to 40 feet above its grade, the Kersey stage. These events on the main stream were inadequately reflected on the tributaries. The post-Timnath and post-Pleasant Valley periods of cutting are merged into one period of downcutting. Even the period of filling of the main valleys, so well marked by the Kersey terrace, is inadequately shown. The Kersey terrace, when traced up the minor streams, particularly the Boxelder drainage, becomes lower, and the gravel decreases in thickness. Instead of a terrace composed of gravel and representing a downcutting of the stream below the present grade, followed by a refill to a grade 30 to 40 feet above that of the present, the minor streams have a terrace consisting of a platform cut on bedrock, with a thin gravel cap that lies 10 to 20 feet above the stream grade. The terrace in the minor streams represents a single downcutting and widening of the valley. The process, however, was continuous throughout the post-Timnath period of cutting. The time of deposition of the Pleasant Valley and the time of the post-Pleasant Valley period of cutting are both included in the time of formation of the terrace whose completion corresponds with the end of the Kersey period of deposition.

In the post-Timnath to Kersey time interval, the Lindenmeier Valley took its existing form. Stream piracies occurred. An eastern tributary of Boxelder Creek, known as Sand Creek, gained the Lindenmeier Valley by headward erosion into the area D-E, figure 2, cutting into and diverting the drainage of the valley that formerly led into the existing dry valley, H. This newly formed valley in the area D-E also gained the upper Lindenmeier Valley by capturing its drainage at some point between C and D. Thus, all the area became drained on a more easterly course, and the Lindenmeier Valley took its present form and was widened to its present size. At a somewhat later period a tributary of Boxelder Creek, by way of another tributary that is also called Sand Creek, cut a deep gulch west of point A and thus beheaded the Lindenmeier Valley. The beheading of the valley is well shown in the photograph, plate 1.

The development of these piracies seems to represent a remarkable series of events. To them we owe the peculiarities of form of the Lindenmeier Valley and the preservation of the culture layer. The general reasons for the piracies have already been stated, but the particular reasons for these piracies and for the times at which they occurred are not wholly clear. At least two factors were important. The tributaries of Boxelder Creek flow from the escarpment southward, and cross two sets of resistant beds. The outcrop of Cretaceous sandstones swings from the general north-northwest trend west of Fort Collins to a general east-west trend near Round Butte, about 4.5 miles south of the valley and site. Near and north of this locality the basal conglomerate of the Brule formation crops out. Thus each tributary of Boxelder Creek encounters resistance to downcutting by two resistant formations, the Cretaceous sandstones and the basal Brule. As each tributary encounters the most resistant of the Cretaceous beds at a slightly different level and as the basal conglomerate of the Tertiary is irregularly cemented, the factors of resistance in downcutting operate on different streams at irregular intervals throughout any one period of downcutting. First one tributary is held to a higher gradient while another is able to cut downward and thus gain advantage at the headwaters. In the next interval of time, the other tributary may have the advantage.

The factor of ground water in piracy is too little considered, but its effects in an area such as this, where a strong spring zone exists at the Arikaree-Brule contact, cannot be disregarded. These springs are powerful agents in erosion because the emergent water dissolves the cement of the Arikaree and reduces the rock to gravel. It also softens the Brule tuff into a slippery claylike mass. Obviously an ephemeral stream reinforced by a spring is more powerful in extending its drainage than a similar stream without such help. In the beginning of the history of the area, up to the periods of the piracies, the grades of streams in the area of the Lindenmeier Valley were above the spring horizon, and the effects of the emergent water were negligible. Farther to the south, the springs may have played a large role in the planation that occurred. Furthermore, the piracy from the east, which brought the Lindenmeier Valley into the drainage of Sand Creek in the post-Timnath period of downcutting, may have been largely brought about by the diversion of ground water in that direction by reason of the extension of Spottlewood Creek.

The period of piracy of post-Timnath time produced the Lindenmeier Valley, and, by the close of Kersey time, it was broadened and reduced to its present grade. This valley with its almost east-west course, its low rim to the south and its swampy floor, slightly incised below the Arikaree-Brule contact, was a suitable camping and hunting ground for the Folsom people.

Modifications of the valley were, however, in progress. Streams heading in the ridge on the south flank of the valley have a direct course to Boxelder Creek and by headward erosion produced the plain M-R-P, figure 2. These streams by headward erosion reduced the ridge or southern wall of the Lindenmeier Valley at two levels of erosion. On the west the streams cut the plain M nearly 75 feet higher than the plain R-P on the east. This plain appears to have been cut at the Timnath stage. The lower plain, however, reached its present smooth grade in the Kersey stage and downstream merges into the 20-foot terrace of the streams. The form of the upper portion of the valley and the thinning of the southern wall by this process of headward sapping is shown in profile WZ, figure 3.

It is obvious that the streams on the grade of the plain R-P (fig. 2) were most successful in reducing the valley wall, which became a low, rounded ridge. Even today this ridge is being reduced, and the former floor of the Lindenmeier Valley crops out as a dark layer on the white Brule tuff-clay from points S through C to K, except where protected by blocks of Arikaree derived from slopes that have now disappeared. This relation is brought out in profiles WZ and UV (fig. 3).

The lowering of grades and abandonment of the Kersey terrace on the South Platte River was followed by a period of filling to a level 20 feet above grade to form the Kuner terrace. Since that time the river has cut to or below its present grade and formed the existing wide flood plain. These events are imperfectly preserved on the tributary streams. The Kuner terrace cannot be followed up the minor tributaries and appears to merge with their flood plains. In the area south of the Lindenmeier site, on the plain R-P, there is only a set of deep ravines to represent the post-Kersey series of events on the main stream.

Furthermore, the continued development of the plain R-P, figure 2, and the continued sapping of the south wall of the valley led to the loss of the ground water and finally to piracy of the surface drainage. During the period of occupation, as shown by excavation, the south slope of the valley and presumably a large part of the valley floor was covered by dark earth similar to material now underlying the spring meadows of nearby localities. Thus, the conclusion is forced that the valley floor was a wet and springy meadow, which stood at elevations 50 to 75 feet higher than the plain R-P, immediately to the south. As the plain advanced northward by the erosion of the dividing ridge, the hydraulic gradient between the valley and the plain became steeper. Eventually the ground water was drained out through one of the joints in the Brule. The diffused spring or wet meadow was converted into a definite spring opening at a lower level.

With the drying of the valley floor, hillside wash covered and preserved the old meadow soil and thus entombed the relics of the Folsom peoples. Furthermore, the valley was no longer as attractive to man and beast, whose activities would be transferred to the plain R-P. Thus, the rubble which overlies the culture layer is barren of fossil bone and almost barren of the relics of man.

The formerly moist Lindenmeier Valley thus dried up by groundwater piracy was drained by an ephemeral stream. This stream enfeebled by the piracy at A, was attacked in its lower portions by headward erosion in post-Kersey time. In the area E-D, figure 2, especially near the cornfield of Bear's Ranch, the original valley floor was largely destroyed and persists only as a series of terrace remnants. This gully extended upstream past the site, a little past the point B, and was later filled by the alluvial deposit barren of cultural remains, which has already been described. In turn, this deposit has been eroded by the gully extending from B to C, figure 2.

The date of these events is unknown. Many valleys of the southwestern United States were eroded, filled, and again eroded within the period of Pueblo occupation (Bryan, 1926). It may be that these events lie within this very recent period of alternate erosion and alluviation.

The most striking event of relatively recent time is the formation of the gulch extending from the plain R-P to B, figure 2. This gulch, according to the local residents, antedates occupation of the area by the white man. It is about 70 feet deep near the point C, and is being actively deepened, widened, and advanced headward at the present time. The piracy of the surface drainage of the Lindenmeier Valley by this gulch is a logical aftermath of the piracy of the ground water. The existence of a spring within this gulch leads to softening and weathering of the Brule, to the trampling of the surface by animals, and to active wind erosion, by which small tuff-clay dunes were built (fig. 2), and to active gullying. For these reasons the original hill in the areas S to C was carried away by the ephemeral streams forming the plain R-P. Eventually that ridge was so lowered that the surface drainage poured over the ridge to form the beginning of the gully. As this gully, or gulch, retreats, the spring also retreats to the north and west, softening the Brule and preparing the way for active erosion during the periods of storm, when water pours into the gully from rains.

CONCLUSION

The successive stages during which the grades of streams in the region were lowered promoted and also timed the successive piracies by which the Lindenmeier Valley gained its present topographic form.

Here, in the interval when the main rivers were forming the Kersey terrace, was a relatively sheltered valley with water and grass, attractive to animals and an ideal site for a hunting camp. No doubt there were other such sites in the region, but at no other yet found has later erosion been so feeble as to preserve, and yet so active as to expose, the deposits of that time.

PEDIMENTS AND TERRACES OF THE COLORADO PIEDMONT

GENERAL STATEMENT

The northern part of the Colorado Piedmont was developed as a great lowland below the grade of the High Plains surface in several successive stages of erosion. Each stage was begun by a lowering of grade of the main river, followed by a stabilization of grade or by alluviation. Into this sequence of events the detailed story of the Lindenmeier Valley fits. By a consideration of the history of this larger area, the significant event at the site, that is, the formation of the culture layer, may be connected with an event having a large geographic range.

The first period of incision of streams below the original grades led to the development of a broad lowland in almost the same position, and having nearly the same area, as the present Colorado Piedmont. Within this lowland the tributaries of the Cache la Poudre-South Platte Rivers shifted from one position to another over the broad, sloping plains with comparative ease (fig. 4). Obviously the development of so large and so perfect a surface, even in rocks relatively as easily graded as the Tertiary and Cretaceous rocks of this area, must have consumed a considerable time.

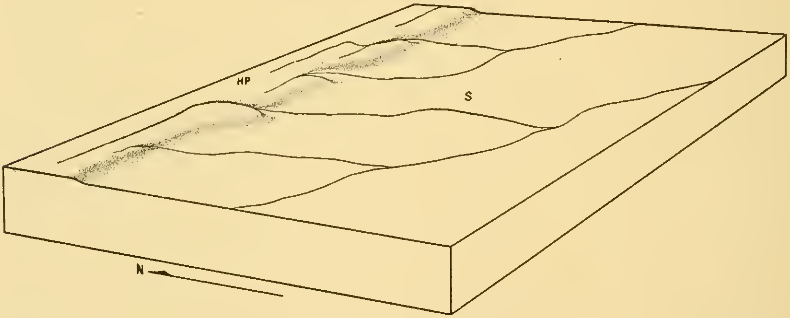

Fig. 4.—Generalized block diagram showing development of the Spottlewood pediment below the High Plains surface in the northern Colorado Piedmont.

This lowering of the stream grades within the Colorado Piedmont took place in post-Pliocene time and occupied most of the early and middle Pleistocene. It seems probable that each lowering of the grades, by which the pediments were formed, was due to uplift of both the mountain area and the western portion of the plains, as has been established for the similar sequence of events in Montana (Alden, 1932). On the other hand, during the Pleistocene there existed a fluctuating climate, the effect of which on the grades of streams (Johnson, 1901) is as yet imperfectly understood.

This period of dissection was relatively long and efficient. After each incision of the streams there was stabilization of grades, and broad surfaces of erosion (pediments) were developed, which in places bevel the underlying deformed bedrock.[2] Each surface was more or less covered by a thin mantle of gravel—the channel deposits of the streams to whose lateral planations much of the development of the surfaces is due.

The last of the pediments was strongly dissected in the "canyon-cutting cycle," when the major streams cut to, or below, present stream grades. There are alluvial terraces younger than this period of canyon-cutting, and their distribution is restricted to narrow belts in the existing stream valleys. Each of these terraces records a filling of the valley and a reexcavation to, or below, the present grades of the major streams.

The gravel-capped pediments were formed in the earlier part of the Pleistocene. The terraces are, however, Wisconsin and later in age, and, as will be shown, are directly related to the later stages of mountain glaciation.

SPOTTLEWOOD PEDIMENT

The oldest and highest of the pediment surfaces (fig. 4) has now been so nearly destroyed that only a few scattered remnants yet rise above the younger erosion surfaces of the area. The name "Spottlewood pediment" is given to the surface because it is preserved along the escarpment between the High Plains and the Colorado Piedmont, in the headwater area of Spottlewood Creek, near the Lindenmeier site. It also forms the upper surface of Wildhorse Tit, a well-known landmark in sec. 23, T. 10 N., R. 64 W. (see Eaton Quadrangle). Remnants of the Spottlewood pediment are gravel-capped, and the term "Spottlewood" includes both the gravel and the time interval during which the pediment was formed.

Along the High Plains escarpment, in the vicinity of the Lindenmeier site, the Spottlewood pediment is represented by numerous gravel-capped spurs that slope gently southeastward and bevel the Arikaree formation. The high hills, approximately 16 miles west of

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[2] Figures 4, 5, 6, and 7 are generalized block diagrams which represent the northern portion of the Colorado Piedmont in the Livermore and Eaton topographic quadrangles and adjacent regions. These are intended to give a general pictorial history of the development of the pediment and terrace surfaces and not to furnish details of the actual development in each minor area.

Wildhorse Tit[3] are relatively large remnants of this surface. Overlying their cap of well-rounded stream gravel is a thin layer of wind-blown sand, which has at its base a layer of ventifacts. At the Lindenmeier site the Spottlewood pediment is preserved in the south-eastward-sloping, flat-topped ridges that lie to the north of the valley.

COALBANK PEDIMENT

Along the Cache la Poudre River and extending up its tributaries there are remnants of an easily recognizable pediment. On the main streams it has a grade about 50 feet below the Spottlewood pediment (fig. 5). Because it is well preserved on the high ridge 24 miles northwest of the junction of the Cache la Poudre and South Platte Rivers, it has been named the "Coalbank pediment,"[4] a term applicable to the synchronous gravel and the time interval involved.

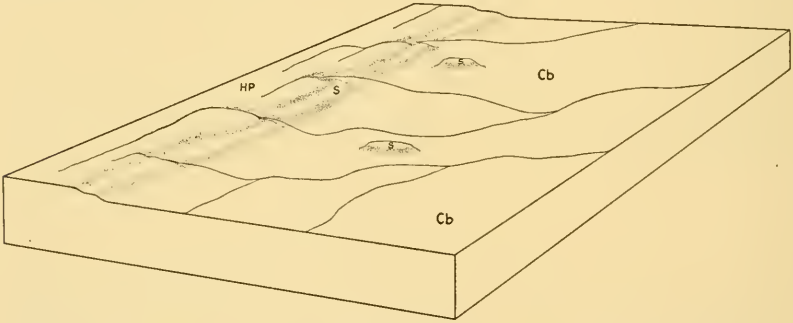

Fig. 5.—Generalized block diagram showing development of the Coalbank pediment below the Spottlewood pediment.

This surface, like the Spottlewood, bevels bedrock and is covered by a gravel cap, overlain by scattered ventifacts and wind-blown sand. It was formed during a period of stationary base level and lateral planation of streams. In the Coalbank stage the streams near the borders of the Piedmont area widened their floors into broad valleys, as shown in figure 5. However, planation did not continue long enough for the complete destruction by stream action of all the remnants of the previously formed Spottlewood pediment. These remnants, then as now, stood as hills and flat-topped ridges above the broad, sloping plains of the Coalbank surface (fig. 5). At the Lindenmeier site, as described on page 14, the Coalbank pediment is preserved in the form of two gravel-capped mesas, G and F, figure 2.

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[3] These hills are 4 miles west of the railroad siding of Dover, a locality in the Eaton Quadrangle.

[4] "Coalbank" is the local name of the ridge between Lone Tree and Boxelder Creeks in the Livermore and Eaton Quadrangles.

TIMNATH PEDIMENT

A third period of stream incision, followed by planation by streams and the development of a broad valley stage in the tributaries of the main rivers, produced the Timnath pediment (fig. 6). This surface, the synchronous gravel, and the time interval are named for the village of Timnath.[5] The hills east of this village lie about 21 miles northwest of the junction of the Cache la Poudre and South Platte Rivers.

Near this junction the Timnath surface lies approximately 70 feet below the grade of the Coalbank pediment and about 80 to 100 feet above the river. Except that the areas of planation are smaller, this pediment has the same characteristics as the two older surfaces. In the vicinity of the High Plains escarpment, relatively narrow valleys were developed, so that near the Lindenmeier site the most easily recognized remnant of the Timnath pediment is a flat-floored valley (H in fig. 2), lying between the two mesas that are, as previously stated, remnants of the Coalbank pediment.

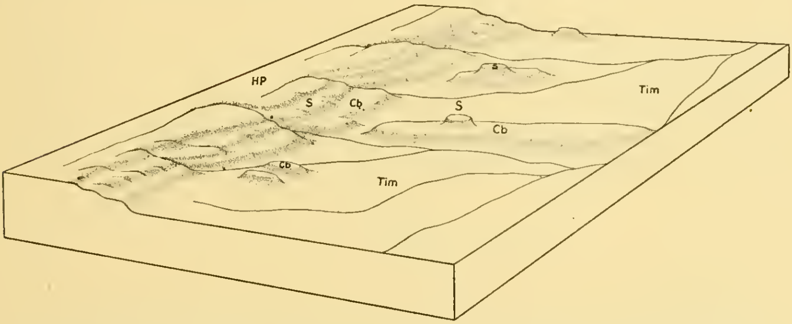

FIG. 6.—Generalized block diagram showing development of the Timnath pediment below the Coalbank pediment.

The gradients of all the pediments steepen toward the mountain front and toward the escarpment of the High Plains. The pediment surfaces can be traced into the mountains, where they are represented by rock benches and spurs along the main drainage streams, and in a few localities by open valleys with subdued and terraced topography. Examination of the High Plains escarpment shows that the area of the Colorado Piedmont has not been much extended since the initial incision of the High Plains surface by the streams

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[5] Timnath, a railroad station and village, shown on the Eaton Quadrangle, approximately 17 miles northwest of Greeley, Colo.

which cut the Spottlewood pediment. The Colorado Piedmont has been deepened and its borders diversified by newly cut canyons and gulches.

PIRACY BY THE SOUTH PLATTE RIVER

The South Platte River, above its junction with the Cache la Poudre at Greeley, has a course inconsistent with the slope of the Spottlewood and Coalbank pediments. However, the Timnath pediment is developed along the course of this stream. It appears, therefore, that at the beginning of the development of the lowland of the Colorado Piedmont, the Cache la Poudre and the part of the South Platte east of their present junction formed the main stream of the region. The upper part of the South Platte River appears to have been a tributary of the Arkansas River. In the interval of stream incision between the Coalbank and Timnath stages a tributary of the Cache la Poudre captured the waters of the large area drained by the upper part of the South Platte. This recently acquired drainage is larger and better watered than the original area, and the South Platte River has become the main stream of the region, reducing the Cache la Poudre to a tributary (fig. 1).

THE CANYON-CUTTING CYCLE

Following the development of the Timnath pediment, there was a new period of stream entrenchment. Not only were the streams of the Piedmont area deeply incised to grades below the present grades of the rivers, but great erosion occurred in the mountains. The streams of the mountain area cut canyons almost as large and as deep as their present canyons, and hence this period is known as the "canyon-cutting cycle" (Van Tuyl and Lovering, 1935). It is merely a repetition of the three preceding periods of incision, the pre-Spottlewood, pre-Coalbank, and pre-Timnath cycles. The severity of the entrenchment, both in the mountains and in the plains, is marked. Furthermore, it ushered in a new series of changes in stream gradients in which, between periods of incision, aggradation rather than planation was characteristic.

ALLUVIAL TERRACES

After the canyon-cutting cycle the main streams built up their channels with alluvium in successive intervals, separated by intervals of renewed downcutting (fig. 7). On the minor tributaries of the Piedmont area these changes are, however, not perfectly recorded.

The stages appear to have been short, and the minor tributaries were too feeble to accomplish complete gradation to the main streams at each successive change in grade.

A careful study of the valleys of the Cache la Poudre and South Platte Rivers has brought to light only a few remnants of the earliest and highest of the alluvial terraces. Later erosion has destroyed and carried downstream much of this material. Also, wind action has accumulated many dunes which so bury the areas adjacent to the rivers that remnants of terraces are concealed. The most extensive and most easily recognized terrace representing the maximum of valley filling is at the locality called Pleasant Valley, north of the confluence of the Cache la Poudre and the South Platte Rivers. The highest alluvial terrace is named for this locality, where the top of the terrace lies more than 50 feet above the river grade. The terrace consists mostly of sand with moderate amounts of gravel. Here, and in other localities, it is masked by wind-blown sand, and in many places merges topographically with the lower terraces. Terraces attributed to the Pleasant Valley stage may represent two periods of alluviation. The terrace remnants are so few and are so obscured that such a relation might exist without leaving easily detectable traces.

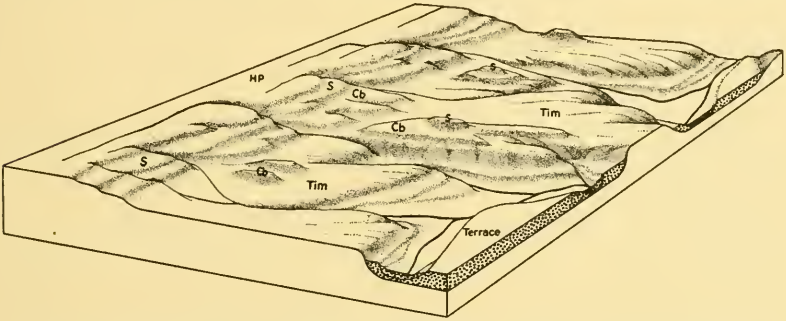

Fig. 7.—Generalized block diagram showing development of alluvial terraces in deep valleys cut into the Timnath pediment during the canyon-cutting cycle.

Strong stream erosion destroyed most of the alluvial fill represented by the Pleasant Valley terrace, and the main rivers once again cut down to, or below, their present grade. Deposition then began anew, and river gradients were built up to form alluvial plains now represented by a strong terrace, which is very well preserved, and forms the main agricultural area on the South Platte River. It is prominent near the village of Kersey, a railroad station, approximately 7 miles east and slightly south of Greeley, Colo. The alluvium of this terrace, as shown in numerous pits, is largely a fine-grained gravel and sand. Much of the surface of the Kersey terrace is covered by dune sand and by alluvial fans, especially on the borders away from the rivers (pl. 3, fig. 1). Its general surface lies between 25 and 30 feet above the present stream grade at the type locality. Near the valley walls the terrace surface may rise gradually to elevations of 40 to 45 feet because of accretions to the strictly river-laid fill. At places along the main streams and the tributaries the upper 2 to 12 feet of terrace gravel is deformed into an involuted and formless mass in which ventifacts may be found. This material is a characteristic warp attributable to intensive frost action in a severe and windy climate such as no longer exists.

Separated from the Kersey terrace by a well-defined scarp is the lowest recognizable terrace. At the type locality, near Kuner, a railroad station 5 miles east of Kersey (fig. 1), this terrace, to which the name "Kuner" is applied, lies about 12 feet above the river. Gravel and sand pits show that its composition is essentially the same as the older and higher Kersey terrace. In some places the surface of the Kuner terrace rises to as much as 20 feet above the level of the South Platte River.

The Kersey stage of alluviation was followed by erosion and the lowering of river grades to, or below, the present grade. The Kuner terrace represents a period of alluviation in which the river grades were not built so high as in the earlier stage. Again the rivers incised themselves and dissected the Kuner terrace. Between the Kuner terrace and the broad flood plain of the rivers no lower terraces have been detected.

MODERN FLOOD PLAIN

The flood plain of the South Platte and Cache la Poudre Rivers is broad, with a width ranging from a few hundred feet to a mile and a half. Across the surface the rivers flow in a channel which in places is braided, suggesting aggradation. The rivers, at ordinary low water, flow in channels 4 to 6 feet below the flood plain, as at Kersey, or less than a foot, as at Platteville. This variation is the result of the numerous irrigation dams which create, at moderate river stages, an artificial gradient. It is now impossible to measure the height of the lower terrace level above the natural stream grade, for one must use this artificial grade. However, the discrepancies between these grades are of small importance in the study of the higher surfaces. In spite of the dams, the river in times of flood covers the whole of the flood plain, as attested by local residents, and thus it may be that the present artificial grade at low or medium stages is not reflected in the flood gradient, which may be identical with that existing before the dams were built.

The surface of the flood plain is not a perfect flat, but in a number of places there are small meander marks, abandoned stream channels, and gentle ridges and furrows 2 to 3 feet in height. None of these features seems to indicate the existence of a terrace younger than the Kuner, although many of them cannot be clearly interpreted. Materials composing the visible portion of the flood plain are of small size, containing none of the coarse well-rounded boulders characteristic of the higher terraces or of the river bed at the mouth of the Cache la Poudre Canyon. At many places there are thin lenses of sand and loam interbedded with equally thin beds of fine-grained gravel, composed of quartz and pink feldspar.

SUMMARY

As a result of uplift and dissection of the High Plains surface, three successive periods of incision and planation by the streams in the northern Colorado Piedmont have produced three successively lower gravel-capped pediment surfaces, cut on bedrock. Alternate incision and alluviation have produced three or perhaps four alluvial stream terraces at lower elevations. The important period of valley deepening, the canyon-cutting cycle, separates these two sequences of events and is of greatest value in the correlation of the history of the Colorado Piedmont with that of the mountains. As hereafter shown, the pediments and erosional surfaces, well developed in the soft sandstone, shale, and limestone of the Piedmont area, are now represented in the mountains by spurs on the canyon wall, which are relics of old broad valleys. The alluvial stream terraces can be traced continuously along the major streams from the Piedmont into the mountains, where each terrace ends at the moraine left by an ancient glacier. The alluvial terraces are thus directly correlative and synchronous with glacial stages.

GLACIATION OF THE CACHE LA POUDRE VALLEY

It has long been known that during the Pleistocene period the mountains of Colorado supported extensive valley glaciers. Even now small glaciers and permanent snow fields linger in sheltered cirques of the high mountains. The northernmost of these, Hallet Glacier, nestles in a cirque head on the northeast flank of Hagues

Peak, only 45 miles southwest of the Lindenmeier site and 25 miles due west of the mountain front. To the south, in similar cirques along the high crest of the Continental Divide, there are numerous ice and snow masses. Northward, and west of the area here considered, the peaks of the Colorado Front Range decrease in altitude and lie too low to support permanent snow fields under the present climatic conditions.

Although numerous descriptive studies have been made of the glaciers of Colorado and of other parts of western United States, there has been, with the exception of Blackwelder's comprehensive study (1931), little or no attempt at regional correlation of glacial stages. By the very nature of the problem, a great deal more data, both descriptive and quantitative, must be gathered before the complete picture can be brought into focus. Until that time, workers must be content with local chronologies and a correlation with continental glacial stages based on purely qualitative evidence.

General geologic thought, as summarized by Blackwelder (1931), assumes that the last advances of the valley glaciers in the Colorado mountains, and elsewhere in the Rocky Mountains, were contemporaneous with the advances of the continental glaciers in Wisconsin time. This assumption is granted by the writers and is used as one of the bases for correlation.

In the drainage basin of the Cache la Poudre River there is definite evidence for one glacial stage of pre-Wisconsin age and three glacial substages of Wisconsin age. There is reason to believe that a fourth substage, the earliest Wisconsin, occurred but left so few traces that its existence is not completely proved. Furthermore, a fifth substage is represented in this region, not by the morainal relics of glaciers, however small, but by the less prominent effects of a strong refrigeration of climate. These glacial stages will be reviewed in a chronological order, from the oldest to the youngest.

PRAIRIE DIVIDE GLACIAL STAGE

The oldest glacial deposit of the Cache la Poudre drainage forms the surface of Prairie Divide, a broad mountain flat, with an altitude of approximately 7,900 feet (T. 10 N., R. 72 W., Livermore and Home Quadrangles). Here, weathered gravel rests upon a deeply weathered glacial till. The gravel and till form a plain, so perched above the level of the present drainage that it is being eroded from all sides. Great bodies of slumped material fill valleys which have cut headward into the mass (pl. 3, fig. 2). Small patches of weathered loess, containing calcareous concretions, or *loess kindchen,* lie within the slumped masses, below the general level of the plain, and the loess may, therefore, be younger than the till and gravel.

The till and gravel of Prairie Divide represent a widespread glaciation. Their weathered condition and their topographic position above the valleys containing the more recent glacial deposits testify to the relatively great age of this glacial stage. The locality is also far to the east of the most advanced position of the later glacial moraines, a fact which suggests a very much larger glacier than any formed in later time. This glaciation is here named the "Prairie Divide stage" and is probably correlative with the Cerro glaciation of the San Juan Mountains (Atwood and Mather, 1932).

OTHER POSSIBLE PRE-WISCONSIN GLACIATIONS

No evidence of a glacial stage comparable in size and position with the Durango stage of the San Juan Mountains (Atwood and Mather, 1932) has been discovered in the Cache la Poudre drainage basin. The Durango stage is, however, assigned somewhat doubtfully to the Iowan, here termed "Wisconsin I." Further study may indicate that the pre-Home glacial substage, to be described, is correlative with the Durango glaciation, but at present it can be suggested only as a possibility.

At several places in the Colorado Front Range, Ray has observed glacial till which is best attributed to the Durango stage. A detailed description of these deposits will appear in a forthcoming paper on the glaciation of the Southern Rocky Mountains.

THE CANYON-CUTTING CYCLE

During the long interval which separated the earlier from the Wisconsin glaciations of the Colorado Front Range, streams entrenched themselves deeply in both the mountains and the plains. This period of erosion, called the "canyon-cutting cycle" (Van Tuyl and Lovering, 1935), marks the time immediately preceding the Wisconsin glaciation. Remnants of the materials deposited by the two earlier glacial epochs were dissected during this stage. The general relationship between this period of stream entrenchment and the stages of glaciation characteristic of other mountains of the Cordilleran region appears to hold throughout this area.

The Cache la Poudre Valley within the mountains is deeply entrenched, set within an older, broader valley that is now represented by prominent rock spurs. The lower, or downstream part of the canyon is typically unglaciated and **V**-shaped. The upper, or upstream part, is characterized by a **U**-shaped profile and also by erratics, roche moutonnée surfaces, small hanging valleys, and isolated patches of glacial debris. Transition between the two valley types occurs at Home Post Office (fig. 1), at an elevation of about 7,600 feet. Here, a terminal moraine stretches almost completely across the valley, rising about 135 feet above the level of the river, which flows through a notch between the moraine and the bedrock of the northern valley wall (pl. 4).

HOME, AND A POSSIBLE EARLIER, GLACIAL SUBSTAGE

The moraine at Home Post Office (pl. 4) presents a rounded and mature aspect. However, careful examination shows that this smooth topography is the result of a covering of wind-blown sand. On the upstream side of the moraine the cover is thicker and more effectively conceals the bouldery surface than on the downstream side. Scattered over the surface of the moraine are ventifacts, or stones that are polished, grooved, and faceted by wind-blown sand. Obviously, sand is not now moving down the valley, and one must suppose that the small dunes behind the moraine and the sand that cut the ventifacts were moved by winds that swept down the valley over the glacier. The sand was derived from the surface of the glacier and from the barren outwash plains. Such cold glacial winds moving down the valley under gravitational forces are characteristic of the valleys below existing glaciers in Alaska, where dunes are being built from sands of the outwash plains. Similar dunes are built and stones are being cut on the outwash plains of Greenland (Hobbs, 1931). In the Sierra Nevada of California, Blackwelder (1929) has described a boulder carved during the Pleistocene by wind-blown sand.

Roche moutonnée surfaces adjacent to the moraine are fresh and show glacial striae at localities that are protected by a slight covering of glacial drift or of vegetation, whereas unprotected surfaces lack polish or striations. When fully exposed to weathering at the present rate in these altitudes, the bedrock is so easily weathered that it is unable to retain the marks of glaciation for any great length of time. For the foregoing reasons, the apparent lack of glaciated surfaces related to the moraine does not necessarily imply great age. Observation throughout the Colorado Front Range indicates that glaciated surfaces, related to moraines otherwise similar, are, unless protected, preserved only on unusually durable rock.

The question has been raised whether the moraine at Home, and the glacial substage named for it (Louis L. Ray, 1938), are possibly of pre-Wisconsin age. The subdued topography of the moraine might, as some writers hold for other localities, be attributed to long weathering of the surface during and after the retreat of the ice. One needs to guard against attempting to date glacial stages on the basis of a subdued topography of the moraines, for in this case it is not due to processes of weathering and denudation, but to wind deposition. Considering the topographic position of these moraines within the present canyons, the relatively slight degree of chemical alteration and slight compaction of the till, and the lack of deep gullying on the Home moraine, or on similar moraines in other areas of the Front Range, the writers believe that it is impossible to assign an age older than Wisconsin. General indications are, however, that these moraines were not made by the first advance of the valley glaciers in Wisconsin time, that is, the Iowan substage or Wisconsin I, but were made by the second advance of the Wisconsin time, or Wisconsin II.

Several lines of evidence point to the possibility of a pre-Home glacial substage, the terminal moraine of which, now removed by erosion, was almost coincident with the Home moraine. As shown in plate 5, figure 1, several large erratic boulders lie well above the valley floor on the south valley wall, immediately upstream from the Home moraine. Inasmuch as they lie above the reconstructed grade of the ice which built the Home moraine, it is conceivable, but highly improbable, that they were brought to position during that period of glaciation. A somewhat larger glacier, which extended perhaps as much as half a mile farther down the valley, would have had a height sufficient to have deposited the boulders in their present position. For the half mile below the Home moraine, the canyon is open and U-shaped, and is then sharply constricted into a V-shaped gorge. This narrow, winding gorge shows no signs of glaciation.

The most definite evidences for a pre-Home period of glaciation are small lateral valleys, some 250 feet or more above the present level of the valley floor (C and D in fig. 8). Compared to the lower and similar valleys at B (fig. 8) they are relatively old, as the walls are much weathered and the floors are filled with talus. These valleys were formed by streams which drained the lateral margin of a valley glacier too high to have been related to the Home moraine. These small valleys are similar in origin to the lateral channel that lies about 140 feet below (B in fig. 8). This valley has straight clean walls and is so youthful that it seems to have been deserted only yesterday by the waters which carved it. It stands at an elevation so low that it must have been cut by streams draining the lateral margin of the ice as it began to retreat from the Home moraine. It is not necessary to postulate a long period for the formation of these little canyons, for similar straight-walled cuts in bedrock form in short periods of years along the lateral margins of the present retreating glaciers of Alaska (Louis L. Ray, 1935, pp. 304-307).

Further evidence for this postulated pre-Home glacier exists in the lower canyon in bodies of gravel which stand too high above the river to be remnants of the valley train produced by the Home glaciation (see pp. 42 and 43).

The positions of erratics near the Home moraine, the high lateral canyon, and the pre-Home valley train all seem to indicate that a valley glacier, whose terminal moraine has been completely removed, once existed. On the basis of this evidence, the writers postulate a pre-Home glacial substage of Wisconsin I (Iowan) age, but they have refrained from giving it a name.

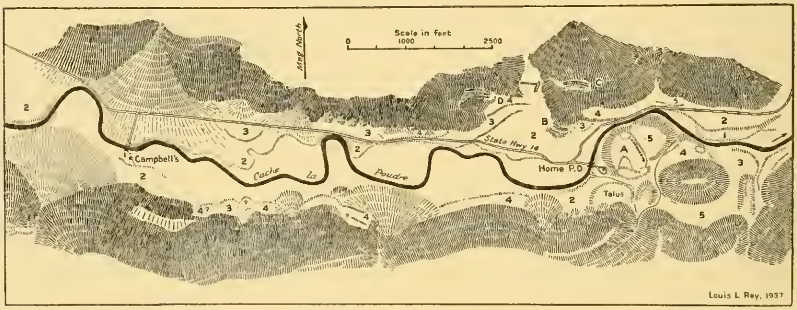

FIG. 8.—Sketch map of the Cache la Poudre Valley at Home Post Office, showing: A, Home moraine; B, low lateral bedrock gorge; C and D, high lateral bedrock gorge; and terraces of 5 groups, numbered from youngest and lowest to oldest and highest.

The evidence in the Cache la Poudre Canyon for this pre-Home substage is not as complete as is desirable, but in adjacent regions there is additional evidence, of which the most important may come from the region immediately south of the Rocky Mountain National Park, near Ward (Wahlstrom, 1939). Furthermore, Ray has examined the moraines of the Libbey Creek Valley in the Medicine Bow Mountains, described by W. W. Atwood, Jr. (1937).

The moraine near Libbey Lodge, which has been attributed to the Wisconsin by Atwood, has an aspect similar to the Home moraine. It is here correlated with the Home moraine and attributed to Wisconsin II. The lowest moraines in the inner valley, between Libbey Lodge and Centennial, which Atwood considers pre-Wisconsin, have a somewhat older aspect, and may be correlated with the pre-Home, or Wisconsin I. It is possible that Atwood uses "pre-Wisconsin" in the sense of Iowan of the older terminology. Under present usage Iowan is equivalent to Wisconsin I, in which case, his correlation is equivalent to the one here given.

The Home substage of glaciation is represented by the moraine, already described, and the outwash plain, or valley train, preserved as terrace remnants approximately 90 feet high, immediately below the moraine. Small lateral channels cut as sharp boxlike canyons 15 feet wide and 20 feet deep in bedrock occur on the north side of the valley, 60 feet above the stream grade (fig. 8, B). Patches of striated and wind-polished rock occur on the flats above and on the upper parts of the walls of these little canyons. That these surfaces are yet unharmed by weathering is in itself evidence of the relatively recent date of the Home substage, which is considered to be of Wisconsin II age.

CORRAL CREEK SUBSTAGE OF GLACIATION

Following the retreat of the glaciers of the Home substage, or their possible complete disappearance, there was another glacial advance. The ice streams were relatively small and reached down to and formed moraines at elevations ranging from 9,100 to 10,100 feet in the valley of the Cache la Poudre River and its major tributaries. Instead of a single moraine, there are moraines in the tributary canyons that lie from 1,500 to 2,500 feet above the moraine at Home. The ice tongues that built these moraines descended from cirques down the valleys of Long Draw, Trap, Joe Wright, and Corral Creeks, and also in the so-called main valley of the Cache la Poudre.

The best-developed moraines lie in the valley of Corral Creek, whose name has been given to this substage (Louis L. Ray, 1938). Here the ice tongue extended approximately 4 miles from the cirque, to an altitude of 10,100 feet (pl. 5, fig. 2). The moraine stretches almost completely across the valley, except for a small notch along the south side, through which Corral Creek flows to join the Cache la Poudre River about a mile and a half downstream. Up the valley, there are small patches of glacial debris, scattered along the broad, flat valley floor, deposited during retreatal pauses of the Corral Creek glacier as it receded from the advanced position marked by the main moraine.

In general, the surface of the Corral Creek moraine is subdued and has an aspect similar to that of the Home moraine, except for the presence of a greater number of large scattered boulders. A careful search revealed a few stones that are slightly wind-cut, but none show faceting. Little wind-blown sand is present. The feeble wind action thus indicated, implies a less active and less prolonged period of wind activity than occurred during the Home substage.

The ice mass moving down Joe Wright Creek (Home Quadrangle) was larger than those in the other valleys, for it was fed from a larger area of accumulation below the high summits of the Medicine Bow Mountains to the west. This glacier moved into the Laramie River valley, where it built a moraine; it also pushed a lateral tongue down the valley containing the present Chambers Lake. This tongue reached into the drainage of the Cache la Poudre River, where a morainic complex was built that now dams the valley and holds in the waters of Chambers Lake. Recently an artificial dam has been constructed on one of these retreatal moraines to raise the level of the water of the natural lake. Light blue-gray bouldery till, with unweathered blocks of all the local rock types, is revealed in a road-cut through this moraine. This till is so fresh as to be in marked contrast to the highly weathered till of the Prairie Divide stage. It is also slightly fresher than the till of the Home moraine.

The difference in the amount of weathering of the till, the distinct topographic position of the moraines in the valleys, and the widespread distribution of comparable moraines lead to the conclusion that these features indicate a glacial substage separate and distinct from the Home substage. According to the terminology used, this is considered to be Wisconsin III.

LONG DRAW SUBSTAGE OF GLACIATION

Immediately below the cirques at the heads of Corral Creek and Long Draw Creek there are evidences of an ice advance. Below the cirque of Corral Creek there is an outwash plain, pitted with kettle holes (pl. 6, fig. 1)—material evidence for a slight readvance of glacial ice, although in this valley no terminal moraine was developed (Louis L. Ray, 1938). Remarkably fresh, soled and striated boulders occur in this outwash.

Below the lip of the nearby cirque of Long Draw Creek (secs. 7 and 17, T. 6 N., R. 75 W.) there is a low and poorly developed moraine, apparently contemporaneous in age with the pitted outwash plain of Corral Creek. These features are the youngest and least altered glacial deposits in the drainage basin of the Cache la Poudre River.

The name "Long Draw" is here given this glacial substage. Examination of many cirques throughout the Colorado Front Range indicates that this slight advance is general and not peculiar to the mountains of northern Colorado. It is thus a definite stage of re-advance of the ice or a prolonged halt in the final recession. In the nomenclature here adopted it is considered to be Wisconsin IV.

PROTALUS SUBSTAGE

In the Corral Creek cirque lies a great ridge of angular debris, which from a distance appears to be a glacial moraine (pl. 6, fig. 2). However, close inspection of the mass of poorly sorted and angular boulders gives no indication of till or outwash of glacial origin. This ridge is a protalus rampart (Bryan, 1934), built of blocks from the cirque head wall, loosened by intense frost action, or nivation, and accumulated by rolling down over the snowbanks that once occupied the cirque. Because at the present time snowbanks of such size no longer form in the Corral Creek drainage, this is an ancient feature. Similar snowbanks and small ice masses, over which rocks roll each spring, still exist in the nearby cirques of the higher parts of the Colorado Front Range, in Rocky Mountain National Park. During the last general period of refrigeration the snowbanks, or perhaps the last remnant of glacial ice, still lingered in this shady head-wall region of the Corral Creek cirque, its record surviving only as this rampart of rough blocks.

Protalus ramparts may be seen in numerous cirques of the Colorado Front Range. They thus indicate a period, or periods, of slightly colder climate preceding that of the present.

SUMMARY

In the Cache la Poudre drainage basin there is direct evidence for an early Pleistocene glacial stage, the Prairie Divide, which is probably correlative with the Cerro stage of the San Juan Mountains. In the inner canyon of the Cache la Poudre there are terminal moraines of three substages of the Wisconsin: Home, Corral Creek, and Long Draw. Less conclusive evidence indicates that there is also a pre-Home substage of the Wisconsin. A protalus rampart in the valley of Corral Creek records a recent period of refrigeration, too feeble to produce ice tongues which moved from the cirques.

Similar features in other parts of the Southern Rocky Mountains are proof of a similar number of advances of the ice. On this account, the stages differentiated locally may be considered the records of climatic changes that were of wide extent and were not unique to the Cache la Poudre Canyon.

TERRACES OF THE CACHE LA POUDRE CANYON

THE CANYON

The Cache la Poudre River, with its headwaters at the Continental Divide, flows for about 58 miles through a deep, and in places narrow, mountain canyon. Near the village of Bellvue, the river leaves the canyon through a gateway in the hogback ridges and begins a meandering course across the Colorado Piedmont (fig. 1). The fall of the canyon floor between the headwaters and the mouth is more than 5,500 feet, so that the average gradient of the stream is approximately 95 feet per mile, or 1°. This is in marked contrast to the gradient of the stream between the mouth of the canyon and the confluence with the South Platte River, near Greeley, where the gradient is only about 10 feet per mile.

The inner canyon of the Cache la Poudre River, here discussed, is a deeply entrenched valley, cut below an older broad valley during the last great period of stream entrenchment, the canyon-cutting cycle. Numerous high bedrock spurs rising to more or less accordant heights indicate former positions of the valley floor, at each of which the stream excavated a valley broader than the present inner canyon. These stages are of the same age as the pediments of the lower country and therefore are not directly pertinent to the problem of the age of the terraces. The glaciers of the Wisconsin stage and the associated low gravel terraces are confined to the present inner canyon and are definitely younger than the rock spurs.

The inner canyon of the Cache la Poudre River is separable into two divisions, the glaciated portion above Home Post Office, and the unglaciated portion below. The gradient of the canyon floor in the unglaciated portion averages about 80 feet per mile, in the glaciated about 115 feet per mile. These, however, are by no means smooth gradients, for an examination of the river profile (fig. 9) shows a series of breaks in gradient. There are about seven such well-defined breaks in both the glaciated and the unglaciated stretches of this inner canyon. They occur mainly at constrictions, or "narrows," where the bedrock is resistant to weathering and the river has been able to cut only deep, narrow gorges. Where the bedrock is easily weathered, the valley has been widened, the walls are less steep and more widely separated, and the river gradient is smooth.

Large talus cones, developed along the valley walls of the inner canyon, indicate the great amount of weathering which has occurred since the canyon-cutting cycle of late Pleistocene time. The larger of the cones are below the lower limit of glaciation, at Home Post Office.

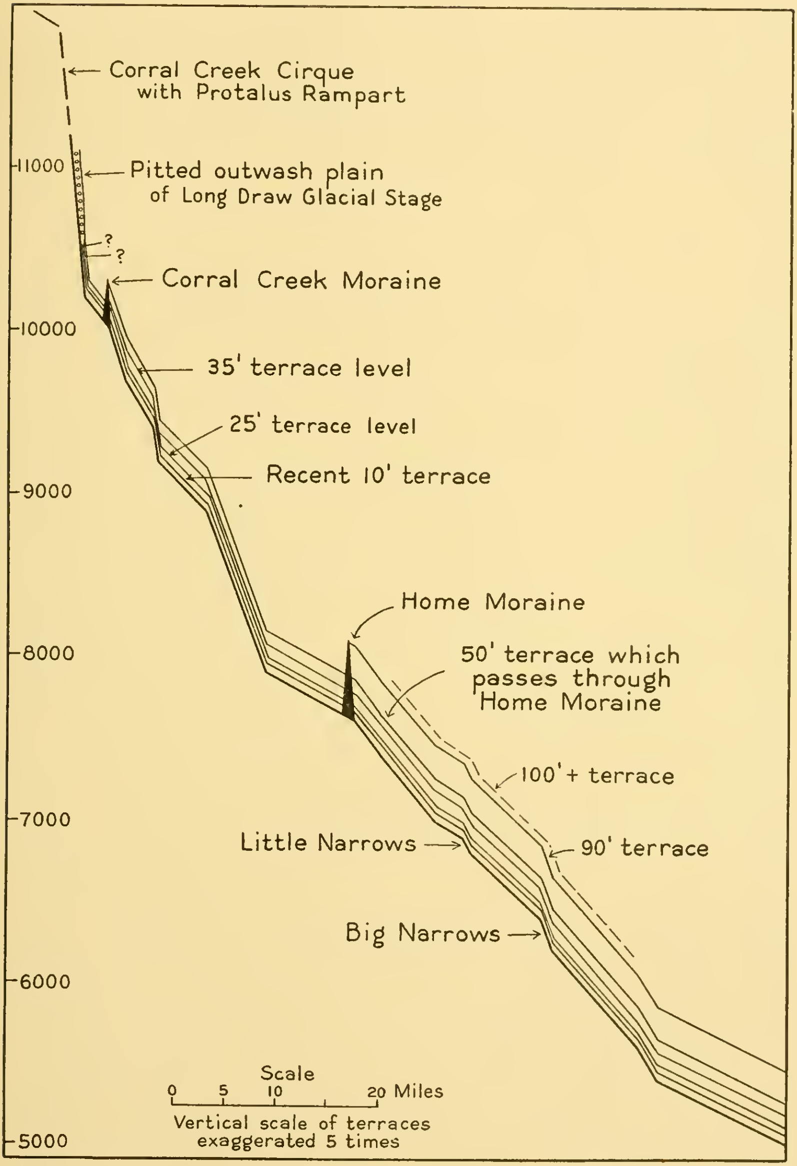

Fig. 9.—Generalized profile of the Cache la Poudre Canyon, showing terrace sequence and relation to glacial features.

Smaller, but well-developed cones occur in the glaciated portion of the canyon, indicating the rapidity with which some of the bedrock of pre-Cambrian granite and schist has disintegrated. The angular debris of these talus cones, in places roughly stratified by gravitational sorting, is displayed where the cones are dissected or cut by the river. A large part of the talus material consists of fine sand and comminuted rock, the products of local weathering and frost action.

NATURE OF VALLEY TRAINS

It is a recognized feature of mountain glaciation that glacier-fed streams carry large quantities of detritus. Because of their overloaded condition they build up their gradients and submerge the lower parts of the valleys with sand and gravel. These bodies of alluvium are termed the valley train, and by continued deposition they increase in height until the glacier has reached its point of maximum extension. On the retreat of the glacier the increased melt-water drainage removes much of the gravel and sand composing the valley train. Thus, in any one period of valley glaciation the lower portions of the valley, below the ice terminus, are first filled with fluvio-glacial debris and are thereafter, on the retreat of the glacier, more or less thoroughly cleared of this material. The pebbles and cobbles of the valley trains do not necessarily show the typical pentagonal, soled, and striated glacial form (Wentworth, 1936), but may be well rounded and give no evidence of their glacial origin (Louis L. Ray, 1935, p. 314). The remnants thus resemble any ordinary terrace recording a period of alluviation followed by a period of dissection.

Glaciers of three, possibly four, Wisconsin substages moved down the Cache la Poudre Canyon after the entrenchment of the stream during the canyon-cutting cycle. During each stage of glaciation a valley train was produced which was partially removed during the retreat of the ice from its position of maximum advance, marked by a terminal moraine. Each successive period of glaciation, each less extensive than the previous one, should be indicated by a terrace. The amount of glacial filling of the valley, and therefore the height of the valley train, is directly proportional to the size of the glaciation. Not only do greater glaciations endure longer, but the ice mass is larger and extends farther downstream. The terraces of the Cache la Poudre are not only comparable in number to the number of stages of valley glaciation, but certain terraces can be traced directly into terminal moraines. The details of the terraces and the methods by which they are correlated with each other and with the glacial stages are here set forth.

METHODS OF TERRACE STUDY

In the canyon of the Cache la Poudre River the terraces are common topographic features, in places rising steplike one above the other, or occurring as individual broad gravel flats, or as isolated gravel patches caught in minor inequalities of the rocky valley walls. Dissected remnants of these valley trains extend far beyond the canyon mouth and may be traced as terraces on the Cache la Poudre and South Platte Rivers. In order to carry the late glacial chronology of the mountains (see pp. 30-35) into the Colorado Piedmont, it is necessary to correlate the gravel terraces of the canyon with the terraces of the South Platte River.

A small portion of the valley train of the Home stage of glaciation is preserved as a terrace remnant, about 90 feet in height above the river, in front of and adjoining the Home moraine (figs. 8 and 10). Similarly, a remnant of the next lower valley train, whose height is about 50 feet above the stream, is preserved in front of the moraines of the Corral Creek stage, at Chambers Lake. Here, the river has exposed good sections through the moraines and the associated valley train. The transition may be followed between the heterogeneous materials of the morainal till to the roughly stratified fluvio-glacial materials of the valley train.

Downstream from the moraines, the terrace remnants have been mapped, and as shown in figures 9 and 10, they fall into a series of definite and correlatable groups. The highest of the terrace levels are the most poorly preserved, and stretches of several miles separate the remnants. The youngest terraces, on the other hand, are so numerous and have elevations above the level of the river which are so nearly the same that they may be separated into groups only with the greatest difficulty.

The elevations of terrace remnants above the river grade were carefully measured by hand level, from the water level at the time of measurement to the upper surface of the terrace. As the river grade is the only practical base from which to measure the height of the terraces, its fluctuation in water level from day to day, or hour to hour, is important. As the flow of the river, and thus its level, is regulated for irrigation, these fluctuations are highly irregular. A fluctuation of 2 feet, caused by the opening of water storage reservoirs near the headwaters of the river, does not materially effect the measurements of the higher terraces that lie from 35 to 90 feet above the grade of the river. However, the elevation of the low terraces, closely spaced and lying from 6 to 12 feet above the river, are seri-

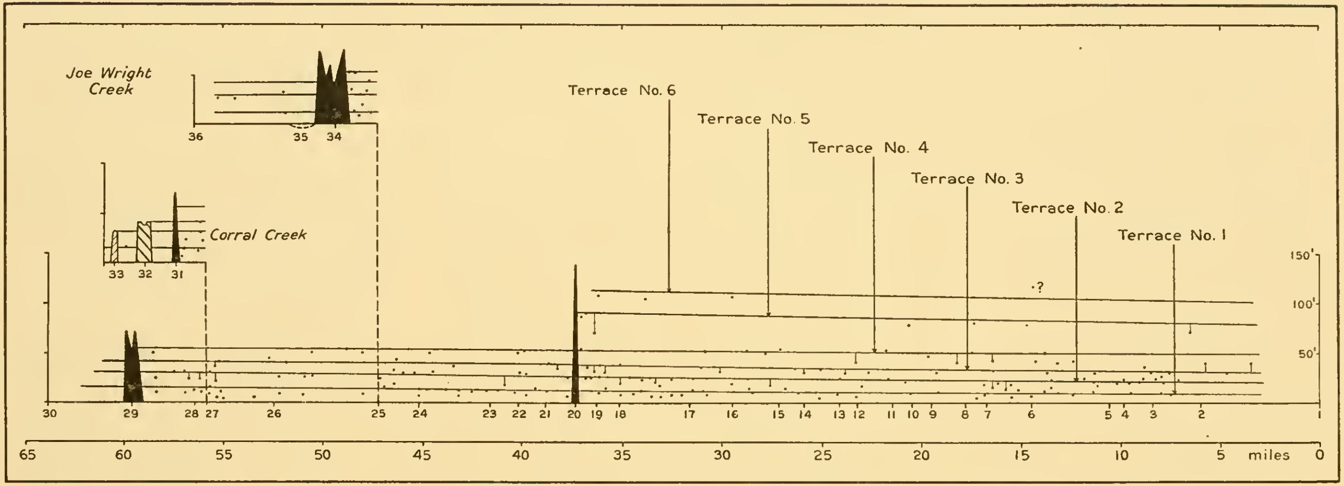

FIG. 10.—Diagram showing distribution of the terrace remnants and their height relative to the Cache la Poudre River within the canyon. Moraines shown in solid black; pitted outwash plain and protalus rampart of Corral Creek cirque are cross ruled.

ously affected. This inherent inaccuracy in the data makes a correct interpretation of the lower terraces difficult. Further inaccuracies arise because the original upper surface of many terrace remnants is not too well defined, and because many of the higher terrace remnants are covered with talus. Many terraces have been so eroded that their remnants show no trace of the original upper surface. Here, only the present upper limit of river-borne gravel can be measured and the original elevation of the terrace level must be estimated. In the correlation of terrace remnants it must be kept in mind that the remnants of a single terrace do not necessarily stand at the same elevation above the present stream. In any one portion of the canyon the present stream does not necessarily follow the course of the depositing stream and may intersect the originally graded plain of deposition at various angles, and thus the stream grade may be at unequal distances below the terrace grade. Furthermore, the heavily laden and swiftly flowing streams which deposited the valley trains probably did not produce plains of absolutely smooth slope. By reason of their great activity, they filled the valley to a general level, but there were doubtless many slight irregularities. Also, with the first and probably hesitating retreat of the glaciers, there were developed slight irregularities on the surface of the valley trains by the erosive action of the melt-water streams (Louis L. Ray, 1935, pp. 303-307).

All terrace remnants are slightly higher above the present stream grade at their points of origin, that is, at the terminal moraines of the glacial stages to which they are related, than at the mouth of the canyon. Profiles of the terraces show that there is a general tendency for the terrace remnants to converge toward the mouth of the canyon. This convergence is continued away from the mountain front, so that in eastern Colorado the higher terraces have been lowered, and several of the lower terraces have completely disappeared.

The lower terraces of the Cache la Poudre Canyon cannot be related to definite periods of ice advance from the cirques, but by analogy with the strictly glacial terraces are held to represent a local refrigeration. Each terrace is considered the representative of a period of increased cold and intensified frost action in the cirque areas of the higher mountains. The overloaded streams built up their grade and laid down a gravel plain similar to, but smaller than, the valley trains of the earlier glacial substages. With each change to a warmer and drier climate, these gravel flats were dissected.

The original correlation of the terraces of the Cache la Poudre Canyon was worked out on a large chart on which the river profile was plotted with a horizontal scale of 2 inches to the mile, and the terrace remnants shown in pattern on a vertical scale of 2 inches to 100 feet. A similar chart on a much reduced scale, with the Cache la Poudre represented as horizontal (fig. 10), shows much of the data of the original profile.

There are in the canyon of the Cache la Poudre River six or more terraces, the oldest related to the oldest glaciation of the inner canyon, the youngest, which may represent several small terraces, so poorly defined that it is thought inadvisable to attempt a separation, but to classify these remnants as a single terrace of postglacial age. For descriptive purposes, the terraces are numbered from 6 to 1, from oldest and highest to youngest and lowest. They are discussed in this order.

TERRACE NO. 6

The highest and oldest terrace of the Cache la Poudre Canyon, No. 6, is poorly defined, and its presence is based on evidence which has resulted from the detailed study of the valley. The first line of evidence has been described on pages 31 to 33, where it has been pointed out that there is reason to believe there was a glacial advance in the inner canyon before the Home substage. This earliest glacier advanced only a few hundred feet farther down the canyon than the glacier of the Home substage, and almost all traces of it have been removed by subsequent erosion. However, this glacier must have built a valley train similar to, and slightly higher than, that of the later Home substage. During the long interstadial period between the recession of this ice and the advance of the ice of the Home substage, erosion removed almost all of the old valley train.

At three localities small gravel patches were found above the general level of the next lower, or No. 5, terrace. These form the second line of evidence for the No. 6 terrace. At Indian Meadows, near Dadd's Gulch, where the valley of the Cache la Poudre is unusually wide, a single gravel remnant lies on the south valley wall, 108 feet above the stream. Although this gravel may represent material brought down into the main valley by a tributary stream and deposited on the 90-foot terrace, No. 5, it may also represent either an unusually high remnant of the No. 5 terrace, or, what seems most reasonable, a remnant of a higher terrace, correlative with the pre-Home glaciation.

Another similar remnant of weathered gravel is perched on the north valley wall, about 4.5 miles upstream, at an elevation about 105 feet above the stream. At Hewlett Gulch another small body of gravel is located on the valley wall some 120 feet above the stream. These gravel remnants lead to the belief that the No. 6 terrace once existed at a grade somewhat more than 100 feet above the present river, and that this terrace is correlative with the pre-Home substage of glaciation. In the lower canyon and in the Colorado Piedmont this terrace has either been removed or obscured and merged with the slightly lower No. 5 terrace.

The third line of evidence pointing to a No. 6 terrace rests on the low, gravel-capped, bedrock spurs, which represent the floor of the Cache la Poudre Canyon belonging to the pre-Home substage of glaciation. Below the moraine at Home there are numerous patches of gravel resting on low bedrock benches, which average about 20 to 30 feet above the present stream grade. These bedrock benches are the remnants of the surface on which the debris from the retreating glacier was deposited to form the No. 6 terrace. During the long interstadial period between the pre-Home and Home glaciations the gravel of the No. 6 terrace was largely removed and the bedrock valley floor dissected. During the later glaciations the old channel has been buried and reexcavated several times. In the canyon, above the Home moraine, no remnants of these bedrock spurs have been found, for they have been removed by the ice of the Home substage or transformed into roche moutonnée surfaces. The fact that the moraine at Home appears to rest upon the present bedrock floor of the canyon indicates that the spurs are not to be associated with the Home substage, but with the previous substage of glaciation.

TERRACE NO. 5

Approximately 90 feet above the Cache la Poudre River there is a gravel terrace, the remnants of which are found only in the valley below the moraine at Home. This terrace is held to be correlative with the advance of the ice of the Home substage and is the oldest and highest terrace in the canyon which may be directly correlated with a terminal moraine. Adjacent to the Home moraine there are several terrace remnants which lie at elevations of 85 to 90 feet above the level of the stream (fig. 8, see terrace marked "5"). A terrace of small extent, near the moraine, with an elevation of 70 feet is considered a reduced portion of the No. 5.

Ten miles downstream, at Stevens Gulch, another large remnant is preserved at 78± feet above the river. Here the general level of the terrace is somewhat lower than 90 feet. This height, however, may not be a great deviation from the actual level of the old surface of the terrace along the axis of the river at this point. Six miles farther east, at Hewlett Gulch, an outcrop of gravel at 80 feet above the stream, indicates a continuation of this terrace.

At the mouth of the Cache la Poudre Canyon, near the Greeley Waterworks Dam, gravel occurs on the valley wall at an elevation of 72 feet above the stream. The upper surface of the deposit has been removed by erosion, but the height of the deposit is such that this is assuredly a remnant of either the No. 5 terrace or the possible older terrace, referred to previously as No. 6.

The gravel of the No. 5 terrace is not definitely distinguishable from that of the younger terraces. It is well rounded, decreasing in size from a maximum of 4 feet near the moraine to 10 to 12 inches at the mouth of the canyon. It is only slightly iron-stained, and not deeply weathered.

The small number of remnants may be considered a challenge to their correlation as a terrace. However, when one considers that no remnants have been found in the canyon above the Home moraine, whereas the remnants at the moraine are definite and obviously related to the moraine, there seems to be no good reason for doubting its validity as the representative of an ancient valley train, contemporaneous with the ice that formed the Home moraine. The upper surface of the No. 5 terrace is considered, therefore, to mark the maximum filling of the valley by debris at the time of the Wisconsin II glaciation.

TERRACE NO. 4

Below the No. 5 terrace a better-preserved series of terrace remnants lie at elevations of approximately 50 feet above the grade of the river. In the lower portion of the canyon, from the mouth to the North Fork, terrace remnants at elevations accordant with this height are lacking. However, near the mouth of the canyon, on the plains near Bellvue, there are terraces with elevations of 40 feet and more, which are considered the equivalent of the 50-foot terrace of the canyon. Above the North Fork the terrace remnants are more closely spaced and better preserved, with especially good examples at Eggers, Elkhorn Creek, Stove Prairie Landing, and Roaring Creek (fig. 10). At Home, below the moraine, there is a remnant of this terrace at approximately 54 feet above the river. Upstream from the Home moraine are a series of remnants lying at the 50-foot level (figs. 8 and 10). Two and a half miles above the Home moraine, at Roaring Creek, there are well-preserved flats at 50 and 52 feet above the river. The gravel of these remnants is comparatively fresh and unaltered.

In the Middle Fork of the Cache la Poudre River, below Chambers Lake, the No. 4 terrace can be carried directly to the moraines of the Corral Creek stage of glaciation, by a series of accordant terrace remnants, which impinge on the moraines. Here a gradual transition can be traced from the till of the moraines to the stratified and sorted material of the terrace. At this point (fig. 10) there is definite evidence that the No. 4 terrace is the product of the Corral Creek glacial substage, just as the No. 5 is held to be the product of the Home glacial substage.

Following the main Cache la Poudre River toward its headwaters at Milner Pass, the No. 4 terrace may be traced to the moraines of the Corral Creek stage at Chapin Creek. They may also be followed up the tributary Corral Creek to the moraine which marks the type locality of the Corral Creek glacial substage. No traces of gravel have been found above these moraines which can be interpreted as belonging to this terrace. The direct merging of the terrace gravel with the moraines, together with the lack of remnants above the moraines, and the relatively large number and close spacing of remnants at approximately 50 feet above the river throughout the Cache la Poudre Canyon, make this terrace the most valid and give certainty to its date as the valley train of the Wisconsin III glacial substage.

TERRACE NO. 3

In the upper canyon of the Cache la Poudre River, remnants of the No. 3 terrace[6] occur at an elevation about 40 feet above river grade and in the lower canyon at 30 feet. The decrease in height is marked, but the remnants are more numerous and more closely spaced than the remnants of the higher and older terraces. At Home, where the terrace passes through the moraine, remnants are broad and easily recognizable (fig. 8).

Especially well preserved are those terrace remnants which lie below the moraines of the Corral Creek substage of glaciation. Above these moraines are numerous low and modified remnants of glacial debris, probably retreatal phases in the recession of the ice from the Corral Creek moraines, perhaps remnants of this terrace. Adequate information is lacking which would definitely prove a direct relationship between the No. 3 terrace and the Long Draw moraines, for in no place can the terrace gravel be found in contact with the moraine, as in the case of terraces Nos. 4 and 5. However, one may assume

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[6] Referred to in preliminary report as 25-foot terrace and incorrectly correlated with 30-foot, or Kersey terrace (Bryan, 1937).

that a genetic relationship with the Long Draw moraines is not only reasonable, but most probable.

TERRACE NO. 2

The second terrace occurs about 18 to 25 feet above the grade of the river. It is represented by more remnants of greater lineal extent than any of the older terraces. Between the mouth of the canyon and the mouth of the North Fork, a long series of terrace remnants lie between 18 and 22 feet above the river. Below the Home moraine is another long expanse of this terrace at 24 feet. Below the Corral Creek moraine is a large and well-preserved terrace remnant with a surface several acres in extent, at an elevation approximately 25 feet above the stream. Similar remnants below the mouth of Long Draw Creek also have a height approximately 25 feet above the stream. There can be no mistaking the identification of this terrace from place to place, and its validity as a stage in the history of the valley cannot be doubted.

No correlation is observed between this terrace and any glacial stage in the Cache la Poudre Canyon. It is, however, tentatively thought to be correlative with a climatic change, probably the one which produced the protalus rampart of the Corral Creek cirque. Such a correlation seems justified on the basis of the terrace and the glacial sequence, but it must await further proof.

TERRACE NO. 1

Throughout the length of the Cache la Poudre Canyon and its major tributaries there are low gravel terraces, ranging from 6 to 12 feet above the level of the stream. It is possible that these may represent two or more distinct terrace levels, but no attempt has been made at subdivision, and they have been grouped into a single terrace, the average height of which appears to be about 8 feet above the stream. Because of the constant fluctuation of the river and the small height of these terrace remnants, the percentage error in the determination of their height is relatively great, as has been previously noted. A bouldery terrace, the general height of which is not more than 6 feet above the stream, may be the result of unusual floods of the river in the present cycle. Terrace remnants at heights near 12 feet probably represent an older terrace, not now subject to the stream floods. The term "No. 1 terrace" is thus a blanket name for low terraces of relatively recent origin. On the plains, immediately east of the mountain front, these low terraces are indistinguishable and have apparently merged with the flood plain of the river.

CORRELATION OF THE TERRACES OF THE CACHE LA POUDRE CANYON WITH THOSE OF THE COLORADO PIEDMONT

It has been shown that the terrace remnants of the Cache la Poudre Canyon fall into six grade lines, the elevations of which above river grade near their points of origin are: 100+, 90, 50, 35, 25, and 6-12 feet. There is doubt as to the validity of the 100(+)-foot terrace, and the lowest terrace level is probably a complex of recent terraces.

Except for the 90-foot terrace gravel, which is slightly iron-stained, no substantial difference can be detected in the amount of weathering of the gravel of the lower terraces, for all the terraces are sufficiently young so that the lapse of time has been too small to produce significant weathering.

The terraces of the Cache la Poudre Canyon are separated from the older broad valley levels of the Cache la Poudre River by a period of canyon-cutting. It has been shown that the alluvial terraces of the Cache la Poudre and South Platte Rivers in the Colorado Piedmont are also separated from the older and higher gravel-capped pediments by a period of stream incision. This period of incision by the streams was simultaneous in the mountains and the plains. Terraces of the inner canyon are found to be correlative with the alluvial terraces of the Cache la Poudre and South Platte Valleys.

Near the mountain front no terrace remnants have been found which can be definitely correlated with the No. 5 and older (?) terrace of the mountain canyon. However, a definite correlation is possible between the 50-foot terrace of the canyon, the No. 4, and a terrace level of about 40 feet elevation above the Cache la Poudre River on its south bank near the village of Bellvue. This terrace may be followed more or less continuously from the vicinity of Bellvue, down the Cache la Poudre River to the South Platte River, where it is seen to be correlative with the Kersey terrace (pp. 25, 26). The lower Kuner terrace is held to be the correlative of the 35-foot terrace of the mountain canyon.

If the No. 4 terrace of the mountain canyon is the correlative of the Kersey terrace, it seems only reasonable to believe that the No. 5 terrace, of Home age, is correlative with the Pleasant Valley terrace. If the No. 6 terrace actually exists, it is doubtful if remnants of it could be distinguished from the Pleasant Valley terrace away from the mountain front. Thus, it would seem that the following correlation may be made between the glacial substages of the mountain canyon, the terraces of the canyon, and the terraces of the Colorado Piedmont:

Glacial substage	Canyon terraces	Colorado Piedmont terraces
Pre-Home substage (Wisconsin I ?)	No. 6, or 100(+)-foot terrace	?
Home substage (Wisconsin II)	No. 5, or 90-foot terrace	Pleasant Valley
Corral Creek substage (Wisconsin III)	No. 4, or 50-foot terrace	Kersey
Long Draw substage (Wisconsin IV)	No. 3, or 35-foot terrace	Kuner
Protalus rampart (Wisconsin V)	No. 2, or 25-foot terrace	River flood plain
Post-glacial or Recent	No. 1, or 6- to 12-foot terrace	

FOLSOM SITES IN THE REGION AND THEIR BEARING ON THE GEOLOGIC AGE OF THE CULTURE

Two other sites in the Colorado Piedmont shed light on the antiquity of the Lindenmeier site. One of these has been described by Figgins (1933), the other has been mentioned before only briefly (Bryan, 1937).

Near Dent, a siding on the Union Pacific Railroad, sec. 13, T. 4 N., R. 67 W. (Greeley Quadrangle), large bones were discovered and reported to Father Conrad Bilgery, S. J., who, on excavation, found an artifact associated with the bones. Father Bilgery enlisted the aid of J. D. Figgins, at that time associated with the Denver Museum, who continued excavations at this site, uncovering a large number of mammoth skeletons, mostly those of young females, and another artifact, associated with the bones. These artifacts are spear points of the type usually referred to as "Folsomoid" and are similar to points which have been found recently at the Lindenmeier site. Thus, the Lindenmeier and Dent sites appear to have been contemporary.

The bones and artifacts at Dent occur on the inner edge of a gravel terrace adjacent to the valley wall and near the top of the gravel. In this vicinity, the top of the terrace lies approximately 27 feet above the flood plain of the South Platte River. The site is accordant in height and has gravel similar to other terraces in this part of the South Platte Valley which are considered remnants of the Kersey terrace.

Near the village of Kersey Mr. Forrest Powars and his son Wayne discovered Folsom points of the normal type, together with numerous snub-nosed scrapers, in a sandy field. The sand is windblown and rises as a dune in a gentle slope from the level of the Kersey terrace to a height of approximately 30 feet (pl. 3, fig. 1). The artifacts are found in the upper few feet of the sand over a large area, but there is no definite culture layer. However, as the artifacts are similar to those found at the Lindenmeier site, it appears that they are contemporaneous and that the Folsom hunters camped on a sand dune blown from the flood plain of the river when the river flowed at the level of the Kersey terrace.

The Dent and Kersey sites confirm the correlation between the culture layer of the little valley at Lindenmeier, and the Kersey terrace, and show that the Lindenmeier site was not the only camping place of the Folsom hunters in the Colorado Piedmont. All three localities were occupied after the upper surface of the terrace had been built and before its dissection. In other words, the sites were occupied either during the maximum advance of the Corral Creek glaciers, or soon after the beginning of their retreat. The finds at Dent are in the upper part of the terrace, just how near the top is not quite clear from Figgins' (1933) account. At Kersey the artifacts do not occur on the terrace but slightly above the level of the terrace in dune sand. Probably the river periodically washed the foot of the slope and periodically shifted, leaving a barren channel. From this channel the sand was blown onto the terrace. Since the artifacts are not buried more than 2 to 3 feet, we are led to believe that the camp must have been occupied at the end of the period of building of the sand dunes or at the time when the glaciers of the Corral Creek substage had already reached their maximum.

GLACIATION AS A CHRONOLOGY

The culture layer at the Lindenmeier site is of the same age as the Kersey terrace and cannot have continued to form for any great length of time after dissection of the terrace began. The Kersey terrace is the equivalent of the No. 4 terrace in the Cache la Poudre Canyon, which in turn is the outwash train of the Corral Creek glaciers. The Lindenmeier culture layer is thus of the same age as a glacial substage which is presumably Wisconsin III. In order to complete the history of the Lindenmeier site and to provide as close an approximation to a date as is possible in the present state of knowledge, it is necessary to relate the glacial substages in the Cache la Poudre Canyon with the North American and European glacial chronologies. Such a correlation involves grave possibilities of error in itself, and further, the standard chronologies are not without flaw. These difficulties are here set forth in considerable detail.

The discovery on all the continents and many oceanic islands of deposits laid down by glaciers that have since disappeared, long ago raised the problem of the contemporaneity of these ancient glaciers. With the further discovery that glaciation is multiple, that at nearly every place two or more, usually four, major glacial advances have occurred, and that these advances of the ice were separated from one another by intervening times of warm climate comparable to, or warmer than, the present, the problem was intensified.

All phases of this problem have been recently summarized by Daly (1934, pp. 30-41). He has ably marshaled all the evidence on several lines of analysis, which indicates contemporaneity. The viewpoint is not universally accepted (Lugn, 1935, p. 31) and is not at present subject to absolute proof. Nevertheless, the authors hold with Daly that the major advances of the great continental ice sheets were broadly contemporaneous. It does not necessarily follow that the climaxes of these ice advances were precisely synchronous. In fact, American geologists have brought forward proof of a progressive shift from east to west of the main ice center throughout the last, or Wisconsin, glacial stage. Yet, as methods of obtaining data are imperfect and subject to error, there is an unavoidable tendency to use any ascertained date as a world-wide reference point.

In the following discussion, the European chronology will be first considered, and thereafter the North American. The two will then, so far as possible, be brought together and a correlation made with the glacial stages of the Cache la Poudre Canyon.

THE EUROPEAN GLACIAL CHRONOLOGY

THE MAJOR ICE ADVANCES

Investigation of the European glacial deposits and related interglacial sedimentary beds has been very active in the past 20 years. At present so many new facts and conclusions are being published that no general statement on chronology can be made that will meet the views of all authorities.

The concept that the glacial period was marked by four great glacial advances, separated by periods of mild climates as warm as, or warmer than, the present, is generally accepted. This is the familiar subdivision current for many years, which is set forth in table 1. There is, however, a growing tendency to consider that each of the glacial stages was multiple and consisted of at least two ice advances, separated by a definite interstadial period of ameliorated climate. This viewpoint is supported by many new field facts relating to the terrace systems, loesses, and pollen-bearing beds of the periglacial region of South Germany. The recognition of weathering zones as evidences of the milder climates of interglacial, or interstadial periods, has been of great importance. Also, the study of pollen and other vegetative remains has led to the recognition of many beds deposited in climates as warm as, or warmer than, the present and therefore of interglacial or interstadial age. This recognition of a general climatic rhythm has forced the conclusion that many of the glacial stages heretofore recognized are complex rather than simple.

TABLE I.—*General Glacial Chronologies*

Climatic expression	Alpine area	North German Plain	Continental glaciers of the United States
4th glacial	Würm	Weichsel (incl. Warthe)	Wisconsin (incl. Iowan)
3rd interglacial		"Saw"	Sangamon
3rd glacial	Riss	Saale	Illinoisan
2nd interglacial		"Es"	Yarmouth
2nd glacial	Mindel	Elster	Kansan
1st interglacial		?	Aftonian
1st glacial	Günz	?	Nebraskan (Jerseyan)

This viewpoint is also influenced by the calculations of Milankovitch (1930), whose astronomical theory calls for double or triple cold stages at each glaciation. Direct correlation of glacial substages with the cold periods indicated by the astronomical theory is advocated most strongly by Soergel (1925), and this system has been admirably set forth, with disarming ingenuity and candor, by Zeuner (1935).

It is obvious that the older subdivisions are of less importance in this study. Our concern lies with the subdivisions of the last glacial stage and of the long interval of transition to the present. In this field there is at present no agreement among European students, except that the efforts of each of them makes more apparent than before the complexities of the advance and the final retreat of the last ice. If we accept, for example, the views of Gams (1938), it is necessary to recognize 10 periods of ice advance during the last, or Wisconsin, glaciation. Each ice advance is separated from the other by a time of slightly ameliorated climate, and many of these intervals are recognized by deposits containing pollen, diatoms, and other plant remains, or by fossil animals, either vertebrate or invertebrate.

There are many obvious difficulties in the geologic proof that a certain fossiliferous bed is older than the deposits of one ice advance and younger than the deposits of another. Yet each of these numerous, widely scattered deposits records an ameliorated climate, a definite retreatal or interstadial, or interglacial time. Each is an entity whose presence must be considered. Each represents a period of more genial climate which must be fitted into the pattern of successive climatic fluctuations. The continued study of these deposits and the discovery of new deposits forces reinterpretations of the strictly glacial deposits of the times of ice advance. Whether or not the 10 periods advocated by Gams survive the test of continued study of the problem, it seems evident that the events of the last ice age have been oversimplified. The effect of these newer viewpoints on the interpretation of work in geochronology will be further emphasized.

LATE-GLACIAL CHRONOLOGY

To the classic researches of Gerard De Geer we owe the invention of the method of geochronology by the counting of varves. These double layers of silt and clay silt are the unique deposits of glacier-fed lakes. The silt is deposited by the agitated waters of summer, the clay by the still waters of the ice-locked winter season. The measurement and correlation of such layers required much labor, skill, and judgment, and the scientific world has accorded generous credit to De Geer and his Swedish coworkers for their great accomplishment. The same tribute must be paid to Sauramo and other Finnish geologists for their extension of the chronology to the east side of the Baltic Sea, and also to Antevs, who has found in North America varve sequences exceeding those of Europe in the total number of years by more than three times.

The method, however, is limited by the existence of suitable clays. Not every retreating ice front acted as a dam to hold in a proglacial lake in whose bed varves were deposited. The same ice front that at times during the retreat laid down varves, at other times lay on the land, or was flanked by salt water, so that no varves were formed. Thus, however perfect the chronology attained by varve counts, it is applicable to a part of late glacial time only. The gaps in the chronology must be filled by estimations of one type or another. If this discussion appears to emphasize these gaps, the reason lies in the present-day tendency to a glib assumption that the dates of many Pleistocene events have been fixed. They have been merely estimated. Skill, judgment, and the result of much labor by many earnest geologists have all contributed to these estimates. Nevertheless, as shown herein, the results have no binding authority and are at best provisional.

As shown in figure 11, which is based on the map by Antevs (1928), the last ice in North Europe deposited three morainal systems, the Fläming, the Brandenburg, and the Pomeranian (Great Baltic). Each moraine represents an advance of the Scandinavian ice sheet after a period of retreat. Opinions differ as to the length of these periods of ameliorated climate and their value in classification, but all students admit that in each interval the ice retreated and the climatic conditions may have been somewhat similar to those of the present.

The question of the age of the Fläming moraine, which is also termed the Warthe glacial stage, is still the subject of much discussion (see the brief review by Gams, 1938). Some hold that this stage is the Third Glacial, or the equivalent of the Riss stage; others, an advance just before the last ice age; still others consider it the first forward shove of the last ice. Thus, the Warthe occupies in Germany much the place of the Iowan of North America. If, following the recent decision on the Iowan (Kay, 1931, and Leighton, 1931), the Warthe is considered as an early substage of the last ice age, it may be the first major advance. It would then fit into the scheme of Soergel (1937) and Zeuner (1935). This placing of the Iowan as the first Wisconsin advance in North America is not, however, universally accepted by American geologists (Leverett, 1939, and Lugn, 1935).

The Brandenburg moraine, or Weichsel substage, is generally believed to represent the climax of the last ice age, except by De Geer, who has always believed that the Pomeranian should hold that honor. Most students now consider that the last glaciation had three maxima, the Warthe, Weichsel, and Pomeranian substages, the designations of which they frequently abbreviate to W1, W2, and W3.

The recessional stages during the retreat from the Pomeranian moraine are shown in figure 11, after Antevs (1928), whose names

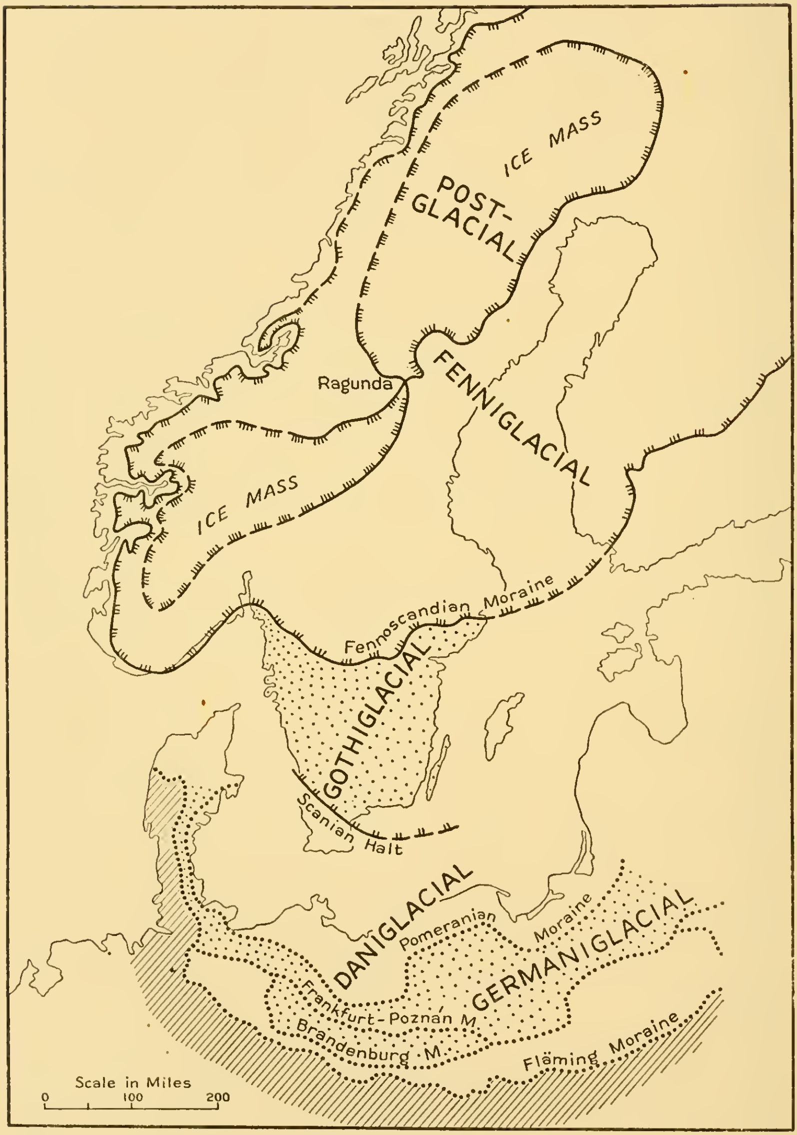

FIG. 11.—Map showing moraines of the last glaciation and retreatal substages on Europe. Modified from Antevs.

for the intervals of retreat are followed. The advances and retreats involved in these time intervals, as interpreted from Antevs' text (1928), are shown diagrammatically in figure 12.

No diagram is attempted for the retreat from the Fläming moraine, although it may have been, and according to Soergel (1937) was, quite complete between the Fläming (Warthe) advance and the Brandenburg (Weichsel) advance. Similarly, the retreat from the Brandenburg (Weichsel) and readvance to the Frankfurt-Poznán moraine is shown by but two simple lines. It is probable that this is an oversimplification and our ignorance of the facts prevents representation of the complications that probably exist. From the Frankfurt-Poznán moraine to the Pomeranian moraine, there were numerous advances and retreats. These movements were complicated, and the data are obscure, but the problems involved are being vigorously attacked by Richter (1937) and others.

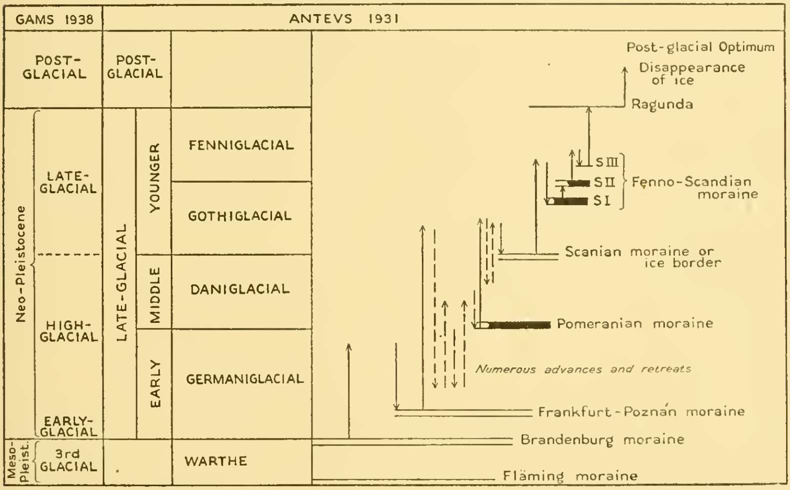

FIG. 12.—Subdivisions of the late glacial period, with diagrammatic representation of the several advances and retreats of the ice. Moraines shown in black are included in the next youngest substage.

The time of final dissipation of the ice began with the retreat from the Pomeranian moraine. To some geologists this marks the end of the glacial period, a viewpoint set forth by Gams (1938), whose classification is shown on the left in figure 12. From the standpoint of geochronology, this interval of time is the most important, as parts of it have been measured by the methods of varve-counting.

Figures 11 and 12 show that this interval is divided into the Daniglacial, Gothiglacial, Fenniglacial, and Post-glacial substages, which are separated from each other by halts in the ice retreat or by other ascertainable events. The relation of the intervals to the moraines varies. Thus, the time necessary to form the Pomeranian moraine is held to be part of the Germaniglacial, and the time interval of the Scanian halt is assigned to the Gothiglacial. The first two halts of the Fennoscandian (Salpausselkä) moraine are also part of the Gothiglacial. The third halt falls in the Fenniglacial. This third period of recession is terminated by the bipartition of the ice mass at Ragunda.

The length of these time intervals is only partly known. The Postglacial time interval is estimated to be 8,700 years on the basis of varve counts and estimations by Lidén (1913), which are only in part published. The extensive work of De Geer (1926 and earlier papers) on varves yields a complete sequence of 1,703 years for the Fenniglacial, which is partly confirmed by the work of Sauramo (1928). For the Gothiglacial there is no complete varve count. Sauramo has shown that the Salpausselkä double moraine required 670 years, and he has counted 1,250 or more annual varves in Finland, south of this moraine. De Geer (1926) has long sequences of varves in south Sweden, but the time interval of the Gothiglacial is nevertheless an estimate. Some authors give 2,500 and some 3,000 years for this interval.

De Geer (1926) identifies one of the moraines of southwestern Sweden, apparently somewhat beyond the position of the Scanian halt, as the equivalent of the Pomeranian. He gives, without full explanation, a date of 18,000 years ago for this supposed Scanian-Pomeranian moraine. This figure has been accepted without much question by many coworkers. Antevs (1928, pp. 157-160) discusses the problems involved at considerable length, and following several Danish geologists and his own field work, considers that the Pomeranian is represented by the East Jylland moraine of Denmark. Thus, he makes clear the existence of the time interval that he calls the Daniglacial. He estimates this time interval to be 10,000 to 15,000 years long, but there is no continuous varve count to support this estimate. The moraines in southern Scania, which De Geer (1926, pl. 3) correlated with the Great Baltic, or Pomeranian, are, as Antevs points out, much younger. De Geer (1926) gives an estimate of 9,500 years as the time interval between these moraines and the Ragunda bipartition of the Fennoscandian ice mass.

The length of the Gothiglacial, that is the interval from the halt in Scania (southern Sweden) to the end of the halt at the Fennoscandian moraine, is not distinctly set forth by De Geer, but Antevs (1928, p. 160) estimates it to be 2,000 years, plus the 670 years required for the building of the moraine which was determined by Sauramo in Finland. Sauramo (1928) states that he counted 2,400 varves in southern Finland, which together with the time interval of 670 years for the moraine would give 3,000+ years for the length of the Gothiglacial—a figure which is accepted by many authors.

The length of the Fenniglacial interval is given by De Geer (1926) as 1,703 years. This interval includes the period of retreat of the ice from the moraine to its bipartition at Ragunda. Sauramo (1928) has found this interval to be almost the same length as that given by De Geer. The relations, shown in his figures 18 and 19, reconcile the two chronologies. The data of these figures are here reproduced in table 2. It will be noted that there are discrepancies, but that for the whole period counted, they balance out. However, for the Fenniglacial, De Geer gives 1,703 years, and Sauramo 1,100 years of his chronology, plus 500 years of the Swedish, or only 1,600 years.

TABLE 2.—*Correlation of Swedish and Finnish Geochronologies, According to Sauramo*

Years of Swedish chronology	Years of Finnish chronology	Intervals between correlated positions in ice retreat in Sweden	Intervals between correlated positions in ice retreat in Finland
(at Ragunda) 0	Not determined		
− 500	1,100	600	580
−1,100	520	400	420
−1,500	100	100	100
−1,600	0	400	500
−2,000	− 500	1,000	900
−3,000	−1,400		
	Totals	2,500	2,500

The complex glacial chronologies of Europe have been reviewed and an attempt made to clarify the European picture of the recession of the ice of the last glaciation. It has been shown also that the length of the Late-glacial period of Europe is largely estimated and that the varve counts give sure information for only a small part of the total time involved.

GEOCHRONOLOGY IN NORTH AMERICA

METHODS AND RESULTS

Estimates of the time back to the last ice age were made long ago, using many geologic methods, of which the most important was the rate of recession of Niagara Falls (for history, see Taylor, 1913). This method is supplemented by Antevs (1922, 1928, and 1931), who has combined with it the system of geochronology introduced by De Geer. There are, however, many difficulties in providing a complete chronology, primarily because varved clays are lacking in suitable positions, and secondarily because the details of geologic history are not wholly known, as much of the work in glacial geology has been in the nature of reconnaissance. Compared to the intensive study of the Pleistocene in the Baltic region, work in North America has lagged in the past 30 years. The material which follows is largely a critical review of the long-continued work of Antevs, who has summed up the difficulties in the introductory paragraphs of his paper of 1936.

As shown in figure 13, Antevs measured 5,500 varves from New Haven to Hartford, 4,100 from Hartford to St. Johnsbury, and 2,000 from Montreal River to a point north of Cochrane, Ontario. These intervals in the retreat are the only ones for which there is a geochronological dating, and the other intervals must be estimated in one way or another.

The interval from Stony Lake to Mattawa is estimated on the rate of retreat of Niagara Falls. Obviously this estimate is based on the present rate of retreat which has been established by historical means and by certain assumptions as to variations of the rate of recession in the past by reason of variations in the quantity of water pouring over the falls. However much care may have been put in such an estimate, it has sources of error quite different in amount and in kind from the errors of varve measurement.

In table 3, the several retreatal substages, their distances from each other, and various measurements and estimates of the time intervals are shown. In columns 2 and 5 are shown Antevs' estimates of 1928 and 1931, the differences in which will be discussed. Considering column 2 first, the elapsed time from the present to the moraine at St. Johnsbury, Vt., is $15{,}000+x+y+z$, in which x and y are unmeasured intervals of the retreat, and z is the time required for the melting of the ice from a point near Cochrane to the present. The period of ice retreat from Montreal River to a point beyond Cochrane is 2,000 years, represented by varves counted by Antevs. The period of retreat from Stony Lake to Mattawa is based on the

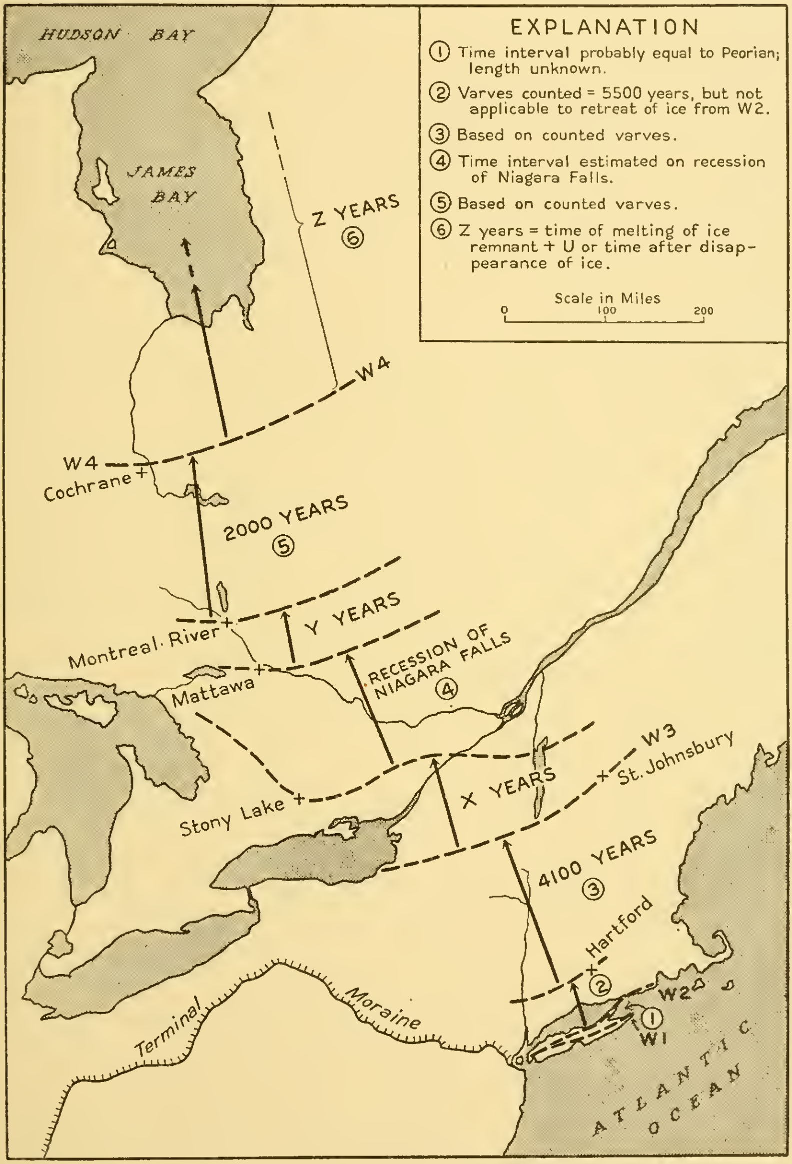

FIG. 13.—Map showing retreat of the continental glacier in eastern North America. Modified from Antevs.

TABLE 3.—*Recession of the Last Ice According to Various Estimates*

	1 Distance (km.)	2 Time (years) Antevs, 1928	3 Rate of recession (yrs./km.)	4 First recalculation (Bryan)	5 Time (years) Antevs, 1931	6 Rate of recession (yrs./km.)	7 Second recalculation (Bryan)
Present time to time of disappearance of ice in James Bay plus retreat from Cochrane	1,500 – 1,800	z	(0.7)	1,000 + u	2,000 + and $u = 7,000$	(1.25)	1,875 + u
Cochrane from Montreal River	1,200	2,000	1.4	2,000	6,000	1.25	200? 725 1,500
Montreal River from Mattawa	850	y	(1.4)	1,200		1.10	1,000
Mattawa from Stony Lake	750	13,000	17.3	13,000	10,000 ±		
Stony Lake from St. Johnsbury	525	x	(17.3)	9,000			10,000
St. Johnsbury from Hartford	298	4,100	13.0	4,100	4,100 11,500	13.00	4,100
Hartford from Harbor Hill	95	5,500	(13.0)	1,235 + 800 = 2,035	5,500	(13.00)	2,000
Harbor Hill from Ronkonkoma	0-20	2,000			2,000		
Elapsed time to St. Johnsbury = Pomeranian		15,000 + x + y = 16,400 – 17,400 + z		26,200 + u	25,000 ±		15,300 + $u = 22,300$
to Harbor Hill = Brandenburg				32,300 + u			21,400 + $u = 28,400$
to Ronkonkoma = Iowan = Warthe		28,000 + z = 37,000		?	36,500		?

recession of Niagara Falls. The missing intervals *x* and *y* are estimated at 1,400 to 2,400 years, but no information is given as to how the estimate is made, except general statements that ice retreat was rapid in these areas.

The interval St. Johnsbury to Hartford was determined by Antevs (1922) by numerous measurements of varves in the gray clays of this area. Here there is a long sequence of 4,100 varves, representing the same number of years. The interval of retreat from Hartford to New Haven is represented by 5,500 varves, measured by Antevs in the red clays of this area, largely before 1922. This sequence has been correlated with a similar sequence in the Hudson Valley. However, it has never been demonstrated that these varves represent the retreat of the last ice. In the New Haven area the top of the clay beds is always eroded and the base largely unknown. At Berlin, Conn., according to observations by Bryan, the clay is overlain by a solifluction layer, or warp, and the upper part of the clay is so weathered as to destroy its original lamination. It is also cut by joints and cracks containing colloidal clay. This zone has the character of the lower part of the B-horizon of a weathering profile. It thus appears that the clay has been exposed and has suffered from weathering in a climate at least as genial as the present. At a later period the upper part of the soil zone was carried away and a warp developed in a climate of Arctic severity. Leached clay is reported by Antevs at station 129 (Middletown, Conn.) and station 134 (Berlin, Conn.), and various kinds of disturbed or changed clay at nearly every locality from New Haven to Berlin (Antevs, 1928, pp. 184-188). On this evidence, it appears that the red clays of the Berlin area are older than the last interglacial, or interstadial, and may belong to an earlier ice advance. Under such an interpretation, varve measurements of these clays cannot be used in this sequence.

There is a further difficulty to be faced. Antevs follows all earlier authorities in assuming that the two moraines on Long Island were the result of a single period of ice advance. If this were true, they represent a forward movement to the southerly moraine, or Ronkonkoma, a slight retreat and a forward movement to the Harbor Hill moraine. Such a history might require only a short time. For the time interval, Antevs allows 2,000 years. Recent work in southern New England (Bryan, 1936) indicates that the Watch Hill moraine of Rhode Island, which is the equivalent of the Harbor Hill moraine of Long Island, differs markedly from the moraine of Cape Cod and Marthas Vineyard in its preservation of glacial topography and in its state of weathering. The moraines of Cape Cod and Marthas

Vineyard lack true morainic topography and are formed of sand and till stained by limonite. The relatively fresh aspect of the topography and the till of the Watch Hill moraine are proof of its relative youth and indicate that it is separated from the earlier moraines by a long interval of time. Between the fresh Harbor Hill moraine and the older Ronkonkoma this difference is implied in the descriptions by Fuller (1914). His statements make it impossible to believe that these two moraines record merely a pulsation at the maximum advance of the ice. They must be separated from each other by an interstadial, if not an interglacial period of weathering. Insofar as this point of view has merit, it is a mistake to attempt to carry a reckoning of the chronology, based on varve counts, to the southerly, or Ronkonkoma moraine.

The Ronkonkoma moraine of Long Island and the moraines of the Cape Cod region are largely formed of folded and deformed members of the Manhasset beds, which according to both Fuller, and Woodworth and Wigglesworth (1934) are next younger than the Gardners clay and are the equivalents of the Illinoisan, or Third Glacial. Recently MacClintock and Richards (1936) have correlated the Gardners clay with the Cape May formation of New Jersey, which is of Sangamon or third interglacial age. Thus, the Manhasset would fall in the earlier part of the Fourth Glacial, or Wisconsin. This correlation is accepted by Flint (1935) and applied specifically to Marthas Vineyard and Cape Cod. With such a correlation the ridges, known as moraines, are obviously due to shove by the same ice sheet which deposited the materials. How great an interval there may have been between the glacial deposition of the Manhasset and its deformation by ice shove there is at present no means of estimating.

The moraines of southeastern Massachusetts and their correlative, the Ronkonkoma of Long Island, under this interpretation probably represent the earliest Wisconsin substage, or Iowan. The interval of time between their formation and that of the Harbor Hill-Watch Hill moraine is long and corresponds to the Peorian. After withdrawal of the ice there was a considerable period of weathering. This interstadial is possibly not completely represented in the famous Farm Creek section of Illinois (Leighton, 1926). However, observations by Leighton and Bryan in 1938 indicate that additional information on the climate of the interstadial may be obtained by further study of this locality.

As the warmer climate of the Peorian interstadial deteriorated, a forward movement of the ice toward the position of the Harbor

Hill moraine occurred. How long a time interval is required for forward movement over the area from which the Ronkonkoma (Iowan) ice had retreated is unknown. It may easily be that the red varved clays of the New Haven-Berlin area were laid down during the recession of the Ronkonkoma ice. If so, they were weathered in the interstadial and overridden by the Harbor Hill ice. The confused varves at the top and the evidences of disturbance described by Antevs (1922 and 1928) may be due to this overriding and also to erosion and solifluction during the retreat from the Harbor Hill moraine.

In the calculation of elapsed time, Antevs, in his book of 1928, is conservative. For the St. Johnsbury substage he estimates the intervals x and y (fig. 13) as 1,400 to 2,400 years, without stating the evidence on which these figures are based. Using this estimate he has obtained for the age of the St. Johnsbury substage a total of 16,400 to 17,400 years, plus z, or the time of final melting north of Cochrane, Ontario. His figure for the moraines of Long Island is $26{,}600+x+y$, or 28,000 to 29,000 years.

However, it is possible to make a re-estimate, using a somewhat arbitrary system. If the assumption is made that the rate of retreat in the intervals unrepresented by measurements of varves, or by other chronological data, is similar to that of adjacent intervals that are so represented, a total as shown in column 4, table 3, can be computed. Here the Ronkonkoma to Harbor Hill interval is omitted as being impossible to estimate. Harbor Hill to Hartford is estimated by applying the rate of recession of the next northerly interval to the distance which is 95 km., or 1,235 years, and arbitrarily adding 800 years as the estimated time that the ice lingered on the moraine. Thus, the interval becomes 2,000 years. The intervals x and y are estimated by applying the rates of the next intervals, yielding 9,000 and 1,200 years respectively. The interval z, or 1,500 miles, is arbitrarily given a rate of retreat half that of the previous interval, and thus yields 1,000+ years. However, there remains a time interval u, from the last disappearance of the ice in Labrador to the present. The totals for St. Johnsbury and for Harbor Hill by this method are $26{,}200+u$ and $32{,}300+u$, and thus considerably higher than Antevs' totals.

In 1931 Antevs again published on this subject, recording new observations in Canada. His statements in this paper are in many instances cryptic, and it may be that he is here misinterpreted. He redivides the retreat and uses arbitrarily stated figures. Thus, the interval z, the Post-glacial, is given as 9,000 years. This figure is explained in part on his pages 18 and 19, where detailed studies of the advance and retreat of the ice near Cochrane are discussed. The retreat from Montreal River extended 50 miles north of Cochrane, and is measured by varves totaling 2,025 years. The ice then readvanced to the Cochrane moraine in a time interval estimated as 200 years. These years are excluded from the Post-glacial, which consists of the retreat from Cochrane and the final disappearance of the ice, including the remaining time to the present. The Post-glacial is preceded by the slight advance of the ice to Cochrane which is presumably correlatable with a climatic shift toward the cold, such as was coincident with the last Yoldia Sea in Europe. The 9,000 years of Antevs' estimate is thus obviously the 8,700+ of the European reckoning of the age of this last Yoldia Sea.

The retreat from Mattawa to Cochrane is estimated (column 5, table 3) at 6,000 years. This figure includes the 2,025 plus 200 years of the Montreal River-Cochrane interval previously explained, plus 3,775 years arbitrarily assigned to the interval *y*.

The interval from St. Johnsbury to Mattawa is reduced to 10,000± years as a result of recent work on Niagara Gorge by Johnston (1928) and further study by Antevs. However, a critical reading of the discussion (Antevs, 1931, pp. 20-24) does not reveal the number of years actually assigned to the interval Stony Lake-Mattawa, the time of Lake Algonquin, or any comment on the interval *x* (St. Johnsbury-Stony Lake). It appears, therefore, that this new estimate is largely arbitrary, although it may be very nearly correct and is certainly entitled to much respect by reason of Antevs' long consideration of the problem of the age of Lake Algonquin.

The estimate of the time involved in the interval St. Johnsbury to Ronkonkoma is unrevised and not discussed, so that its existence must be inferred from the statements that the total time to the "New York Moraine," or Ronkonkoma, is 36,500 years.

The foregoing estimate has been recalculated in column 7, in the same fashion as the previous estimate is revised in column 4 of table 3. Accepting Antevs' new estimate of 1,500 years for the Montreal River-Cochrane interval, and 725 years for the retreat beyond Cochrane, with 200 years as necessary for the readvance to Cochrane, the Post-glacial retreat from Cochrane at the rate for the previous interval will be 1,875 years. There is also the unknown length of time from the final disappearance of the ice to the present, or *u*. Antevs (1931, pp. 18-19) also gives a new estimate for the Mattawa-Montreal River interval as 1,000 years. Such a time interval could be arrived at by assuming any reasonable rate, and differs by only 200 years from the estimate of column 4, table 3. It may then be accepted. Also, Antevs' (1931) new estimate of 10,000 years for the two intervals St. Johnsbury-Stony Lake and Stony Lake-Mattawa, although not completely supported, is doubtless not far from correct. Furthermore, using the varves as a basis, the Hartford-St. Johnsbury interval is 4,100 years. If then the same approach is used for the retreat from the Harbor Hill moraine, the interval is 2,000 years. By this substitution the time back to the St. Johnsbury is 15,300 + u, and to the Harbor Hill 21,400 + u. If the interval u is 7,000 years, as assumed by Antevs, these intervals become 22,300 and 28,400 years.

VALIDITY OF RESULTS

The foregoing tedious survey reveals a closet of dry bones in which there survives an emaciated creature having promise for the future, but of little value in the battle of the moment. Estimates have been piled on estimates and added to known time intervals, none too securely tied to the geologic framework. If, however, the data of table 3 are examined, the elapsed time to the St. Johnsbury moraine has been estimated by somewhat different methods to give the following results: $16{,}400 + z = 25{,}400$; $26{,}200 + u = 33{,}200$; 25,000 ± ; and 22,300 years. All these figures are of the same order of magnitude. The Harbor Hill, or what many consider essentially the equivalent, the Ronkonkoma moraine, is estimated with the following results: $28{,}000 + z = 37{,}000$; 32,300; 36,500; and 28,400 years. These estimates are also of the same magnitude. It is true, of course, that all these figures are influenced by the same basic measurements and estimates and particularly by the assumption of 9,000 years for the length of Post-glacial time. This figure is obviously based on the rather well-supported European figure, but as it has a magnitude of more than a third, or, at least, a fourth of any one of the totals, it affects them all to an almost dominating extent.

Antevs' estimates of 1931 are obviously improved over those of 1928, largely because of the adjustment for the life of Lake Algonquin, based on the history of Niagara Falls. His estimate of 25,000 ± years for the St. Johnsbury moraine may eventually be reduced, as indicated in column 7, table 3. The reduction, however, will probably be moderate. Similarly, his estimate of the date, and the time elapsed since the New York (Ronkonkoma) moraine, which he assumed to be the climax of the Wisconsin, is more likely to apply to the Harbor Hill moraine. It may be that the reduction of this interval to 28,400 years may prove to be too conservative. To the extent that the calculations of Milankovitch are accepted, any of these estimates of the age of the Harbor Hill moraine are much too low.

If now the dates of the North American chronology are compared with those of Europe, the concordance is not as close as could be desired. It is obvious that none of the existing estimates, however ingenious, or based on however much laborious work, is as yet so close to the true figure that it must be accepted without qualification. In truth, we have not yet arrived at such a stage in research on the Pleistocene. The figures given are merely first approximations which with some confidence may be considered of the correct order of magnitude. They may be received with respect, but the inherent errors are so great that the figures in years must be considered merely as indicators of relative age, rather than true figures. They are pegs on which to hang ideas.

If we consider the errors of the several dates, the amount of error varies. Thus, the length of the Post-glacial rests on the incompletely published work of Lidén, but it has been checked as to relative lengths of the intervals by archeological means as far back as the Ancylus and Litorina stages. Also, many pollen analytical studies have been made which reach back into the Gothiglacial substage. These studies confirm the order and general relative length of the substages of the younger Late-glacial and Post-glacial substages. The error in estimation of the length of the Post-glacial substage is probably small and its true length is neither longer nor shorter by more than 10 percent.

As the Fenniglacial period has been measured both in Sweden and in Finland by varve counts, which agree within 100 years, the error in the length of this period is so small that the total error in the elapsed time to the present is no greater than that involved in using the much longer Post-glacial interval.

However, the length of the Gothiglacial is not so well-determined and an estimate of 2,500 years for this time interval is subject to error of as much as 500 years, and in fact, 3,000 years is accepted by many workers. Furthermore, the length of the Daniglacial is uncontrolled by varve counts and is a pure estimate. The date given in Europe for the Pomeranian moraine depends largely on the length of time assigned to the Daniglacial. It is likely that Antevs' date for the St. Johnsbury is more nearly correct. Assuming, therefore, 25,000 years as the elapsed time since the Pomeranian, this estimate may be too large by 25 percent, or too small by as much as 30 percent.

Estimates of the elapsed time to the Brandenburg moraine have no actual basis. In America Antevs' estimate for the "New York" moraine involves a long varve count and therefore, has a value for the minimum. If 35,000 years is adopted, the figure is 10,000 years longer than the elapsed time to the Pomeranian moraine. The date is, therefore, a minimum; the time figure may be much larger and as great as 60,000 years.

Estimates of the elapsed time to the Iowan is almost purely speculative, but there is every geologic reason for believing that Kay's estimate (1931) of 55,000 years is a minimum, and that the true figure may be twice as large.

These doubts and questions may be put in summary form by listing the time intervals with estimates of the corresponding errors, as in table 4.

TABLE 4.—*Elapsed Time to Important Ice Advances of the Wisconsin, with Estimates of the Percentage Error*

Short designation	American substages	European substages	Years from 1900	Date B. C.	Range in error of estimates:	
					(too small)	(too large)
	Post-glacial (beginning of, at Cochrane)	Post-glacial (beginning of, at Ragunda)	8,700	6,800	*percent* 10	*percent* 10
W4	?	Fennoscandian moraine	10,400	8,500	10	10
		Scanian halt	13,400	11,500	15	10
W3	Mankato	Pomeranian	25,000	23,100	30	25
W2	Tazewell-Cary	Brandenburg	35,000	35,000	75	25
W1	Iowan	Warthe	65,000	65,000	100	10

GLACIAL SUBSTAGES IN COLORADO CORRELATED

In table 5 a correlation is made between the substages of the last glaciation in the Rocky Mountains and those of the continental glaciers of North America and Europe. There is in this correlation a large uncertainty. The only available method of making such a correlation is by a general argument, as it is as yet impossible to use either the vertebrate fossils or the cultural remains as guide fossils.

The line of argument is as follows: 1, the pre-Home substage is almost completely obliterated by erosion, a condition, in view of the position of the ice mass in a narrow mountain canyon, more or less comparable to the degree of weathering of the Iowan; 2, the Home moraine retains its topographic form, and the small lateral rock gorge is fresh and shows little weathering, a condition comparable to the degree of preservation of the Tazewell-Cary moraines, formerly considered early Wisconsin; 3, the Corral Creek moraine is fresh in form and lacks weathering, much like the Late Mankato moraines of Minnesota. The sequence appears to fit fairly well, although there is no provision for the decided oscillation of the Early Mankato, unless moraines of that age form part of the morainic complex of the Corral Creek substage. 4, The Long Draw substage, by reason of its modest moraines and other evidences of its existence, appears to be recessional, and its correlation with the Cochrane and Fennoscandian moraines seems appropriate. Such an arrangement leaves the Scanian halt without a counterpart.

TABLE 5.—*Correlation and Dating of Rocky Mountain Glacial Stages*

Short designation	North European Continental substages	North American Continental substages	Cache la Poudre Valley, Colorado	Antevs' generalized dating from 1900	Milankovitch's generalized dating from 1800
	Post-glacial		Protalus rampart		
W4	Fennoscandian	Cochrane (?)	Long Draw	10,000±	
	Scanian	?	?		
W3	Pomeranian	Late Mankato (St. Johnsbury)	Corral Creek	25,000±	19,500 to 29,500
W2	Weichsel (Brandenburg)	Tazewell-Cary (Harbor Hill)	Home	35,000±	67,000 to 78,000
W1	Warthe (Fläming moraine)	Iowan (Ronkonkoma)	Pre-Home		111,000 to 122,000

This correlation can only be defended by a negative and inconclusive argument that the Home can hardly be other than the climax of the Wisconsin, as understood in North America. If such an assignment is made, the strong readvance of the ice of the Mankato substage, separated from the Tazewell-Cary by an interstadial climate, as shown by the Two Creeks Forest bed (Wilson, 1932), seems to correspond to the similar advance of the Corral Creek moraine. The interval between the Home and Corral Creek substages seems to be too long to fit into any other place in the glacial sequence. The Corral Creek moraine may represent all of the Mankato, but the highest level of its outwash plain is doubtless the equivalent of the Late Mankato. For the present considerations, the glacial substage is traced to the plains by means of the terraces of glacial outwash, and therefore the late stage of the moraine is the time represented by the terrace.

If this correlation is accepted, the Corral Creek moraine, the Kersey terrace, and the old floor of the Lindenmeier Valley were completed approximately 25,000 years ago. The Long Draw moraine, the Kuner terrace, and the dissection of the Lindenmeier Valley occurred approximately 10,000 years ago. The reader will have no illusions about these dates, and will realize that even if the correlations here made between the valley glaciers of Colorado and the continental ice sheets are entirely correct, the dates themselves are subject to large errors, as previously set forth.

FOLSOM CULTURE OF LATE-GLACIAL AGE

SUMMARY OF EVIDENCE

The difficulties of geochronological work have been reviewed, and the uncertainties set forth. It is now necessary to make application to the antiquity of the Folsom culture.

In brief, the culture layer of the Lindenmeier Valley shows that the Folsom hunters camped on the edge of a springy meadow, when the adjacent minor streams flowed at the level of the 20-foot terrace of these streams. This terrace, traced 30 miles down these minor streams, is correlative with the Kersey terrace of the main rivers of eastern Colorado. Here also, sites at Kersey and at Dent indicate that Folsom hunters camped and hunted on the borders of the river flood plains during this stage. Traced up the Cache la Poudre River, the Kersey terrace is the equivalent of the No. 4 terrace in the mountain canyon. In the narrow rock-walled gorges, the remnants of this terrace are small and infrequent. With reasonable assurance this terrace is interpreted as the valley train of glaciers that extended from the now empty cirques of the high mountains to Chambers Lake and to similar elevations in other canyons. This is the Corral Creek substage of glaciation.

The correlation of this hitherto unrecognized stage of glaciation in the Rocky Mountains with continental glaciation in central and eastern United States involves much uncertainty. It is however thought to be the equivalent of the Late Mankato-St. Johnsbury substage, which in turn is considered the equivalent of the Pomeranian substage in northern Europe. Such a correlation has provided a date in years. Antevs has estimated the St. Johnsbury as separated from our time by 25,000 years, and has argued that the Pomeranian has about the same antiquity. The validity of this date has been considered in some detail. It is without much question of the right order of magnitude and can be no more than 25 percent too large, or on the other hand more than 30 percent too small.

As the camps and relics of Folsom man are found on the completed surface of the terraces, or in the upper gravel, the culture should be younger rather than older than the climax of this glacial substage. No evidences of Folsom implements have as yet been discovered on the Kuner, the next younger terrace. This terrace and its equivalent, the Long Draw glacial substage are apparently younger than the culture. On a comparable line of reasoning the Long Draw is considered to be the equivalent of the Cochrane and Fennoscandian substages, to which an age of 10,000 years may be assigned.

Thus, the Folsom culture of this area and the Lindenmeier site in particular, have an antiquity which is between 10,000 and 25,000 years, if the errors inherent in the methods used are not too great. These methods have been very thoroughly reviewed. It is obvious that much more confidence can be placed on the statement that the culture is older than 10,000 years, than on the statement that it is as old as 25,000 years. However, it is believed by the writers that the age must be much nearer 25,000 years than 10,000.

EVIDENCE FROM OTHER FOLSOM SITES

Other sites at which Folsom or Folsom-like points have been found in association with extinct animals afford some data on this antiquity. The most important is the locality in the Portales Valley of New Mexico, known as the Clovis site (Howard, 1935). Here, in "bluish" sand, silt, and clay, have been found artifacts and the bones of mammoth and bison. Weathering from these materials, Folsom and Yuma points are found. Diatoms, invertebrate shells, and charcoal from a hearth have been discovered and identified. All point to a climate cooler than the present. In an attempt to fix the date of these deposits, Antevs (1935) has made a number of assumptions: 1, that the "bluish" silts represent lake beds; 2, that these lakes are contemporary with the high stand of Lake Estancia, an ancient lake 160 miles to the west; 3, that Lake Estancia reached its highest stage of water level after the maximum of the Wisconsin glaciation. It should be noted, however, that there is no confirmatory evidence that the moist conditions in the Portales Valley coincided with the high stand of Lake Estancia. This is a plausible but unproved assumption. If it is true, the question then arises whether Antevs' assumption that the Pluvial period, coinciding with the high stand of Lake

Estancia, came after the Wisconsin maximum, or coincided with it, or with one of the later substages of glaciation. As Antevs (1935, p. 310) gives 25,000 years for the culmination of the Wisconsin glaciation, he obviously refers to the Late Mankato-Pomeranian substage, whereas others would place the culmination at the Tazewell-Cary-New York-Brandenburg substage. If the glacial history of the Southern Rocky Mountains herein outlined is followed, and the dates accepted, there were at least four Wisconsin glacial substages: the earliest, or pre-Home, of unknown date, the others 35,000+, 25,000±, and 10,000± years ago. The present writers place the climax of the Wisconsin at the time of the Home-Tazewell-Cary-New York-Brandenburg substage, some 35,000+ years ago.

Regardless of the merits of Antevs' meteorological argument that the pluvial periods in the country south of the Rocky Mountains are later than the glacial advances and not coincident with them, it is obvious that there is no direct proof that the lakes are associated with one of these glacial substages rather than with another. The obvious method is to consider the cultural and faunal materials. On such a basis, the Clovis beds may easily be of the same age as the culture layer of the Lindenmeier Valley. The presence of Yuma points, so far not found at the Lindenmeier site, gives a measure of uncertainty to such a correlation.

Folsom points associated with mammoth remains have also been found at Angus, Nebr. (Figgins, 1931), at Miami, Tex. (Sellards, 1938), and 30 miles from Abilene, Tex. (Bryan and C. N. Ray, 1938). None of these localities affords any present help in the problem of a definitive association of the Folsom culture with a datable geologic horizon. At Lake Mojave, in California (E. W. and W. H. Campbell, 1937), Folsom points have been found but not in place. Flint flakes in beach gravel show that man was present when the lake stood high, but his cultural status is uncertain. Rogers (1939, p. 43) states that not only flakes but implements of his Playa culture occur in gravel at this locality, but he casts doubt on the association of the gravel with the lake. The discrimination and tracing of the *Citellus* zone in Nebraska, as described by Schultz and by Lugn (1935, pp. 142-145) affords a promising lead whereby the younger artifact-bearing terraces may be dated. Furthermore, the terraces of the Colorado Piedmont may in the future be traced into the deposits associated with the continental ice in eastern Nebraska. The attribution of the *Citellus* zone to the Peorian, that is, to the interstadial between the pre-Home and Home glaciations, would place the cultures associated with the overlying loess and terrace deposits at a date much too early to fit into the correlation here made. The continued detailed efforts of the Nebraska geologists promise to provide a solution for this difficult and intricate problem.

GEOGRAPHY OF THE FOLSOM CULTURE

The correlation in time between the Folsom culture and the Corral Creek glacial substage here presented, leads to several conclusions regarding the local and general climatic conditions.

That the climate of the northeastern Colorado Piedmont was cooler is attested by invertebrates found in the Lindenmeier culture layer (Eisley, 1937). It was at times almost Arctic, as shown by the solifluction phenomena still preserved in terrace gravel. Strong winds blew across flood plain surfaces not well protected by vegetation, so that dunes were piled up and pebbles polished and cut by drifting sand. Presumably, the precipitation in the mountain area may have been greater. In the plains, however, a dry, near-Arctic climate must be postulated, similar to that of the Canadian Great Plains. The cold drying winds from the mountains prevented the formation of true forests, so that presumably the plains were covered by prairie types of vegetation, with only scattered groves of trees.

In such a severe environment the sheltered Lindenmeier Valley, with grass and water in its springy meadow, must have been an ideal spot—a place beloved by the beasts. Here a hunting people would find year after year the necessities—water and game for food. It is, however, hard to believe that the larger grazing animals remained in the area in the winter. Just as the bison of recent history migrated southward to more genial winter climates, so the ancient bison probably also migrated. Doubtless, the hunters moved with the animals. If so, an explanation for the lack of remains of shelters at the Lindenmeier site is afforded, and an explanation is presented for the wide distribution of Folsom finds throughout the Great Plains region, from Saskatchewan to Texas.

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1. Spring at the Lindenmeier site. The water seeps out along the top of the tuff-clay several feet above the top of the storage tank. The tents of the Smithsonian Institution Expedition are on the level of the old valley floor.

2. Brennigan Spring. The light-colored ground is covered with the ordinary grama grass of the dry hills and plains. The dark areas extending down the sides of the gulch are meadow grasses supported by the emerging ground water.

1. The Kersey terrace. View to the north, across the terrace to the South Platte River. Folsom artifacts have been found in the dune sand in the foreground, which rests on the Kersey terrace.

2. View to the east from the summit of Prairie Divide. Plains of the Colorado Piedmont in background. Valley in foreground filled with irregular masses of slumped gravel and glacial debris.

The Home moraine, as seen from the upstream side. The Cache la Poudre River flows from right to left in front of the moraine, and through the channel between the moraine and the left valley wall.

1. View across the valley of the Cache la Poudre River at Home Post Office. Home moraine shows as grassy slope in lower left. Glacial erratics of pre-Home glacial substage shown at A and B.

2. The Corral Creek moraine as seen from upstream side. Note subdued aspect and lack of boulders on the surface of this relatively young moraine. Corral Creek flows through a notch in moraine on right.

1. Pitted outwash plain of the Long Draw substage. Corral Creek cirque in the background (see near view below).

2. Protalus rampart of the Corral Creek cirque. Small patches of snow have remained throughout the summer in sheltered niches in the headwall of this cirque (September 1936).