CENOZOIC GEOLOGY OF THE RUBY-EAST HUMBOLDT RANG

NORTHEASTERN NEVADA

by

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divided into a lower, a middle, and an upper member. The Humboldt formation rests unconformably on, or is in fault contact with, older, pre-Tertiary rocks. Vertebrate and plant remains prove that it is of middle or upper Miocene age. Climatic conditions were considerably more humid at that time than at present. Considering northeastern Nevada as a whole, the Miocene area of deposition may have originated by faulting or by warping; but within the area here considered, faulting during the deposition of the Humboldt formation has been established, and the pattern of fault blocks and basins were presumably determined at that time and perpetuated by later movements.

The mountain block consists of a complex of igneous, metamorphic, and sedimentary rocks, containing marble, diopside granulite, quartz-mica schist, sillimanite-garnet schist, quartzite, biotite gneiss, binary granite, porphyritic granite, and pegmatite. Part, and probably all, of the metamorphic and sedimentary rocks are Paleozoic. They have been deformed into a series of folds of diverse trends and character, and have been intruded by Late Jurassic or early Tertiary igneous rocks. The folding is probably Late Jurassic in age. The internal structure is discordant with the trend and shape of the range, and folds are truncated obliquely or longitudinally by the faces of the range.

Geologic and geomorphic criteria of faulting, developed on the west side of the range in a dissected basin, have been applied to the east side which is flanked by a closed, detritus-filled basin. The range is bounded on both sides by steep, normal faults which dip 60 to 70 degrees basinward. Displacement on the east boundary fault has been at least twice as great (5500 to 6000 feet) as on the west boundary fault (2000? feet), and the range has been both uplifted and tilted westward. It is a tilted horst. No evidence of Tertiary or Quaternary compression was found in the range or in the adjoining basins, so that its uplift must be attributed to vertical movements operating in a neutral or tensional state of the crust.

The scarps bounding the range are composite, in major part to be attributed directly to faulting and in minor part related to erosional removal of soft beds from the downthrown block. In places, the composite scarps are rejuvenated by late Pleistocene to Recent fault movements.

Four and possibly five periods of accelerated faulting have been recognized as follows:-- (1) A period of questionable faulting of relatively small displacements whereby the Miocene area of deposition originated, dated as middle or upper Miocene. (2) A later middle or upper Miocene period during the deposition of the Humboldt formation, displacements greater than in the first period. (3) A post-Humboldt and pre-Pliocene(?) lava period, amount of displacements unknown. (4) A period younger than the Pliocene(?) lavas but older than middle or upper Pleistocene. The last major uplift of the range occurred in this period, displacements relatively large. (5) A period in the late Pleistocene to Recent of small amount, indicated by piedmont scarps which cut glacial drift correlated with the Iowan substage of the Wisconsin on the west side of the range.

At least one of the latest displacements on the east boundary fault has been an absolute upward movement of the mountain block of 200 feet.

The glacial features of the Ruby-East Humboldt Range show that it has been glaciated during two substages of the Wisconsin glaciation, locally named the Lamoille and Angel Lake substages. No evidence of an earlier glaciation was found. The Lamoille substage is correlated with the Tahoe stage of the Sierra Nevada which in turn is correlated with the Iowan substage of the Wisconsin. The Angel Lake substage appears to be the same as the Tioga stage of the Sierra Nevada and is later Wisconsin.

The glaciers of the Lamoille substage were the more extensive, and a glacier 12 miles long, the longest in the range, occupied Lamoille Canyon during this period. The ice descended to its lowest altitude, 6100 feet, at the mouths of Lamoille and Seitz Canyons, and glaciers emerged from the mountains onto the piedmont slope in several places on the east and west sides of the range. The maximum amount of bedrock erosion has been 50 feet since the Lamoille substage and 5 to 7 feet since the Angel Lake substage.

The topographic features of the mountains indicate an extended period of erosion in the Miocene or Pliocene, prior to the last major uplift. Remnants of an open valley stage in the mountains indicate a pause in Pliocene or Pleistocene during the last uplift of the range.

On the west flank of the range and in the adjoining basins are seven surfaces, of which the two highest are pediments and the others terraces or partial pediments. The range is flanked on the east by a narrow, alluvium-covered pediment which has been exposed by locally rejuvenated drainage. The surfaces on the west side have been cut and dissected under a régime of exterior drainage, and those on the east side have been formed under a régime of interior drainage. The origin of pediments on the east and west sides under different climatic, drainage, and geologic conditions has been considered, and the following conclusions on the origin of pediments are presented: (1) Pediments are formed by lateral planation by streams, weathering, rill wash, and rain wash. The relative efficacy of these various processes differs with the geologic and climatic conditions. (2) Lateral planation is most effective in areas of permanent streams and soft rocks. (3) Weathering, rill wash, and rain wash are most effective in areas of ephemeral streams and hard rocks. (4) All variations from pediments cut entirely by lateral planation to those formed entirely by weathering, rill wash, and rain wash are theoretically possible. The surfaces on the flanks of the range probably date in the latter half of the Pleistocene and Recent.

p. 540, vol. II).* King divided the basin deposits in the vicinity of Elko and the Ruby-East Humboldt Range into an Eocene and a Pliocene group. The Eocene group was correlated with the Green River formation of Utah and Colorado, and the Pliocene deposits were named the Humboldt group from their excellent exposure on the North Fork of the Humboldt River. Fish and plant remains were reported from the Eocene deposits, and a small vertebrate fauna, believed to be of Pliocene age, was collected from the Humboldt group at Bone Valley on the North Fork of the Humboldt River. Evidence will be presented in this chapter which shows that both the Eocene and Pliocene deposits described by King are parts of the same formation, which is of Miocene age.

Lesquereux (22, pp. 314-329) in 1878 listed 14 species of plants from the so-called Eocene deposits near Elko.

In 1914 Merriam (30) described a small vertebrate fauna from the McKnight Ranch on the North Fork of the Humboldt River. He concluded that the fauna was of upper Miocene age. Merriam pointed out that the McKnight locality is the same stratigraphically, if not

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*Numbers in parentheses refer to bibliography at the end of the chapter.

geographically, as King's "Bone Valley" site. The "Bone Valley" site furnished the fauna upon the basis of which King assigned a Pliocene age to the Humboldt group.

In 1910 Emmons (13, pp. 21-23) and in 1916 Hill (16, pp. 54-63) reported on some mining districts in eastern Nevada. They both discussed briefly the nature and distribution of the Humboldt formation. Hill and Emmons made no particular study of the basin sediments and seem to have taken their material largely from King's report.

Knowlton (20, p. 796) lists 17 species of plants which have been collected from the basin deposits near Elko (King's Eocene deposits). He gives the age of these plants as Miocene.

Winchester (48, pp. 91-102) gives a discussion of oil shales in the Tertiary deposits near Elko, which he calls the Green River formation. In a footnote, Winchester (48, p. 91) records that J. P. Buwalda has found a middle or upper Miocene vertebrate fauna in this series of deposits.

H. L. Mason (27, pp. 154-156) mentions two conifers from the Tertiary deposits near Elko and gives the age of the deposits as Oligocene or Miocene (27, p. 140).

Formation Name

Various names have been applied to the Tertiary basin deposits of the Elko region. This confusion has been caused largely by the fact that King described what he thought were both Pliocene and Eocene deposits from this region. Data will be presented in the following pages to show that only one formation is present. In this paper it is proposed to call these deposits the Humboldt formation. The Humboldt formation includes the Humboldt group as originally defined by King and the so-called Eocene deposits, which have been correlated with the Green River formation of Utah and Colorado.

LITHOLOGY OF DEPOSITS

The Humboldt formation is composed of a series of continental deposits of fluviatile and lacustrine origin. Breccia, fanglomerate, conglomerate, sandstone, mudstone, siltstone, shale, lignite, oil shale, diatomite, limy shale, limestone, rhyolitic tuff, and ash beds make up the formation. A few thin rhyolite flows are interbedded in the sediments on the flanks of the East Humboldt Mountains. The detrital deposits such as conglomerate, sandstone, mudstone, siltstone, and shale make up the greater part of the formation.

Breccias

Basal Breccias--Breccias have been noted at the base of the Humboldt formation at a number of localities. These basal breccias are composed of angular fragments of the immediately underlying rock, which, in most localities, is Carboniferous limestone. Some of the breccias have developed almost in situ by the disintegration and spalling of bedrock outcrops; others indicate considerable movement of material and resemble slope-wash breccia and fanglomerate.

Intraformational Breccias--At the north end of the East Humboldt Mountains on the east flank 6 miles southwest of Wells are a number of prominent outcrops of a limestone breccia interbedded in the Humboldt formation. This breccia ranges from light to dark gray and is composed of extremely angular fragments, one inch to several feet long, of limestone set in a sparse matrix of limestone fragments. The mass is well cemented by a calcareous cement and is hard and resistant. Worthy of note is the fact that in any one outcrop the fragments are entirely of one type of limestone which may be slightly different from the limestone composing the fragments of the same breccia half a mile away.

Two distinct beds of breccia separated by several hundred feet of coarse fanglomerate have been observed. The lower breccia bed is the more extensive, as it crops out more or less continuously for at least two miles along the strike. The maximum thickness observed is about 100 feet, though the upper boundary is difficult to determine, for the breccia grades gradually upward into fanglomerate. The lower breccia is underlain by a series of silt, sandstone, and fine conglomerate beds.

These limestone breccias lie a mile east of the bold fault-scarp face of the East Humboldt Mountains. They have clearly been derived from an extremely steep slope, and it seems well within reason to assume that they represent slide masses from a new-born fault scarp. The face of the new-born scarp must have been composed entirely of limestone of the type found in the breccia, for the same limestone is now found in place at the base of the scarp where it has not yet been removed by erosion. The lack of gneiss, quartzite, and granitic fragments in the breccia may be accounted for by the fact that erosion had not eaten far enough into the fault block to expose these rock types which underlie the limestone.

The sudden lithologic change from silt, sandstone, and fine conglomerate to coarse limestone breccia suggests a sudden and catastrophic change in deposition which might easily be caused by faulting. The overlying fanglomerate also fits well into the picture of deposition along the face of a new-born fault scarp, for the slide masses should be followed by deposits of coarse angular fragments swept down the slope as talus, slopewash breccia, and fanglomerate. The two separate beds of breccia might be taken to indicate two separate uplifts along the fault, though the upper breccia is of such limited extent that it possibly represents merely a local slide mass of limestone from the eroded fault scarp.

Longwell (23, pp. 1420-1429; 24, pp. 434-438) has recently described similar, but more extensive, slide breccias from the flanks of the Virgin and Black Mountains in the Boulder reservoir region, Arizona-Nevada, and from the Triassic deposits of the Connecticut Valley. The breccias described by Longwell are also associated with fanglomerate (or fan breccia) in the same manner as the breccias described above. He has presented facts which strongly suggest that the breccias and associated fanglomerates were derived from an actively growing fault scarp.

The breccias and fanglomerates of the Humboldt formation may have a considerable extent along the strike, parallel to the mountain block, but the exact extent cannot be determined, for they are cut off to the north by a cross fault and pass under younger fan deposits to the south.

Fanglomerates

The thickest and most extensive fanglomerate in the Humboldt formation is exposed at the north end of the East Humboldt Mountains in the same place as the intraformational breccias described immediately above. This fanglomerate is brown, gray, or nearly black, depending upon the type of rock composing it. Angular fragments, a fraction of an inch up to four feet in length, of white, gray, buff, or black limestone (some containing fossils, chiefly brachiopods), quartzite, and pebble conglomerates compose the fanglomerate, Plate III. These fragments are imbedded in a sparse sandy to gravelly matrix. Some red sandy lenses are interbedded in the mass. In places the fanglomerate is composed entirely of quartzite fragments, in other places entirely of limestone fragments, and all gradations between 100 percent limestone and 100 percent quartzite seem to exist. The fanglomerate is generally well cemented and forms bluffs and prominent outcrops.

This fanglomerate immediately overlies the intra-formational breccias described above and grades downward into those breccias. The fanglomerate has clearly been derived from the same fault scarp as the breccias, but at a later time when the scarp was being eroded and dissected. The coarse detritus from the scarp was deposited in long sloping fans closely resembling those found at present along steep fault scarps.

Similar fanglomerates (or fan breccias) thought to have been derived from an actively growing fault scarp have been described by Longwell (23, pp. 1420-1429; 24, pp. 434-438; 25, pp. 63-64) from the Boulder reservoir area (Nevada-Arizona) and from the Connecticut Valley Triassic deposits.

On the west side of the Ruby Mountains near the mouth of Secret Pass is a red fanglomerate, 200 feet thick, which has been traced for a mile along the strike sub-parallel to the mountain front. This fanglomerate may be related to the same uplift which is thought to have given birth to the breccias and fanglomerates described above.

Conglomerate

Basal Conglomerate--Basal conglomerates, 20 to 200 feet thick, have been mapped in several localities. They can be seen to rest directly upon pre-Tertiary rocks, commonly Carboniferous limestone or quartzite. The conglomerate beds contain roundstones* up to 1½ feet in diameter.

Intraformational Conglomerates--Intraformational conglomerate is abundant, especially near landmasses which were supplying detritus in the Miocene. Along the west flank of the Ruby-East Humboldt Range, and along the east flank of this range where Miocene beds outcrop, conglomerate, containing roundstones of the various rock types exposed in these mountains is particularly common, indicating that a positive landmass stood on the present site of the Ruby-East Humboldt Range during Humboldt time.

Along Huntington Creek, south of Twin Bridges, conglomerate first becomes abundant at about 1400 feet above the base of the Humboldt formation. The lowermost conglomerate bed in this locality is composed almost entirely of limestone roundstones; chert makes up the remainder. Successive conglomerate beds higher and higher in the series contain more and more crystalline

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*Term suggested by Fernald (14) for pebbles, cobbles, and boulders, etc. in a conglomerate.

material such as quartzite, gneiss, and granitic igneous rocks and less and less limestone. At 2000 feet above the base, a conglomerate bed contains 50 percent limestone and 50 percent crystalline roundstones. At 2300 feet above the base, a conglomerate contains 75 percent crystalline material, at 2800 feet 90 percent crystalline material and 10 percent limestone, at 3300 feet approximately 100 percent crystalline material. These relations indicate a gradual uncovering of the crystalline material which underlies the limestone in the source blocks.

The conglomerate in the upper part of the Humboldt formation is composed of small, one inch in diameter, well-rounded pebbles, largely of crystalline rocks.

All the conglomerate in the Humboldt formation is clearly stream-laid. Some of the conglomerate on the South Fork of the Humboldt River and on Huntington Creek contains well-rounded cobbles up to six inches in diameter. These cobbles are at least 8 to 10 miles from a possible source block, as far as known, and indicate transportation and deposition by a fairly large and powerful stream.

Sandstone, Mudstone, Siltstone, and Shale*

Sandstone, mudstone, siltstone, and shale with considerable intermixed ash grade one into the other and grouped together make up the larger part of the Humboldt formation. These beds are white, brown, tan, and light green. They are composed of mineral fragments which seem to have had the same source as the pebbles, cobbles, and boulders in the conglomerate. In some cases large amounts of volcanic ash are intermixed with the detrital mineral fragments.

The oil shale of the Humboldt formation is a finely bedded, dark-colored, petroliferous shale exposed near the base of the formation in the Elko Range south of Elko. This shale contains considerable carbonaceous material and small fresh-water shells. Winchester (48, pp. 98-100) reports six separate groups of oil shale beds in the vicinity of Elko; any one group of beds is seldom over a few feet thick. Dark brown beds of lignite, a few inches thick, are interbedded with the oil shale beds.

Fresh-Water Limestone

Fresh-water limestone crops out near the base of the Humboldt formation at a number of localities. The

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*These terms are used in the sense defined by the Committee on Sedimentation (45, pp. 97-98).

limestone is white to light brown, chalky to dense and finely crystalline, and ranges from thin beds a fraction of an inch thick to rather massive beds a few feet thick. The limestone at all localities observed contains numerous shells of fresh-water invertebrates, chiefly gastropods and pelecypods. Along Huntington Creek near Twin Bridges the limestone contains a great number of irregular black and gray or white nodules of chert ranging from an inch to a foot in diameter.

Where exposures are good the limestone is seen to rest directly on a basal conglomerate or breccia and to pass upward into limy shale, silt, sandstone, and ash. The oil shale beds at Elko overlie the limestone. A thickness of 870 feet of limestone has been measured on Huntington Creek; this is the greatest thickness exposed.

Diatomite

Two groups of diatomite beds, each 7 to 10 feet thick, crop out near Carlin, 25 miles west of Elko, Figure 2. The diatomite is pure white, loose and friable, and moderately massive.

Ash and Tuff

Ash and tuff beds are particularly abundant about 1000 feet above the base of the Humboldt formation, and pyroclastic material is a common constituent of the detrital deposits throughout the whole formation. Many of the tuff beds are massive and give no evidence of being water-laid. They are composed of fragments and crystals of quartz, feldspar, biotite, glass, and angular fragments of rhyolite, and in places are better classed as lapilli tuff (47, p. 47). Most of the ash beds are water-laid and rather thin bedded. The greater number of ash beds are composed of fragments of volcanic glass and very minor amounts of mineral fragments, chiefly quartz and feldspar.

Relative Percentages of Lithologic Types

An attempt has been made to estimate the relative percentages, by volume, of the various sedimentary types in the Humboldt formation. At the best, this is only a very crude estimate and may be considerably in error.

Limestone	Conglomerate	Fine sediments (ss., sh., mudstone, siltstone, etc.)	Ash and Tuff	Fanglomerate and Breccia
5-10%	10-15%	60-75%	5-10%	2-3%

STRATIGRAPHY AND THICKNESS

The Humboldt formation in the area studied possesses certain characteristics which facilitate the division of the deposits into three rather distinct members as follows.

Lower Member

The lower member is composed of shale, fresh-water limestone, oil shale, and various detrital deposits ranging from sandstone to conglomerate. Oil shale or limestone beds identify this member. In places the limestone and oil shale grade laterally into mudstone, sandstone, and conglomerate, and there the member loses its distinctiveness. The lower member is 800 to 1000 feet thick at maximum.

Middle Member

Above the lower member is a middle member characterized by rhyolitic tuff and ash. Tuff and ash beds are found throughout the Humboldt formation, but they are particularly abundant in the middle member. A single outcrop of ash or tuff does not identify this member, but a thickness of a hundred feet or so of associated tuff and ash beds does, as far as known. Volcanic activity of an explosive nature seems to have been at a peak during the time when the beds of this member were being deposited.

The middle member has a maximum measured thickness of 1300 feet.

Upper Member

The upper member contains a series of fine conglomerate, sandstone, mudstone, siltstone, and shale beds. Mudstone and shale are particularly abundant near the top of the member. The conglomerate of the upper member is characterized by a large number of pebbles of quartzite and granitic rocks and few of limestone. The cobbles and boulders prominent in the lower member are absent or scarce. On the whole, this member is identified by great thicknesses of mudstone and shale with few conglomerate beds. The maximum measured thickness of the upper member is 3600 feet, though it may be much thicker, for the top of the Humboldt formation is not known.

Figure 3 shows a series of columnar sections from various places in the area studied. The three members of the formation are shown clearly in these sections.

Thickness of the Humboldt Formation

By far the best exposed and most continuous section of the Humboldt formation is along Huntington Creek south of Twin Bridges. Here a section has been measured in detail by a pace and compass traverse, and the data from this traverse are presented in column A of figure 3. The base of the formation is exposed near Twin Bridges, but structural complications make an exact measurement from the base impossible. The section has been measured from

Miocene and older rocks have also been noted near Twin Bridges, near Thorpe Creek on the west flank of the Ruby Mountains, on Sheep Creek a bit farther south, and at the gorge of the Humboldt River 20 miles west of Elko.

Overlap

In some localities, overlap of beds higher in the section brings beds of the middle member and even of the upper member to rest directly upon pre-Tertiary rocks. An excellent example of such an overlap is at the mouth of Thorpe Creek where a coarse conglomerate rests directly on Carboniferous limestone. The conglomerate contains a number of roundstones of gneiss, quartzite, and igneous rocks in addition to limestone. In the Humboldt formation along Huntington Creek roundstones of gneiss, quartzite, and igneous rock do not appear lower than the lower part of the middle member. Therefore, the base of the Humboldt formation at the mouth of Thorpe Creek is probably some place within the middle member and considerable overlap is indicated.

Folds

Within the basins, especially near the center, the structure tends to be relatively simple. The beds have gentle dips seldom over 15 degrees. Near the edges of the basins the structure becomes more complex. Dips up to 50 degrees are not uncommon, and higher dips can be measured. No systematic arrangement of folds could be worked out in the beds at the edges of the basins. The sediments seem to be broken into separate blocks with diverse dips. On Huntington Creek, near Twin Bridges, a broad, open anticline has been mapped. This fold trends roughly northwest and the beds on the flanks dip from 20 to 28 degrees. Winchester (48, p. 94) mentions folds in the Humboldt formation in the Elko Range.

Fault Contacts with Older Rocks

In a number of places the beds of the Humboldt formation are in fault contact with the pre-Tertiary rocks. Many of the mountain ranges separating the areas of basin deposits are known to be fault-block mountains, bounded on one or both sides by faults which separate the older pre-Tertiary rocks of the mountain block from the Miocene deposits of the basins. This relation is demonstrated along the west flank of the Ruby and East Humboldt Mountains where streams have deeply dissected the mountain front and the forelying basin sediments. Here the beds of the basin can be seen dipping directly toward the older rocks of the mountain block, and ample evidence for faulting, such as truncation of structures and stratigraphy, triangular facts, and recent piedmont scarplets, show that

Vertebrate fragments have been collected or reported from five localities*.

(1) On the South Fork of the Humboldt River, in several places along the cuesta on the north side of the road to Lee.

(2) On the North Fork of the Humboldt River near the McKnight Ranch, Merriam's (30, pp. 276-277), McKnight locality, or King's (17, p. 439) "Bone Valley" site.

(3) Near the Triolite plant mine 3 miles northeast of the town of Carlin, which is 25 miles west of Elko on U. S. highway number 40. The locality where fragments are most abundant is the southeast corner of section 7, T. 33 N., R. 53 E.

(4) In Lamoille Valley along Rabbit Creek about 3 miles northwest of the Rossi Ranch, in the northwest quarter of section 11, T. 34 N., R. 57 E.

(5) On Camp Creek, one-fourth to one-half mile above the junction with Sussie Creek. This junction is 21 miles by road up Sussie Creek from U. S. highway number 40. The Sussie Creek road turns off 2 miles east of Carlin. The locality is in the southwest quarter of section 36, T. 36 N., R. 53 E.

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*Names of local residents who can be of assistance in locating fossil localities: Mr. R. A. Kinne, Municipal Water Department, Elko, Nevada; and Mr. Gerald Trescarte, Lamoille, Nevada.

The vertebrate fragments collected on the South Fork of the Humboldt River come chiefly from sandy mudstone beds near the base of the middle member. The exact stratigraphic relations of King's "Bone Valley" site are not known, but the general relations strongly suggest that it is well up in the upper member of the Humboldt formation. The bones at the Triolite mine near Carlin are in a sandy mudstone 10 feet above the diatomite bed worked at the mine. The fossiliferous bed has been traced along the strike for about three-quarters of a mile, and vertebrate fragments have been found throughout that distance. This fossiliferous bed is only several hundred feet above the base of the formation here, but there is good evidence of considerable overlap; and the fossil bed is probably in the middle member of the formation. The fossils on Rabbit Creek in Lamoille Valley are in sandstone and mudstone beds in the upper member. The Camp Creek locality is in sandy mudstone beds interbedded with ash. The exact stratigraphic relations of these beds are not known, but their lithology suggests that they belong to the middle member of the Humboldt formation. By far the best locality seen, and the one most worthy of consideration as a possible collecting site is the Camp Creek locality. Here whole bones are imbedded in the

BOUNDARY STRUCTURE OF THE RUBY-EAST HUMBOLDT RANGE

General Statement

Twenty to thirty years ago considerable argument raged as to whether the Basin Ranges were erosional features, or features directly caused by tectonic movement, more specifically faulting. Work by Gilbert (31, 32, 33), Davis (16, 17, 19, 20), Louderback (62, 63, 64, 65), Reid (73), I. C. Russell (74, 75, 76), R. J. Russell (78), Gilluly (34, 35), Bryan (10, 11), Fuller and Waters (28), and others too numerous to mention, has shown that the Basin Ranges are bounded by faults and owe their topographic expression in large part directly to movements on those faults.

Many of the ranges of the Great Basin are bounded on both sides by closed, detrital basins. The detrital filling of the basins has, in most places, lapped over onto the mountain block and makes study of the features of the boundary structure of the mountain block difficult, if not impossible. Physiographic studies have proved a helpful tool in such cases. The Ruby-East Humboldt Range is one of the rare examples of a Basin Range in which the detritus filling one of the basins adjoining the mountains has been dissected by through-flowing streams, so as to expose the boundary structure of the mountain block. The range offers the further advantage of being bounded on one side, the west, by a dissected basin with through-flowing drainage and on the other side, the east, by a closed basin filled with undissected detritus. This offers opportunity to apply geologic and geomorphic criteria of faulting, as developed in a dissected basin where the structural evidence of faulting can be directly observed, to a closed and filled basin where the boundary structure itself cannot be directly observed.

Before any discussion of the boundary structure is given, the various criteria for faulting, which were of use in this study, will be given and discussed briefly. These criteria are divided into two groups: (1) Geologic and (2) Geomorphic.

Geologic Criteria of Faulting

(1) Actual exposures of the fault plane itself-- Very few actual exposures of the fault plane or zone have been seen in the Ruby-East Humboldt Range, in spite of the extensive dissection at the western base of the range. Faults between the pre-Tertiary rocks of the mountain block and the Miocene basin sediments

have been observed in the vicinity of Willow Creek along the east base of the East Humboldt Mountains and in Secret Valley. Subsidiary faults in the basin sediments have been observed in Secret Pass on the west side of the range and along Willow and Clover Creeks on the east side of the range. Wherever observed, the faults were normal and dipped basinward 60 to 70 degrees.

(2) Drag, brecciation, and minor faults--These are all well-known features of faulting and will not be discussed particularly. Beds of the Miocene Humboldt formation are strongly dragged up into dips of 50 to 60 degrees along the east front of the range southwest of Wells. Minor faults in the basin sediments in front of the mountains have been observed in a number of places. These were all normal faults dipping steeply basinward.

(3) Juxtaposition of different formations where relations cannot be explained by folding or deposition--This has been one of the most useful of all criteria, especially on the west side of the range. In a great number of places on the west side, north of Secret Pass, beds of the Miocene Humboldt formation dip toward the mountains and can be traced to within a few hundred feet, or less, of the pre-Tertiary rocks of the mountain block.

Section CC' of figure 8 illustrates this relation. In many cases, these beds are much too fine grainded to have been deposited in such close relations to the steep face of pre-Tertiary rocks, which at the present time is shedding coarse detritus to the basin. Furthermore, the dip of the beds toward the pre-Tertiary rocks shows that the relations cannot be explained by folding. The reasonable conclusion is that the rocks have been brought into their present relations by faulting.

(4) Truncation of beds or structures--The truncation of the internal structures of the range has already been described and discussed in the section of the paper dealing with internal structure. In a few cases, it has been possible to prove that beds within the basin sediments are also truncated by the boundary fault of the mountain block.

(5) Coarse detrital deposits such as slide breccias and fanglomerates derived from a growing fault scarp--Longwell (59, 60, 61) has recently emphasized the significance of deposits of this nature as related to an actively growing fault scarp. Fanglomerates and slide breccias interbedded in the Miocene sediments have been described in detail in Chapter II. They indicate an actively growing fault scarp on the east side of the Ruby-East Humboldt Range in Miocene time.

(6) Springs--Springs, both hot and cold, have long been recognized as features related to faulting. Hot springs are found on both sides of the Ruby-East Humboldt Range, for example near Lutts Creek and the Warm Springs Ranch on the east side and along Warm Creek on the west side. In addition, cold springs along the base of the mountains are extremely common. The conception generally held is that the spring water finds it way to the surface through the broken and fractured zone of the boundary fault. An impenetrable layer of gouge serves to keep the water from dispersing into the relatively permeable basin deposits on the basin side of the fault.

Geomorphic Criteria of Faulting

Many of the geomorphic criteria of faulting are of value only as they are supported by geologic criteria and in themselves are not *ipso facto* evidence for faulting. If geomorphic criteria can be established in areas where faulting can be proved on geologic grounds, they may be of use in an area where direct geologic evidence of faulting cannot be obtained.

(1) Triangular facets--Triangular facets as geomorphic evidence of faulting have been made famous by Davis (16, 17) and no discussion of them will be made

here, other than to mention that excellent examples of triangular facets have been observed on the west side of the range in the vicinity of Murphy and Ross Creeks.

(2) Piedmont Scarps--Piedmont scarps (33, p. 34) came into prominence as evidence for boundary faults through the early studies of Gilbert (32, 33) and I. C. Russell (74, 75, 76, 77) and have been emphasized by numerous later workers. Excellent examples of piedmont scarps exist along the west side of the Ruby-East Humboldt Range. These scarps are clearly not lake shore features, for the basin west of the mountains did not contain a lake in Quaternary time. Furthermore, the scarps do not follow a contour line but cut straight across alluvial fans. It is possible that a stream which is dissecting its fan can, upon emerging from the mountain block, swing almost or entirely at right angles to its former course and cut a bank which will roughly parallel the mountain front across one side of the fan. That this same stream will, at a later date, change its course by 180 degrees and cut a corresponding bank down the other side of the fan seems unlikely, if not impossible. Furthermore, when the same scarp continues for a distance of a number of miles more or less continuously,

erosional scarp, other than one controlled by structure, is almost certain to have a sinuous trend and projecting spurs.

Other geomorphic criteria have been developed and used by other workers in other areas. Among these criteria are: steeper stream profiles toward the front of the range, oversteepened scarps, remnants of a faulted erosion surface, narrow gorges along the streams at the mountain front, and truncated canyons. These criteria, too, are dependent upon direct geologic evidence of faulting for support.

Description of the Boundary Faults

By use of the various geologic and geomorphic criteria listed above, the Ruby-East Humboldt Range can be shown to be bounded on both sides by faults. The range is a tilted horst. The purpose of this section of the chapter is to describe briefly these boundary faults, starting first with the faults on the east side of the range, from north to south, and finishing with the faults on the west side, from north to south.

Faults on the east side of the range--The faults bounding the east base of the range are covered by Quaternary basin fill in most places, so except for the northern end of the East Humboldt Mountain little direct geologic evidence offaulting is available. The east front of the East Humboldt Range is a remarkably straight, steep scarp rising abruptly 4000 to 5000 feet above the floor of Clover Valley. This scarp is one of the finest in the Great Basin and rivals the east face of the Sierra Nevada in ruggedness and beauty, though it is not as high, Plate IX .

At the north end of the East Humboldt Mountains a subsidiary, westward-tilted fault block, bounded by a fault on the east side, lies east of the main scarp of the range, figure 14. Between the main scarp of the range and the crest of the forelying block, beds of the Miocene Humboldt formation are exposed. These beds have been folded into an open syncline by squeezing between the westward tilted forelying block and the main mountain block. They have also been strongly dragged up along the fault which forms the main scarp of the range. In this area, direct geologic evidence for faulting, such as drag, minor faults, truncation of structure, and coarse detrital deposits in the Miocene beds supplement geomorphic evidence. The fault itself has been observed on the north wall of Willow Creek, NW. 1/4 section 2, T. 36 N., R. 61 E. The dip of the fault here is 73 degrees eastward or basinward. The fault is easily traced 4 miles north-northwestward from

Willow Creek to the end of the range. Throughout this distance Miocene basin sediments are exposed on the east side of the fault and pre-Tertiary rocks, largely the Upper limestone and Middle limestone are exposed on the west side. The Miocene sediments are strongly dragged up along the fault and in places dip as much as 50 degrees eastward. They are also broken by a number of minor, basinward-dipping faults which roughly parallel the main boundary fault. Coarse slide breccias and fanglomerates interbedded in the Humboldt formation are taken as evidence of movement on the boundary fault in Miocene time (Chapter II). The internal structure of the range in this area is truncated at a low angle by the range front. The structural relations are shown in section AA' of figure 8.

The direction of drag and the fact that the younger beds are on the east side of the fault show that the downthrown side is to the east. The fault dips eastward; hence it is a normal fault. Emphasis should be placed on the fact that this is the main boundary fault and not a subsidiary fault.

At the mouth of Willow and Smith Creeks, glacial moraines of the Lamoille substage and the Angel Lake substage of the Wisconsin glaciation lie across the fault

Displacements on the boundary faults will be discussed at greater length in a succeeding section of this chapter. A minimum figure for the vertical component of the dip slip on the principal boundary fault in this area is about 4500 feet. The displacement decreases as the north end of the range is approached.

Evidence that the forelying block at the north end of the East Humboldt Mountains is faulted on the east side is largely geomorphic, though a small patch of rhyolite, of the type interbedded in the Miocene deposits, lies immediately east of the block and in itself suggests faulting. This subsidiary fault, lying 4 miles to the east of the main boundary fault, dies out southward toward Clover Valley within a distance of 9 to 10 miles from its northern end.

The main fault at the foot of the principal scarp continues nearly due south along the base of the range for 25 miles. South of Angel Creek it is buried by Quaternary deposits, and the only geologic evidence of faulting is the relation of the internal structure and the range front. The internal structure of the East Humboldt Mountains is a broad anticline trending nearly north-south, the nose of which can be seen at the north up and down over fans, roughly parallel to the mountain front, it seems certain that the scarp is a feature of faulting and can in no way be a feature of stream erosion.

(3) Dissected Pediments on Mountain Block-- Dissected pediments cut on the pre-Tertiary rocks of the mountain block are useful as a criterion of faulting only on the east side of the range where there is a closed basin. The west side of the range has a number of examples of dissected pediments, cut both on the Miocene basin deposits and on the pre-Tertiary rocks of the mountains, but the dissection of these pediments is related to rejuvenation of the Humboldt River drainage caused by a change of base level outside of the area here considered. On the east side of the range, pediments cut on the pre-Tertiary rocks of the mountain block near Lutts, Thompson, Moore, Moose, Wines, Overland, and Dawley Creeks indicate relative uplift of the mountain block. No other mechanism would seem to account for the dissection (150 feet) of these surfaces, for Ruby Valley gives all appearances of having been a closed basin for some time.

(4) Linear Range Front without Projecting Spurs-- This criterion is of value only in so far as the range front shows no relation to internal structure. An

this fold is missing south of Angel Creek. The beds at the crest of the East Humboldt Mountains west of Clover Valley are horizontal or have only low dips. The fold is bisected by the range front, and the eastern part has been dropped from view. To the north and south of Clover Valley, the fold axis and the range front diverge so that a larger part of the east limb of the fold is preserved. The linear trend of the scarp, the lack of projecting spurs, and its abruptness all strongly suggest faulting as a mode of origin. The vertical component of the dip-slip displacement on the boundary fault in Clover Valley is 4500 to 5800 feet at minimum. Southward the height of the East Humboldt Mountains decreases and the boundary fault appears to be dying out. At the Polar Star mine the displacement on the fault is 2000 to 2500 feet.

Eleven miles south of the Polar Star mine is a fault which bounds the Valley Mountains on the east side and along which freshwater limestone and ash beds of the Humboldt formation have been dropped into contact with the Carboniferous limestone of the Valley Mountains. This fault may be a southward continuation of the fault at the base of the East Humboldt Mountains, or it may be an entirely different fault. A strong argument against the two faults being one and the same is the fact that Pliocene(?) lavas between the south tip of the East Humboldt Mountains and the north end of the Valley Mountains are not displaced by the faulting. That the last movement on the faults is as old as pre-Pliocene or early Pliocene is not consistent with other features in the region.

The southern end of the East Humboldt Mountains extends as a southerly projecting ridge east of the principal face of the Ruby Mountains. The north end of Ruby Valley forms a reëntrant between the southern end of the East Humboldt Mountains and the eastern face of the Ruby Mountains. Thus, the first 7 or 8 miles of the east face of the Ruby Mountains faces the back slope of the East Humboldt block. Farther south, the eastern face of the Ruby Mountains is more clearly exposed to view and is a magnificent scarp fully equal to that of the East Humboldt Mountains near Clover Valley, though it is no higher.

The evidence that the east face of the Ruby Mountains is bordered by a fault is both geomorphic and geologic. The internal structure of the Ruby Mountains is discordant with the east face of the range. From Battle Creek southward the axial trend of the folds in the pre-Tertiary rocks of the mountain block is sharply oblique to the east face of the range, in places at large angles. North of Battle Creek the axial trend of the folds is more nearly parallel to the trend of the range, but the limbs of these folds are cut off cleanly by the fact of the range, section DD', figure 8.

Two small outcrops of Tertiary beds at the north end of Ruby Valley suggest that all of Ruby Valley may be underlain by Tertiary beds which have been downfaulted into contact with the pre-Tertiary rocks of the mountain block.

From Smithers Creek south to Battle Creek, a distance of 10½ miles, is a piedmont scarp 50 to 200 feet high. Between this scarp and the base of the range 1/4 to 1 mile to the west is a broad, dissected pediment cut on the pre-Tertiary rocks of the mountain block. This scarp will be discussed in greater detail in the section of this chapter dealing with piedmont scarps. Immediately north of Dawley Creek is a shorter but somewhat similar piedmont scarp. Remnants of pediments cut on the pre-Tertiary rocks of the mountain block have been noted near Overland Creek and other creeks to the south. The fact that these pediments are dissected by streams draining into a closed basin suggests that they have been differentially uplifted by faulting.

The features mentioned above, plus the linear trend of the east face of the Ruby Mountains and its abruptness show that it is a scarp due to faulting.

The east boundary fault of the Ruby Mountains extends from the northern end of Ruby Valley in a direction S. 25° W. for 35 miles to Harrison Pass and beyond. The fault has not been studied south of Harrison Pass, but evidence indicates that it extends south for another 20 miles at least.

A minimum figure for the vertical component of the greatest dip-slip displacement on the east boundary fault of the Ruby Mountains is between 4500 and 5000 feet. The fault appears to maintain about this displacement from a point 6 or 7 miles south of its northern end for 35 miles south before the displacement begins to decrease.

The relations between the faults which bound the Ruby Mountains and the East Humboldt Mountains on the east sides are of interest. A glance at the map, figure 14, will show that the fault at the east base of the Ruby Mountains has to do one of three things. The fault may die out by reason of decreasing displacement, it may pass into the main mass of the southern part of the East Humboldt Mountains, or, it may be terminated by a cross fault. Detailed studies have been made at the north end of Ruby Valley by pace and compass mapping. The results have not been entirely satisfactory, but an interpretation of the structural relations is offered which seems reasonable and fits the field facts.

The displacement on the fault at the east base of the Ruby Mountains decreases progressively northward from a point 6 miles south of Secret Pass. Detailed field studies failed to show that this fault passes into the main mass of the East Humboldt Mountains. Furthermore, no evidence of a terminating cross fault was found. The fault at the east base of the Ruby Mountains seems to die out within a short distance at the north end of Ruby Valley. The displacement on the fault at the east base of the East Humboldt Mountains, 8 miles to the east, increases northward. The complementary displacements on these two faults, accompanied by westward tilting of the mountain blocks, seem to explain the relations.

A rough diagram, figure 9, represents the interpretation offered. In the diagram the pre-faulting surface is assumed to be essentially flat, and erosion during or after uplift is not considered. Both assumptions are incorrect, but their incorrectness does not invalidate the interpretation. The matter of faulting on the west side of the Ruby Mountains will be considered later, as it adds only a minor complication to the picture here presented. The fault face at the east side of the block is that of the East Humboldt Mountains dying out southward. The other fault face, to the left or west, is that of the Ruby Mountains. The reëntrant between the two tilted fault blocks is the north end of Ruby Valley. The gradually decreasing displacement on the fault at the base of the Ruby Mountains is offset by the gradually increasing displacement on the fault at the base of the East Humboldt Mountains.

The west slope of the southern part of the East Humboldt Mountains which faces the east scarp of the Ruby Mountains across the north end of Ruby Valley, here some 3 to 6 miles wide, is relatively steep. At first, the steepness of this slope was taken as an objection to the picture presented above. However, the westward tilted fault block which lies east of the main scarp of the East Humboldt Mountains south of Wells gave the answer to this problem. The streams from the East Humboldt Mountains emerge from the mountain front, cross the intervening area of Miocene deposits and swing north or south along the west side of the forelying block until they find a way through the block to the basin beyond. These streams have undercut the west side of the block, driven the west slope eastward, and considerably steepened the slope. The same processes must have worked at the north end of Ruby Valley. The streams from the east face of the Ruby Mountains undercut the west slope of the East Humboldt Mountains, drove the slope eastward and steepened it considerably. The fact that the streams from the east slope of the Ruby Mountains at the present time are not doing the same thing may be explained by two facts. First, the west slope of the East Humboldt Mountains has been driven so far east that the streams have lost their power to undercut it, and, second, the west slope of the East Humboldts has become so steep that the great amount of detritus which it sheds has driven the streams back toward the middle of Ruby Valley, where they unite to form the southward-flowing Franklin River.

Secret Valley, a small intermontane basin just northwest of the north end of Ruby Valley is a minor structural feature typical of Basin Range structure. Secret Valley is a small, relatively downdropped area of Miocene beds, faulted on two sides and resting with depositional contacts on the older rocks in other places.

Faults on the west side of the range--The west base of the Ruby-East Humboldt Range is more irregular, and the slope is less abrupt than the eastern face. In nearly all parts of the range, the crest line is much nearer the eastern than the western base of the range.

The fault bounding the mountains on the west trends, in general, N. 20° E. to N. 40° E. Local deviations of as much as 50 degrees from this have been mapped. The west face of the mountains is essentially linear in broad view, despite local projections and reëntrants, figure 14. Geologic and geomorphic evidence for a fault at the west base of the range is good.

Starting just south of the north end of the range, remnants of a piedmont scarp at the base of the mountains can be traced 3 miles south to just beyond Greys Creek. This scarp, as far as can be seen, is entirely in fan deposits, though the base of the scarp may really be bedrock mantled by slumped gravels. The average height of the scarp is about 30 feet, and it is highest, 75 feet, at the mouth of Greys Creek. Farther south, between Ackler Creek and Secret Creek, well-exposed sections of Miocene basin deposits give ample geologic proof of faulting. In a number of places, fine-grained basin sediments can be seen dipping directly toward the pre-Tertiary rocks of the mountain block. That such fine-grained sediments could be deposited in such close relations to a steep scarp does not seem possible, and the attitude of the basin deposits shows that the relations are not those of folding. Sections AA' and BB' of figure 8 illustrate the relations as interpreted on a basis of faulting.

In Secret Pass a broad brecciated zone is exposed between the pre-Tertiary rocks of the mountain block and the basin sediments. A subsidiary fault in the basin sediments along the south bank of Secret Creek ½ mile west of the boundary fault strikes N. 35° W. and dips 50° W. This fault is at the eastern edge of section 2, T. 34 N., R. 59 E.

South of Secret Pass, remnants of a piedmont scarp extend along the base of the mountains for 2½ miles to the mouth of Ross Creek. This scarp averages 30 to 40 feet high and is particularly clean cut at the mouth of Ross Creek. As far as can be told, it is composed entirely of fan deposits. Remnants of a piedmont scarp appear immediately south of Talbot Creek and extend more or less continuously for 9 miles south. This scarp cuts glacial drift, correlated with the Iowan substage of the Wisconsin glaciation at the mouths of Lamoille and Seitz Canyons. The scarp has an average height of about 40 to 50 feet.

Isolated outcrops of Miocene basin deposits along the mountain front south of Secret Pass, and some excellent triangular facets, ~~Plate~~, at the mouths of Ross and Murphy Creeks further substantiate the presence of a fault at the west base of the Ruby Mountains in this section.

Evidence for faulting along the west front is poorer in the region of the South Fork of the Humboldt River and southward. Isolated outcrops of Miocene basin deposits, and the truncation of the internal structure of the range indicate that a fault still exists between the Miocene basin deposits and the pre-Tertiary rocks of the range. However, the displacement on the fault seems to be decreasing, and south of Harrison Pass the range looks very much as though it might simply be a tilted block, faulted only on the east side, though no study of the range has been made south of Harrison Pass.

The west boundary fault of the range bifrucates at two places, at the mouth of Cold Creek and between Heenan and Welch Creeks, figure 14. At these localities, the main boundary fault swings sharply to the east and trends southeastward for a few miles before resuming its general south-southwest trend. A minor fault splits off from the main fault where it first swings eastward and continues for a short distance along a line which is a continuation of the trend of the principal fault before bifurcation.

The evidence that the fault really bifurcates is strongest at the locality between Heenan and Welch Creeks. Here the subsidiary fault which lies east of the main boundary fault is marked by a piedmont scarp. The presence of the main boundary fault is shown by the juxtaposition of the Upper limestone and the Quartzite formation. The base of the Miocene deposits is exposed a short distance west of the main boundary fault and trends in such a direction that farther south Miocene deposits are brought into contact with the Quartzite formation. The evidence for bifurcation of the boundary fault at the mouth of Cold Creek is not so strong, but even here the subsidiary fault west of the main boundary fault is indicated by a small block of pre-Tertiary limestone faulted up at the mouth of Thorpe Creek, figure 14. Each of these bifurcations accompanies a notable offset in the west flank of the range. These offsets will be considered in a succeeding section of this chapter.

Throughout its entire length, the west boundary fault of the Ruby-East Humboldt Range is more sinuous and deviates more sharply and to a greater extent from its general trend than does the boundary fault at the east base. It seems entirely possible that pre-faulting structures in the older rocks may have exerted an influence on the trend of the west boundary fault.

Nature of the Boundary Faults

Two decades ago arguments raged as to the existence or non-existence of the boundary faults of the Basin Ranges. Today, the existence of the boundary faults is generally admitted, but various views as to the character of these faults are held.

The boundary faults of the Ruby-East Humboldt Range have been exposed well enough for measurements of the dip of the fault plane only in two localities.

(1) On the east side of the range near the north end on Willow Creek, NW. 1/4 section 2, T. 36 N., R. 61 E. Here the fault plane dips 73 degrees east or basinward. Minor faults in the Miocene basins sediments were also noted in this area, all dipping steeply basinward.

(2) In Secret Valley, NE. 1/4 section 17, T. 34 N., R. 60 E., a fault between the Miocene basin sediments

and the pre-Tertiary rocks of the mountains dips 60 degrees basinward, or northeast.

At the west entrance to Secret Pass along the south bank of Secret Creek, eastern edge of section 2, T. 34 N., R. 59 E., a subsidiary fault 1/2 mile west of the main boundary fault is well exposed. The fault plane here strikes N. 35° W. and dips 50 degrees basinward or westward. This is a normal fault, displacement on which has dropped Quaternary gravel and slope-wash detritus down into contact with Miocene basin deposits of the Humboldt formation, figure 10. In Secret Pass the main fault at the west base of the range is marked by a wide zone of gouge and brecciation.

In the places where the boundary faults have actually been observed, the faults are normal. Minor normal faults have been observed within and outside of the area shown on the map, figure 14. No evidence of thrust faults involving the Miocene basin deposits has been found within the area studied. The Miocene sediments are deformed, it is true, but by simple tilting or warping, not by intensive compression.

Several workers, among them Baker (5), Keyes (49), Lawson (53), Smith (80), and Mayo (67) have proposed that at least some of the Basin Ranges are features of

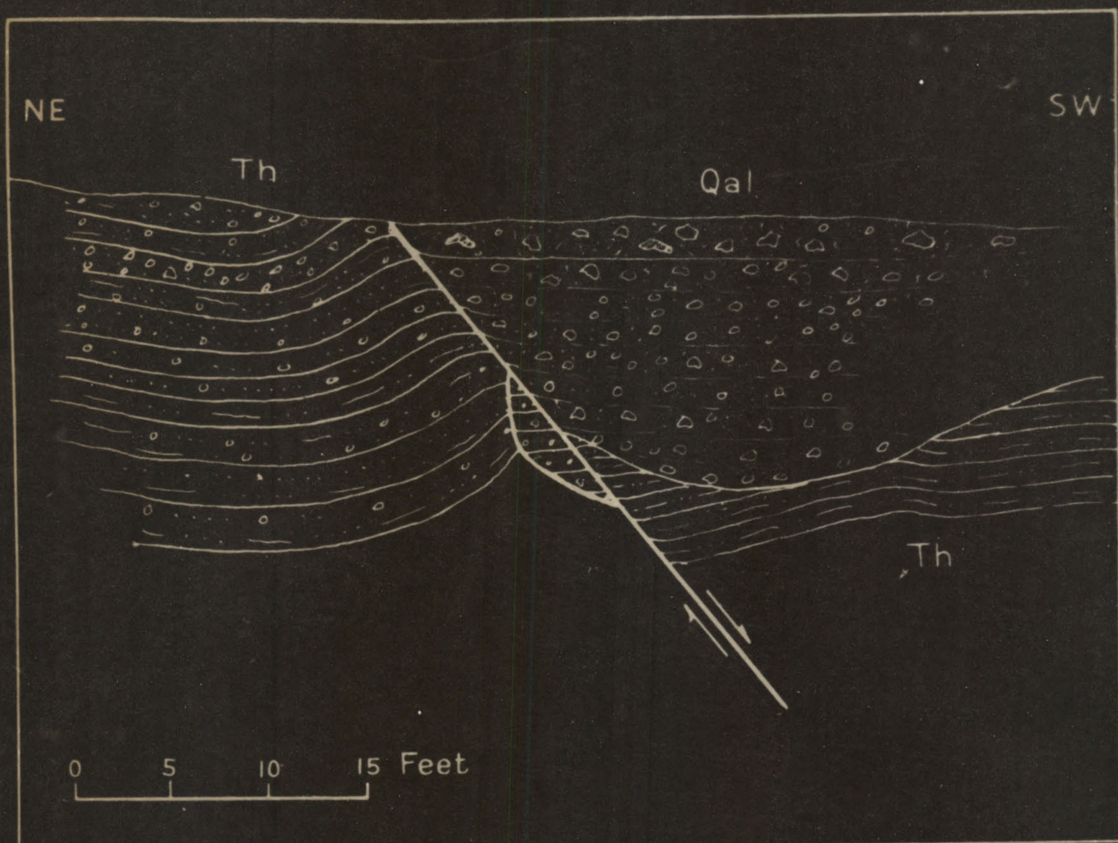


Figure 10
Sketch of a subsidiary fault exposed along the south bank of Secret Creek near the west entrance to Secret Pass. This fault is about one-half mile west of the main boundary fault at the west base of the range. The fault strikes N. 35° W. and dips 50 degrees westward. Qal--Quaternary alluvium, Th-- beds of the Miocene Humboldt formation

Nature of Displacements on the Faults

The general assumption has been that the displacement on the boundary faults has been largely, if not entirely, dip slip. Such seems to have been the case in the Ruby-East Humboldt Range, though some of the latest displacements on the faults have had a large strike-slip component.

Oblique striations have been observed on the plane of a fault at the mouth of Secret Pass, figure 10. This fault strikes N. 35° W. and dips 50 degrees westward. The striations pitch 55 degrees northwestward, or make an angle of 65 degrees with a horizontal line in the plane of the fault. The inclination of the striations indicates that the last movement of the mountain block has not only been relatively upward, but also relatively southward. It is well known that striationson a fault plane indicate only the nature of the last movement, and too much significance cannot be placed upon these oblique striations. In Secret Valley and at the north end of the range along Willow and Clover Creeks, striated fault surfaces indicate that the last movement in these places was essentially a dip-slip displacement.

The fact that some of the larger streams of the western slope swing northward as they approach and emerge from the mountain block might be taken as evidence that the mountain block has been displaced relatively southward. The lack of a similar swing in streams on the east side of the range, and in some of the western streams, too, may be accounted for by the fact that these streams were not and are not intrenched in the basin fill. A moment's consideration will show that a stream must have a confined channel on both sides of a fault to be effected by lateral displacements on the fault.

R. J. Russell (78, p. 454) has also noted some evidence of upward and southward movement of the Warner Range. Gianella and Callaghan have recorded evidence of horizontal displacement on faults which caused earthquakes in western Nevada near Cedar Mountain in 1932 (29, p. 2, 20) and near Excellsior Mountains in 1934 (14, p. 167). Hobbs (42, p. 379) has reported a horizontal displacement of 9 to 16 feet in the Owens Valley, California, earthquake of 1872. Lawson (52, p. 197) notes that oblique striations on a recent fault plane on the east side of the Sierra Nevada, in Carson Valley, indicate relative upward and southward movement of the mountain block. Thus, it seems that there is some evidence that the last fault movements in the Great Basin have been oblique and not simply dip slip.

What the total amount of strike-slip displacement on Basin Range faults may be is unknown. The fact that features, common to faults like the San Andreas, which have large strike-slip components, are not present along the Basin Range faults suggests that the strike-slip displacement is relatively small. The lack of crumpling and structural complications at the ends of the ranges such as would be expected if they had been displaced laterally also suggests that the strike-slip component is small. King (50, vol. I, pp. 742-743) suggested horizontal displacements of as much as five miles on Basin Range faults, but his evidence is not convincing.

The Ruby-East Humboldt Range is a tilted horst, as are other Basin Ranges (1, 2, 28, 51, 78). Tilting of fault blocks means rotation around a horizontal longitudinal axis and infers some sort of adjustment at depth to permit this rotation. Longwell (59) has recently revived the old suggestion that the fault planes are curved at depth. A curved fault plane permits rotation with a minimum of adjustment. The matter is one largely of speculation.

Amount of Displacement on Boundary Faults

An inspection of the various blocks of figure 11 will show that on the east side of the range the difference in altitude between the crest of the range and the base of the Miocene deposits immediately east of the fault gives directly a minimum figure for the vertical component of the dip-slip displacement. The true displacement is greater by the amount of rock which has been removed by erosion from the crest of the range. The situation is entirely different on the west side of the range. Here the vertical component of the dip slip is represented by the thickness of the Miocene deposits immediately west of the fault, plus an unknown thickness of these deposits which has been removed by erosion, plus an unknown thickness of pre-Tertiary rocks eroded from the west slope of the mountain block. The minimum displacements on the west boundary fault are not given by the difference in altitude between the crest of the range and the base of the Miocene deposits immediately west of the boundary fault because of the westward tilting of the mountain block.

The following table gives minimum figures for the vertical component of the dip-slip displacements on the boundary faults at a number of localities. The pre-Miocene surface is assumed to be one of low relief, an assumption supported by the fineness of the basal Miocene deposits. The thickness of basin sediments assumed at each locality is shown in the table.

VERTICAL COMPONENT OF DIP-SLIP DISPLACEMENTS

East side of the East Humboldt Mountains

North to south	Vertical component of dip-slip displacements	Assumed thickness of Miocene deposits
Ralph Creek	4800 feet	1000 feet
Leach Creek	5800 feet	1000 feet
Johnson Creek	4500 feet	700 feet
Polar Star mine	2200 feet	500 feet

East side of the Ruby Mountains

North to south		
Robinson Creek	4200 feet	none known
Smithers Creek	4800 feet	none known
Wines Creek	4600 feet	none known

West side of the Ruby-East Humboldt Range

North to south		
Boulder Creek	2000(?) feet	1000 feet
Secret Pass	1000(?) feet	1000 feet
Thorpe Creek	2000(?) feet	200 feet

The figures are approximate and some of them may be in error as much as a thousand feet and perhaps more. The figures for the west side of the range are all given as questionable and represent the best estimates that can be made with the data at hand. The figures for the east side of the range are given with considerably greater confidence. The actual displacements on the east side are certainly no smaller than the figures given, and they may be much larger. The relative proportions between the displacements on the east and west sides are believed to be about right. The displacement on the east boundary fault has been considerably greater than on the west. The Ruby-East Humboldt Range has not only been uplifted as a horst, but it has been tilted westward in addition.

TERMINATING STRUCTURE OF THE RUBY-EAST HUMBOLDT RANGE

The terminating structure of the Basin Ranges has long been a problem. The two conceptions generally held are: (1) the ranges are terminated by decreasing displacements on the boundary faults, so that in longitudinal section the range looks like a broad anticline, highest in the middle and lower toward both ends, and (2) the ranges are terminated by a cross fault or series of cross faults. The first view has been championed chiefly by Louderback (62, p. 338; 63, p. 667).

The terminating structure of the Ruby-East Humboldt Range has been studied only at the north end near Wells. A structure somewhat different than either of the two outlined above has been found. The crest of the range maintains its usual height, 10,000 to 11,000 feet, to within 3 or 4 miles of the north end of the mountains. A decreasing displacement on the boundary faults in the last 3 or 4 miles explains only part of the termination of the range. A glance at the map, figure 14, shows that the east boundary fault swings westward, and the west boundary fault swings eastward at the north end of the range. The two boundary faults approach each other, and the mountain block narrows progressively between them. At the northern tip of the range, the faults intersect, and the range is terminated.

On the map, the west boundary fault is shown as crossing and terminating the east boundary fault, for a low scarp along the line of the west boundary fault beyond the intersection of the two faults indicates that the latest movement has been on the west boundary fault. At earlier periods, movements on the two faults may have been essentially contemporaneous.

OFFSETS IN THE BASE OF THE RANGE

Offsets, reëntrants, and irregularities along the base of Basin Ranges bounded by a fault are common features and have been explained by different workers in a number of different ways. The west base of the Ruby Mountains is particularly irregular, and it deviates from its general south-southwestward trend to a considerable extent at two places: the mouth of Cold Creek and northeast of Lee between Heenan and Welch Creeks. These offsets are related to bifurcations of the main boundary fault at the base of the range. The main fault in each case swings sharply eastward into a southeast trend, which it follows a short distance before swinging back into the usual south-southwestward trend, figure 14.

This eastward swing in the main boundary fault is accompanied by a corresponding eastward offset in the base of the range. A minor fault, which splits off from the major fault at the point of bifurcation, continues along a line which is roughly the extension of the trend of the fault before bifurcation. This minor fault dies out southward within a few miles. Why the major fault should deviate so sharply from its general trend at the two localities mentioned is not exactly clear, but in the field a striking relation between the trend and shape of the offset and the internal structure of the range has been noted, particularly at the southernmost of the two offsets, between Heenan and Welch Creeks. The internal structure of the mountain block at this offset swings to the east more or less parallel to the trend of the offset in a manner which suggests that the structure of the pre-Tertiary rocks has influenced the trend of the boundary fault. At the Cold Creek offset the relations between internal structure and the trend of the boundary fault are less clear. The relation between internal structure and the trend and configuration of the range is much closer on the west than on the east side. Hulin (45) has recently emphasized the influence which pre-faulting structures may have had on the trend of faults bounding the Basin Ranges, and similar relations have been noted by Eardley (23, p. 389), Ferguson (25, 26), Gilbert, 33, p. 21), and others.

PERIODS OF FAULT MOVEMENTS

Four periods or maxima of Basin Range faulting seem well established in the Ruby-East Humboldt region, and there is some evidence for a fifth. These are: a questionable middle or upper Miocene period, a later middle or upper Miocene period, a Miocene to Pliocene period, a period extending from some time in the Pliocene into the Pleistocene, and a late Pleistocene to Recent period.

The origin of the Miocene areas of deposition in northeastern Nevada is still an unsolved problem. These areas of deposition may have come into being either by faulting or warping. A period of middle or early upper Miocene faulting is a possibility which is as yet unproved. This would be the earliest period of faulting in this region, whereby the basin and mountain blocks were outlined.

In Chapter II a series of slide breccias and fanglomerates, interbedded in the Miocene Humboldt formation, just south of Wells, has been described. These deposits are thought to have been derived from an actively growing fault scarp, a mile to the west. Comparisons with similar deposits described by Longwell (59, 60, 61) indicate that the theory of derivation from an actively growing fault scarp is entirely acceptable. Since these deposits are interbedded in the Humboldt formation, middle or upper Miocene, movement on the faults in middle or upper Miocene time is indicated. All evidence points to the fact that the fault upon which this movement took place is the same as the one which bounds the East Humboldt Mouhtain on the east side today. This period of faulting is later than the questionable faulting which outlined the original area of Miocene deposition.

The relatively fine-grained beds above and below the coarse breccias and fanglomerates show that the faulting represents a distinct break in the preceding and succeeding periods of sedimentation. This second period of faulting is separated from the first by a period of relatively quite sedimentation. Several periods of faulting may have ensued during the deposition of the Humboldt formation, but, since direct evidence for only one period is found, only one period of faulting is listed.

The fault relations between beds of the Humboldt formation and the pre-Tertiary rocks of the mountain block indicate at least one, and possibly several, periods of post-Humboldt faulting. In the Elko Range near Elko, and at the southern end of the East Humboldt Mountains, a series of lavas and lava breccias overlie unconformably, tilted beds of the Humboldt formation. A period of deformation and erosion has ensued between the deposition of the Miocene Humboldt formation and the extrusion of the lavas. Buwalda (12), Louderback (62, 65), and Ferguson (25) among others have noted that the Miocene-Pliocene interval, and the early Pliocene, were marked by deformation and erosion in the western part of Nevada. Similar relations may have obtained in the northeastern section of the state. Therefore, the lavas are tentatively dated as Pliocene(?), and a period of post-Humboldt and pre-Pliocene?lava deformation, presumably faulting, is indicated. This may be called, for convenience, the Miocene to Pliocene period, for it may have occurred any time in the interval from late Miocene to some time in the Pliocene.

The nature of the erosion surface upon which the Pliocene(?) lavas rest indicates that the Ruby-East Humboldt region was reduced to an area of low relief by erosion prior to the extrusion of the lavas. The topography of the Ruby-East Humboldt Range is too sharp and too fresh, particularly the eastern face, to be attributed to the Miocene to Pliocene period of faulting; and the last major uplift of the range, as we see it today, has been somewhat later. Unfortunately, the Pliocene(?) lavas are nowhere directly broken by the boundary faults. However, to the west, in the Elko Range, the Pliocene(?) lavas rest on the top of the range in such relations as to indicate that they were extruded before the Elko Range, a fault block, was uplifted to its present position. Louderback (65) has presented evidence to show that a period of Pliocene-Pleistocene uplift occurred within the Great Basin in western Nevada. The available evidence indicates a period of faulting which may have occurred any time in an interval extending from some place in the Pliocene into the Pleistocene. It is possible that faulting occurred more or less continuously throughout this interval. Pediments and terraces along the east flank of the range are younger than this period of faulting. There is some evidence for believing that these surfaces are not younger than upper Pleistocene, and they may be as old as middle Pleistocene. This period of faulting did not extend beyond the middle or upper Pleistocene and is separated from the succeeding period by an interval of stability during which a series of pediments and terraces were cut.

The latest period of faulting is represented by piedmont scarps on both sides of the range. On the west side, these scarps cut glacial drift which has been correlated with the Iowan substage of the Wisconsin stage of glaciation.

On Heenan Creek, south of Lamoille, outwash gravels of a later Wisconsin glaciation may or may not be cut by a piedmont scarp. The relations at the mouth of Heenan Creek could be explained by stream cutting, so no definite assertion can be made as to the date of the latest faulting in this area. It is certainly later than the Iowan substage of the Wisconsin, and may possibly be post-Wisconsin. This period of faulting may be dated as late Pleistocene to Recent.

It is entirely possible that faulting may have been more or less continuous from the Miocene to the present, and the so-called periods outlined above represent maxima and not necessarily definite, long-separated periods in this faulting. The Ruby-East Humboldt Range may be in the process of being differentially uplifted as rapidly at the present time as at any time in its history.

The following periods or maxima of Basin Range faulting seem to be indicated or well substantiated by the various features of this region.

(1) Pre-Humboldt (middle or upper Miocene) faulting or warping to give rise to the Miocene areas of deposition.

(2) Faulting during the deposition of the Humboldt formation giving rise to slide breccias and fanglomerates.

This period is either middle or upper Miocene depending upon the exact age of the Humboldt formation.

(3) Post-Humboldt-pre-Pliocene?lava faulting. This period may extend from latest Miocene into the Pliocene.

(4) Post-Pliocene?lava faulting. This period may occupy any part of an interval starting some time in the Pliocene and extending well into the Pleistocene, or it may extend throughout this interval. This has been the period of last maximum uplift of the range.

(5) A late Pleistocene to Recent period of faulting represented by piedmont scarps which are known to be post-Iowan substage and possibly post-Wisconsin stage of glaciation.

Ferguson (25) has outlined four periods of Basin Range faulting in the Hawthorne and Tonopah quadrangles of western Nevada as follows:

(1) Pre-Esmeralda (Miocene) or contemporaneous with Esmeralda (Miocene)

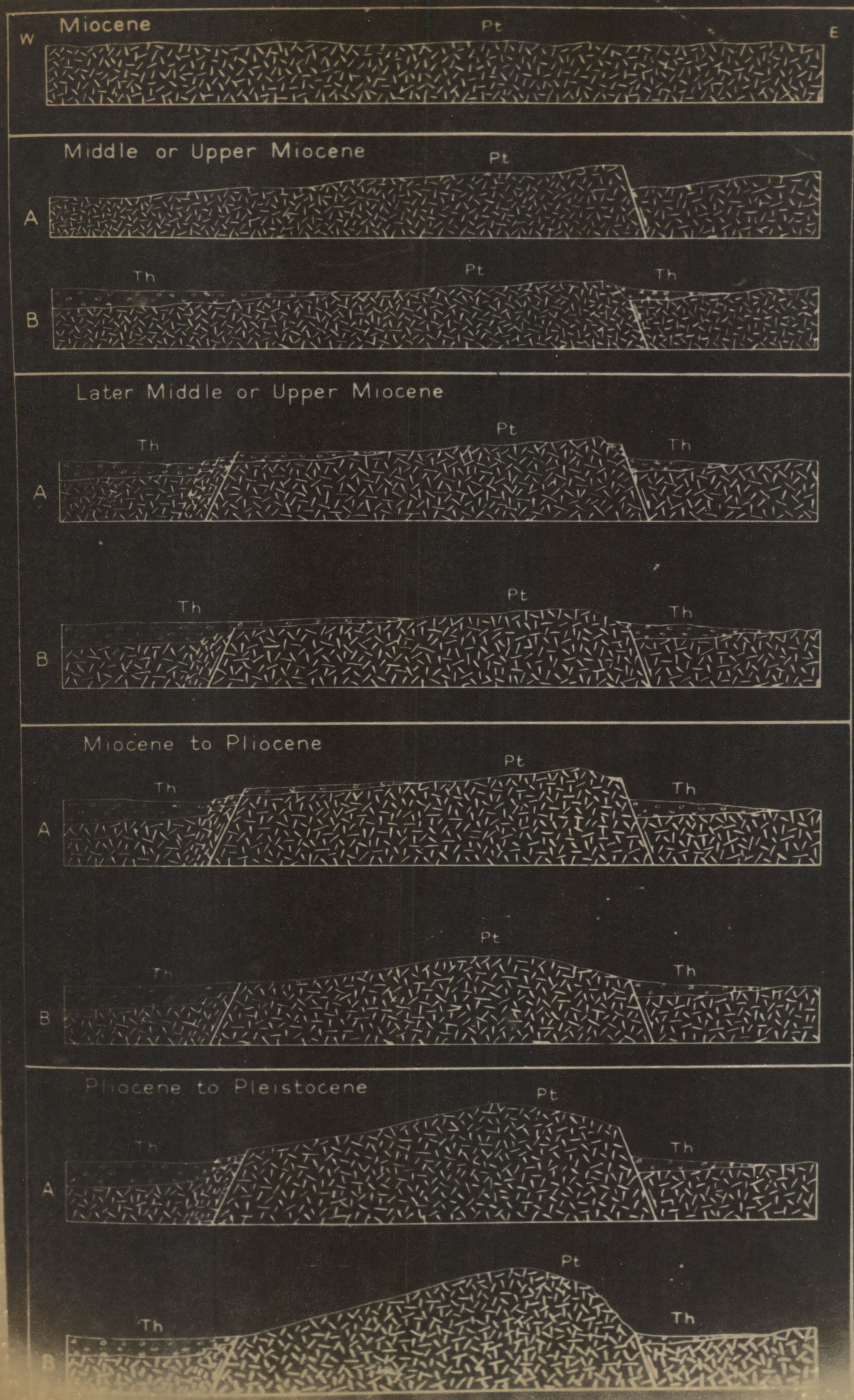
(2) Post-Esmeralda and pre-Pliocene

(3) Early Pleistocene

(4) Late Pleistocene

Figure 11 is a series of diagrammatic cross sections which illustrate the evolution of the Ruby-East Humboldt Range from Miocene to the present. The pre-faulting surface is assumed to be a surface of low relief, practically a peneplain, which is in keeping with what is known in this area and in the Great Basin as a whole. The initial deformation is assumed to be faulting, though no definite proof of this is forthcoming, and the initial deformation may have been warping. In each pair of sections, it is assumed that all erosion takes place after and not during the faulting, an incorrect assumption, but one which does not materially alter the relations as shown in the sections. No faulting is postulated at the western base of the range until the second period. The exact time at which faulting was initiated at the west base of the range is not known and may have been earlier or later than shown. Two small faults are shown west of the principal fault at the west base of the range. One such subsidiary fault has been observed, and the highly deformed Miocene beds along the west base of the range would seem to indicate that others are present.

The surface of low relief upon which the Pliocene(?) lavas have been extruded indicates a considerable erosion


W
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Pliocene to Pleistocene
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interval after the post-Humboldt-pre-Pliocene(?) lava period of faulting. The relief of the Ruby-East Humboldt Range was probably not over 2000 feet before the Pliocene to Pleistocene faulting. Eardley (22) has presented good evidence which shows that the Wasatch Mountains had a pre-faulting relief of 2000 to 3000 feet. He does not consider the possibility that this relief may have been related to a period of faulting earlier than the last maximum uplift.

The last pair of sections (Pliocene to Pleistocene) show the crest of the range a short distance west of the top of the east scarp. This is the case in many places in the range, but not in all. In other places, the Pliocene to Pleistocene crest of the range must have been east of the present crest; for the westward-flowing streams head in broad, open saddles at the crest and have clearly been beheaded by the shorter, steeper streams of the east side which are actively engaged in driving the drainage divide westward.

The last maximum uplift of the Ruby-East Humboldt Range has been in the interval extending from some place in the Pliocene to middle or upper Pleistocene. Eardley (22) has presented evidence which indicates that the last major uplift of the Wasatch Mountains has been late

Tertiary or early Pleistocene. Eaton (24, p. 39) holds that the block faulting of the Great Basin reached a maximum in the upper Pleistocene. Knopf (51, p. 13, p. 88) states that the major uplift of the Sierra Nevada took place at the beginning of the Quaternary. Louderback (65) has concluded that the period of maximum faulting in the western Great Basin was late Pliocene or early Pleistocene. R. J. Russell (78, p. 495) concurs with this view.

In summary, the period of maximum faulting in the Great Basin seems to be latest Tertiary and Quaternary. The Pliocene to Pleistocene period of last maximum uplift of the Ruby-East Humboldt Mountains fits in well with this conception.

PIEDMONT SCARPS

General Statement

The Great Basin as a whole, and Nevada in particular, might well be called the type locality for piedmont scarps. Piedmont scarp was the name given by Gilbert (33, p. 34) to a low fault scarp which breaks the piedmont (fan, bajada) or alluvial slopes which descend from the base of the principal scarp of a Basin Range. Longwell (58, p. 1) has proposed that fan scarp would be a better term, but piedmont scarp seems so well intrenched in the literature that it will be used here.

Piedmont scarps may be located immediately at the base of the principal scarp or some distance out on the piedmont slope. They have been described from a great number of places in the Great Basin by Gilbert (32, 33), I. C. Russell (74, 75, 76, 77), Baker (4), Knopf (51), Louderback (62, 63), Lawson (52), Lindgren (55), Davis (17), Hobbs (42), Longwell (58), R. J. Russell (78), Taber (83), Page (69), Gianella (29), and others.

Features of the Piedmont Scarps of the Ruby-East Humboldt Mountains

Piedmont scarps are prominent features along the west base of the Ruby-East Humboldt Range from the northern end south to a few miles north of Lee. South of Lee no piedmont scarps have been noted. Two scarps which may truly be classified as piedmont scarps, though somewhat older than those of the west side, will be described from the east side of the range.

Near the north end of the East Humboldt Mountains at the mouth of Greys Creek is a piedmont scarp, 75 feet high, which cuts fan gravels at the mouth of the creek, Plate XI . The lower part of the scarp may be bedrock, but the overlying gravels slump down and cover the entire face of the scarp. About 75 feet in front of this scarp, parallel to it, is a low scarp, 20 feet high, seemingly composed of gravel, which faces toward the mountain. A low, graben-like depression separates the two scarps, Plate XII. About 75 feet beyond this second scarp is another mountainward-facing scarp, lower and more subdued than the first. These scarps extend for several hundred feet parallel to the strike of the mountain front. They are clearly not features of stream erosion and may reasonably be attributed to recent movement on the main boundary fault. Gilbert (33, pp. 36-37) has proposed an explanation for these graben and subsidiary piedmont scarps, and his explanation has been accepted by Longwell (58) and Page (69). Taber (83, p. 667) has criticised Gilbert's mechanism, and some further objections are outlined here.

The explanation outlined by Gilbert supposes that the fan gravels or alluvium rest directly against a fault plane, the footwall of which is bedrock, figure 12, A. Whether the alluvium came into this position by an earlier faulting or by deposition, he does not state. When movement occurs on this fault, the hanging wall moves relatively upward carrying a part of the alluvial deposit with it as shown in figure 12, B. The intervening depression or trench is quickly filled, completely or in part, by detritus from both sides, figure 12, C. The double depression at Greys Creek could be explained by two separate pieces of alluvium clinging to the upthrown block. Gilbert has also suggested that a slice or block of gravel may slump and spread during the fault movement and form a graben-like depression as shown in figure 12, D. Gilbert further admits that some piedmont scarps are probably the direct continuation of fault surfaces in the underlying bedrock.

The explanation outlined by Gilbert is in need of modification on two points. In Gilbert's figures, figure 12, the dip of the fault plane is 33 degrees, which is much too low. Furthermore, Gilbert assumes that the initial relations are those of alluvium resting against the fault face, which is not the case except in rare instances. Figure 13, A, represents more truly the relation of alluvium, fault, and bedrock before faulting. The alluvium covers the fault and laps over onto the mountain block. Movement on the fault could produce a trench in the overlying gravel like that shown in figure 13, B. Subsequent slumping and washing of gravel from both sides would fill the open trench in the same manner as outlined by Gilbert, Figure 13, C.

Some graben and piedmont scarps may be formed in the manner outlined above; others probably represent, directly, breaks in the underlying bedrock. Complex distributive faulting would be expected in a wide fracture zone which forms the boundary fault of the mountain block, and within this zone slices or blocks may be relatively depressed in such a manner that a graben-like depression would be formed in the overlying gravel.

Remnants of a piedmont scarp appear immediately south of Thorpe Creek and extend more or less continuously for 9 miles south along the west base of the Ruby Mountains. This scarp cuts moraines correlated with the Iowan substage of the Wisconsin glaciation at the mouths of Lamoille and Seitz Creeks. (The Pleistocene glacial succession outlined by Thwaites (85, p. 72) is followed here.) Outwash gravels associated with an even younger substage of the Wisconsin glaciation are cut by a 20-foot scarp at the mouth of Heenan Creek. This scarp is on a line with remnants of the piedmont scarp exposed at other places along the base of the range. However, it cannot be stated with certainty that the faulting is younger than these outwash gravels, for the relations at the mouth of Heenan Creek could be explained by stream erosion.

On the east side of the Ruby Mountains, extending from Smithers Creek south to Battle Creek, a distance of 10½ miles, is a striking piedmont scarp, 1/4 to 1 mile in front of the face of the range. This scarp is well exposed near Lutts Creek and for the sake of brevity will be referred to as the Lutts scarp. The face of the Lutts scarp is composed of limestone intruded by pegmatitic and granitic rocks. In places, overlying pediment gravels have slumped down over the face of the scarp and have covered the underlying bedrock. However, as far as can be seen, the scarp is nowhere composed of gravel, and in this sense it differs from the piedmont scarps on the west side of the range. The Lutts scarp is highest between Lutts and Thompson Creeks, ranging from 150 to 200 feet high. South of Thompson Creek it decreased gradually in height and disappears south of Battle Creek. To the north of Lutts Creek the scarp also decreased in height and disappears just south of Smithers Creek. Just south of Lutts Creek the measured slope of the scarp is 30 degrees; presumably the dip of the fault plane is much steeper.

A dissected pediment, cut on limestone and igneous rock, lies between the Lutts scarp and the base of the mountains. No evidence of a fault has been found at the base of the mountain slope, though a diligent search has been made, and it seems likely that the Lutts scarp represents a late displacement along the main boundary fault. This means that the mountain front has been worn back to its present position, leaving a pediment between it and the boundary fault. This pediment is broadest, 1-1/4 miles, near Thompson, Moose, and Moore Creeks, and decreases noticeably in breadth south toward Battle Creek, where it is only a few hundred yards wide. To the north of Thompson Creek the pediment is 1/2 to 3/4 miles wide. The more massive and resistant outcrops of igneous rock stand up as low residuals on this surface. The pediment is capped with gravel only near Thompson and Moore Creeks.

Terraces at approximately 100 feet and 50 feet above stream-grade along Lutts Creek between the Lutts scarp and the mountain front, and a few terrace remnants on other streams, indicate that the uplift of the Lutts scarp may have been in stages, separated by short intervals of erosion.

The age of the Lutts scarp cannot be exactly determined. It is dissected to a depth of about 200 feet by large streams such as Lutts, Thompson, and Moore Creeks.

Small headward working canyons have been cut in the scarp face and have extended back as much as a half mile from the front of the scarp. The general topographic features of the Lutts scarp suggest that it is not older than Pleistocene, though it hardly seems as young as the late Pleistocene or Recent scarps described from the west side of the range.

A scarp similar to but less spectacular than the Lutts scarp has been mapped farther south near Dawley Creek. This scarp extends for 1½ miles along the front of the range. It is highest, 125 feet, near the middle and decreased in height toward both ends. The scarp face is composed of binary granite. A pediment 1/4 to 1/3 mile wide has been cut on the granite between the scarp and the base of the mountain slope. This scarp is particularly notable for the great number of springs which emerge along its base. As far as can be seen, everything said about the age and nature of the Lutts scarp holds for this scarp too.

Farther south toward Harrison Pass, are a number of low escarpments cut in the fans in front of the range. These escarpments might be taken for piedmont scarps, but study has shown them to be features of lake-shore erosion, associated with the lake which filled Ruby Valley in late glacial or post-glacial time.

Why the fault movements on the west side of the range should be younger than on the east side is not entirely clear. The suggestion is offered that the latest movements on the west side may be something of a reaction caused by earlier uplift and tilting of the mountain block at the time the Lutts scarp was formed. The initial deformation at the west base of the range at the time of this uplift would be a sort of flexing. At a later date, additional light stresses may have caused the flexed rocks to fracture giving rise to the piedmont scarps now seen on the west side of the range.

Age of Piedmont Scarps

The exact age of piedmont scarps is often difficult to determine. Some are known to be historical: Owens Valley, Calif., 1872 (42); Pleasant Valley, Nevada, 1915 (69); Cedar Mountain, Nevada, 1932 (29). Piedmont scarps younger than the shore features of Lake Bonneville and Lake Lahontan have been described by Gilbert (32, 33) and I. C. Russell (75, 77). Other piedmont scarps appear to be older than these lakes because they are not nearly so well preserved as the shore features of the lakes. Piedmont scarps cutting glacial moraines at the base of Great Basin Ranges have been described by I. C. Russell (77, p. 302) and Gilbert (33, p. 32;

32, pp. 346-347). At the west base of the Ruby Mountains glacial drift correlated with the Iowan substage of the Wisconsin glaciation is cut by a piedmont scarp. Piedmont scarps are certainly features of the Pleistocene and Recent.

ABSOLUTE MOVEMENTS OF BASIN AND MOUNTAIN BLOCKS

General Statement

The relative movement of mountain and basin blocks is clear. The mountains have gone up, the basin down, relative to each other. The nature of the absolute movements of the basin and mountain blocks with respect to a pre-faulting datum plane is another matter. The mountains may have risen while the basin remained fixed, or vice versa, or both blocks may have moved either in opposite directions or in the same direction but to different degrees.

Page (69, pp. 703-704) has recently expressed the opinion that both the mountain and basin blocks were active in the 1915 Pleasant Valley earthquake in west-central Nevada. R. J. Russell (78, p. 492) has presented an extended discussion of features related to the Warner Range of northeastern California and has concluded that the mountain blocks have risen above, and the basin blocks have sunk below, a former level datum plane represented by a large area of horizontal lavas in northern California and southern Oregon. The rising of the mountain blocks above this level is several times greater than the sinking of the basin blocks. Russell (78, p. 494) further points out that the latest movement along the east side of the Warner Range (Surprise Valley) and elsewhere in the Great Basin has been a sinking of the basins. This is shown by the fact that the Quaternary lake terraces, which lie on the mountainward side of recent piedmont scarps, are unwarped. The terraces are clearly older than the piedmont scarps. If the mountain block had been active, the terraces would be warped; for the height of the piedmont scarp and other features indicate that the displacement has not been uniform over any great distance.

Jenney (46) has used the same argument but in the opposite sense for the Humboldt Range of west-central Nevada. Jenney states that Quaternary lake terraces are located on the basin side of recent piedmont scarps, and, since they are unwarped, the mountain blocks must have risen while the basin blocks remained stationary.

Eardley (22, p. 265), as a result of studies in the southern Wasatch Mountains, has suggested that the mountain block rose and the basin block to the west sank, and both tilted eastward. Ferguson (25) likewise holds for absolute uplift of certain horsts and absolute depression of certain graben in western Nevada. Fuller and Waters (28, pp. 212-213) have noted evidence of absolute sinking of the Guano graben in southern Oregon. Lawson (52, p. 199), Lindgren (55, p. 41), and I. C. Russell (77, p. 303) have stated that the position of lakes, streams, and swamps at the base of the eastern scarp of the Sierra Nevada indicates absolute depression of the basin block to the east of the mountains. This argument is not sound with regard to closed basins, for a westward tilting without absolute depression of the basin block would give the same results. Surveys by I. C. Russell (77, p. 303) show that the terraces of Mono Lake at the east base of the Sierra Nevada have been tilted westward. Therefore, an absolute depression of the basin block east of the Sierra Nevada remains unproved. In another study, I. C. Russell (75, p. 282) states that a majority of the mountains in the western Great Basin have moved absolutely upward.

Absolute Movement of the Ruby-East Humboldt Block

Ruby Valley, a closed, detritus-filled basin, bounds the Ruby Mountains on the east side. In most places, the detrital filling of Ruby Valley extends to the base of the mountain slope. In the places where streams have cut through this detrital cover a pediment cut on the pre-Tertiary rocks of the mountain block is exposed. There can be little doubt that the entire eastern base of the Ruby Mountains is flanked by a pediment cut on the hard, pre-Tertiary rocks of the mountain block. The largest exposed area of this pediment is in a 10½-mile long strip extending from Smithers Creek to Battle Creek. In this area the pediment is bounded on the east or basinward side by a piedmont scarp, the Lutts scarp, which is 200 feet high in its highest part near Lutts and Thompson Creeks. The pediment extends westward from the Lutts scarp across pre-Tertiary rocks to the base of the mountain slope. The pediment is 1/4 to 1 mile wide. Diligent studies failed to reveal any fault between the mountain slope and the pediment. The conclusion seems justified that the mountain face has receded from the boundary fault to its present position by erosional retreat, leaving behind the pediment as an erosional remnant. The position of the boundary fault is indicated by renewed movement which has produced the Lutts scarp.

The pediment is dissected by the streams which flow across it, and the depth of dissection shows such close relations to the height of the Lutts scarp as to leave little doubt that the dissection of the pediment is due to the faulting which gave birth to the Lutts scarp. Relative upward movement of the mountain block or relative downward movement of the basin block could account for the dissection of the pediment. North and south of the Lutts scarp the pediment is mantled by a detrital cover and is undissected. Prior to the faulting which produced the Lutts scarp, the whole front of the Ruby Mountains in this section was flanked by a detritus-mantled pediment, which, though not absolutely smooth, was graded to a common base level, the low part of Ruby Valley. The detritus-mantled pediment and the surface of the detrital filling of Ruby Valley formed a more or less graded surface which sloped gently toward the low part of Ruby Valley. Large areas of this surface are still preserved today and indicate that then, as now, the low part of Ruby Valley was the area occupied by Franklin Lake, 10 miles south of the Lutts scarp.

If the absolute movement which caused the dissection of the pediment west of the Lutts scarp had been a dropping of the basin block, that part of the basin along the Lutts scarp should be lower than the parts immediately to the north and south. The topographic map (Halleck quadrangle) shows that such is not the case. The basin immediately east of the Lutts scarp is part of a graded detrital surface which slopes gently southward toward Franklin Lake. If that part of the basin east of the Lutts scarp had been dropped 200 feet absolutely, it would be the lowest place in this part of Ruby Valley, and Franklin Lake should lie at the base of the Lutts scarp.

The argument might be advanced that the part of Ruby Valley which contains Franklin Lake has been depressed at a later time, hence, the present position of Franklin Lake. The lack of dissection of the pediment at the east base of the Ruby Mountains near Franklin Lake shows that the Franklin Lake area has not been lowered.

The other alternative is that the pediment west of the Lutts scarp has been exposed and dissected because of absolute upward movement of the mountain block along the Lutts scarp, and the lack of evidence of depression of the basin indicates that this is the case.

An absolute upward movement of 200 feet of the mountain block is indicated by dissection of the pediment west of the Lutts scarp. This is a relatively young movement (late Pleistocene ?) and does not necessarily mean that all the displacement on the boundary fault at the east base of the Ruby Mountains has been an absolute upward movement of the mountain block.

The glaciation of the Ruby-East Humboldt Range is discussed in Chapter IV. Two substages of the Wisconsin glaciation are recognized, but no good evidence of an earlier stage of glaciation has been found. The suggestion may be advanced that the mountains were not high enough to have been glaciated in the earlier periods. Eardley (23, p. 400) has suggested that the lack of pre-Iowan glaciation in the Wasatch Mountains might be accounted for by the fact that the range has attained its present altitude only in post-Iowan time. If the Ruby-East Humboldt Range were not high enough to be glaciated in the earlier periods of glaciation, considerable absolute upward movement of the mountain block is indicated for the later part of the Pleistocene. The objections which may be advanced to this idea are: (1) The evidence of earlier glaciations may have been entirely destroyed or so far modified as to be unrecognizable. (2) Pediments on the west side of the range extend unbroken across both Miocene basin sediments and the pre-Tertiary rocks of the mountain block. This relation indicates no differential displacement of the mountain and basin blocks since the surfaces were cut. The exact age of these pediments is not known, but they appear to be older than the Wisconsin glaciation and may be as old as middle Pleistocene. If the surfaces are as old as middle Pleistocene, the mountain block has not been differentially uplifted in the late Pleistocene.

In summary, it may be said that at least one of the latest displacements along the east boundary fault has been an absolute upward movement of the mountain block; and it is suggested, but by no means proved, that considerable absolute upward movement of the mountain block has occurred.

FORCES INVOLVED

Recent trends have been to emphasize the importance of compression in at least the western part of the Great Basin - Hewett (37, 38), Mayo (67), Lawson (52), Smith (80), Baker (5) and Keyes (49). As pointed out earlier in this chapter, the thrusting and other features of compression in the western Great Basin may be due to an overlapping influence from the California Coast Range observed on the west side of the Ruby Mountains. These pediment remnants have been correlated with more extensive and better preserved pediments cut on the Miocene basin deposits and the pre-Tertiary rocks of the mountain block along other parts of the range. Detailed study of pediments and terraces on the west side of the range show that their dissection is due to rejuvenation of the Humboldt River drainage by some cause outside of the area and is not related to differential displacements of the range and adjoining basin. In other words, the high pediment remnants on the mountain block are in their present isolated position not because of uplift of the range but because of erosional removal of the soft Miocene sediments in the basin. In these places 500 to 700 feet of the scarp must be a fault-line scarp.

In summary, both the eastern and western faces of the Ruby-East Humboldt Range are composite fault scarps, hence not strictly true fault scarps or fault-line scarps. Cotton (15, p. 161) has suggested that scarps affected by recent displacements be called rejuvenated scarps. Thus, the scarps on both sides are in places rejuvenated composite scarps. It is likely that other scarps of the Great Basin are composite scarps, especially in those areas in which the adjoining basins are filled with soft Tertiary deposits.

FACTORS DETERMINING EXTENT OF GLACIATION

The reason why certain parts of the same mountain range have been more extensively glaciated than other parts has been discussed by a number of workers, more recently by Matthes (23, pp. 51-53). It is generally recognized that altitude is a factor of prime importance, not only because of relatively heavier snowfall at higher altitudes, but because the lower temperature and rarefied atmosphere prohibit quick melting of the snow and ice. The relation between altitude and glaciation is well shown in the Ruby-East Humboldt Range, for the areas of heaviest glaciation coincide exactly with the high areas of the range.

Secondly, it is known that wind shadows and sun shadows are places particularly favorable for the collection and preservation of snow. These relations are again clearly exemplified in the Ruby-East Humboldt Range, for Lamoille and Rattlesnake Canyons contained the longest glaciers of the range. A glance at the map will show that the upper parts of both these canyons turn south and head in northerly exposed cirques. The upper parts of both these canyons are in sun shadows. They are further protected by a high ridge immediately to the west which puts them in a wind shadow, for the storms which brought precipitation to this area came from the west. In addition, both canyons head in areas of high altitude.

The comparative shortness of the glaciers on the east slope may be accounted for largely by three factors. First, the east side of the range lies in a precipitation shadow, for storms coming from the west drop their supply of moisture on the west side of the range. Analogous conditions must have attained in the late Pleistocene. Secondly, as pointed out earlier in the chapter, many of the canyons of the east slope have open, amphitheater-like heads. This means that these canyons have a large catchment area, but that the snow and ice, in most of them, was spread over too large an area to form a powerful glacier. It is true that if the ice ever reached the confined parts of these canyons, a well-defined ice tongue was formed. However, the confined parts of the canyons are so far down the slope that the ice would have to pass well into the zone of wastage before reaching them. The third factor is the steepness of the floors and walls of the upper parts of the canyons on the east side. On such steep slopes, snow cannot gather to any great depth before it is removed by slides and avalanches. These slides and avalanches moved the snow from high places into or near to the zone of wastage where it melted more rapidly. The net effect was to decrease the supply of ice.

The statement is often made that snow blows over the crests of mountains onto the lee side; hence the lee side of a range will have the largest glaciers. Such has clearly not been the case in the Ruby-East Humboldt Range. Not enough snow was blown over the crest of the range to compensate for the natural handicaps of the east side. That some snow did blow over the crest of the range seems to be shown by the fact that Lutts Creek, one of the largest creeks on the east side, which has a large area for snow storage at its head, was only slightly glaciated. Smaller canyons to the north and south of Lutts Creek carried much large glaciers. Lamoille Canyon lies immediately over the crest to the west of Lutts Creek. The snow which ordinarily would have blown over the crest of the range, if Lamoille Canyon had not been there, was trapped in Lamoille Canyon, and Lutts Creek was robbed of its share of wind-blown snow. A glance at figure 16 will help to emphasize these relations.

LATE PLEISTOCENE OR RECENT UPLIFT OF THE RANGE

Pleistocene glacial moraines broken by fault scarps have been reported from ranges of the Great Basin by Gilbert (16, p. 32; 15, p. 346-347) and Russell (32, p. 302). Moraines of the Lamoille substage, which lie on the piedmont slope west of the Ruby Mountains at the mouths of Lamoille and Seitz Creeks, are broken by a fault scarp, 30 to 50 feet high. An escarpment, 20 feet high, in outwash material of the Angel Lake substage at the mouth of Heenan Creek, may indicate faulting later than the Angel Lake substage. This scarp appears only on one side of the creek, and it is possible that it is a feature of stream erosion and not faulting.

The Ruby Mountains have been relatively uplifted by faulting along the west base at least as recently as post-earlier Wisconsin and possibly as recently as post-later Wisconsin. The lack of evidence of glaciations earlier than the Lamoille substage may be advanced as an argument that the Ruby-East Humboldt Range reached its present altitude only in late Pleistocene time.

SUMMARY

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

The various criteria useful in this range for the differentiation of substages of glaciation have been discussed briefly. Application of these criteria to the various glacial features of the Ruby-East Humboldt range shows that the range has been glaciated by two distinct ice advances. The older of these advances has been named the Lamoille substage of glaciation, and the younger has been named the Angel Lake substage of glaciation. Both these substages are thought to be Wisconsin. Evidence for earlier glaciations is poor and the suggestion is offered that either the features of earlier stages have been entirely destroyed or so far obscured as to be unrecognizable, or else the mountains were not high enough to be glaciated before the Wisconsin.

The correlation of the ice advances in the Ruby-East Humboldt Range with those recorded in the Sierra Nevada and in the central United States outlined by Blackwelder (8, p. 918) is followed. The older, or Lamoille substage, is thought to be the same as the Tahoe stage in the Sierra Nevada, which in turn is correlated with the Iowan of the central United States. The Angel Lake substage is thought to be the same as the Tioga stage of the Sierra Nevada, which is Wisconsin.

In keeping with the present consensus of opinion in the central United States, the Iowan is considered the lowermost substage of the Wisconsin. Thus, the Lamoille substage is lowermost Wisconsin. Weathering and dissection of the Lamoille substage drift and the detrital filling of canyons indicate a considerable time interval between the two substages of glaciation. This interval is thought to be long enough to place the Angel Lake substage in the later Wisconsin. Pauses in the retreat of the ice of the Angel Lake substage may be related to subdivisions of the later Wisconsin period recognized in the central United States.

The glaciers of the Lamoille substage were more extensive than those of the Angel Lake substage. Lamoille Canyon contained the longest glaciers of the range. The Lamoille Canyon glacier was 12 miles long in the Lamoille substage and 8 miles long in the Angel Lake substage of glaciation. The ice descended to its lowest altitude, 6100 feet at the mouth of Lamoille and Seitz Canyons. Ice emerged from the mountains onto the forelying piedmont slope in several localities on both the east and west sides of the range. The amount of bedrock erosion since the Lamoille substage has been 50 feet at a maximum. Bedrock erosion since the Angel Lake substage has only been 5 to 7 feet at the most.

Uplift of the range since the Lamoille substage of glaciation is indicated by low fault scarps which break the moraines of that stage along the west base of the range near Lamoille and Seitz Creeks.

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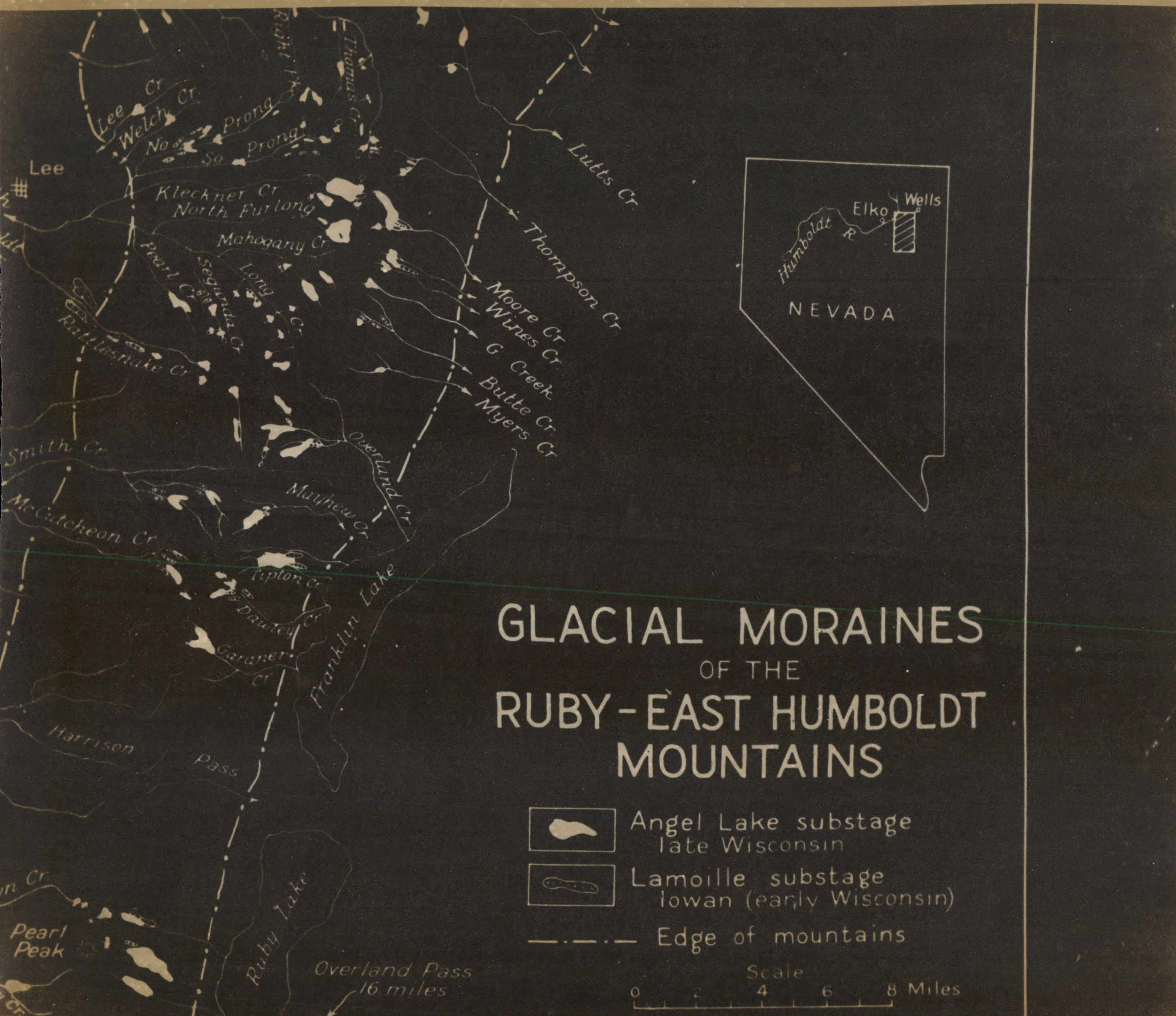
115° 30'
20'
10'
41° 00'
50'
40'
Wells 3 miles
Elko 8 miles
Halleck
Lamoille
Humboldt River
Greys Cr
Trout Cr
Clover Cr
Willow Cr
Herder Cr
Angel Cr.
So Fk Angel Cr
Ackler Cr
Schoer Cr
Ralph Cr.
Boulder Cr
Winchell Cr.
Leach Cr
Weeks Cr
Steels Cr
Johnson Cr
Secret Pass
Pole Cr
Soldier Cr
Cold Cr
Snow Water Lake
Thorpe Cr
Conrad Cr
Talbot Cr
Seitz Cr
Heenan Cr
Young Cr
Brennen Cr
Lamoille Cr
Robinson Cr.
Withington Cr



GLACIAL MORAINES
OF THE
RUBY-EAST HUMBOLDT
MOUNTAINS
Angel Lake substage
late Wisconsin
Lamoille substage
Iowan (early Wisconsin)
Edge of mountains
Scale
0 2 4 6 8 Miles
NEVADA
Elko
Wells
Humboldt R
Lee
Lee Cr
Welch Cr
No Prong
So Prong
Right Fk
Thomas Cr
Lutts Cr
Kleckner Cr
North Furlong
Mahogany Cr
Thompson Cr
Pearl Cr
Segunda Cr
Long Cr
Rattlesnake Cr
Moore Cr
Wines Cr
G. Creek
Butte Cr
Myers Cr
Smith Cr
Overland Cr
Mayhew Cr
McCutcheon Cr
Tipton Cr
Dawley Cr
Gardner Cr
Franklin Lake
Harrison Pass
Ruby Lake
Pearl Peak
Overland Pass
16 miles

march again. In places, the westward migration has extended far enough to behead some of the westward-flowing streams; good examples are some of the branches of Thorpe, Cold, and North Furlong Creeks.

GEOMORPHIC FEATURES OF THE WEST FLANK AND THE ADJOINING BASINS

The various geomorphic features of the west flank of the range and the adjoining basins to the west have been developed under a régime of exterior drainage. The most striking and best-developed erosion surfaces, pediments and terraces, are on the west side of the range. Remnants of these surfaces are particularly well preserved in four areas along the west base of the range. From north to south these are:

(1) A narrow strip, 2 to 3 miles wide, at the western base of the East Humboldt Mountains extending from Secret Pass 13 miles north to Herder Creek. The pediments and terraces of this area are particularly well preserved along Ackler, Deering, and Boulder Creeks, figure 20. Hereafter, this area will be referred to as the Boulder Creek area.

(2) A smaller area just northeast of Lamoille at the west base of the Ruby Mountains. The surfaces of

this area are best preserved along Cold, Thorpe, Talbot, and Conrad Creeks, figure 21. This will be called the Thorpe Creek area.

(3) Along the various tributaries of the South Fork of the Humboldt River, both upstream and downstream from the town of Lee, figure 22. This will be called the South Fork area.

(4) Along the west base of the Ruby Mountains east of Jiggs, particularly along Smith, McCutcheon, and Gilbert Creeks, figure 23. This will be called the Smith Creek area.

The northern two areas are drained by streams tributary to the East Fork of the Humboldt River. The southern two areas are drained by streams tributary to the South Fork.

In nearly all of these areas, remnants of two pediments and three terraces or partial pediments have been recognized. In several places, remnants of a fourth and lower terrace have been noted; and along the South Fork of the Humboldt River, a fifth, and even lower, terrace has been mapped. These surfaces have been numbered successively from higher to lower, so that the highest surface, a pediment, is surface #1; the next lower surface, also a pediment, is surface #2, and so on.

The #2 surface has been named the Lee surface because it is the best-preserved and most extensive of the series. The Lee surface indicates an extended period of stability and it has been named in order to facilitate correlations with neighboring areas.

The following table gives figures on the heights of these various surfaces above present stream level. Most of the measurements have been made by hand-levelling with a Brunton compass; some have been taken from the topographic map. In all cases, the measurements have been made to the top of the surfaces, and not to the contact between the gravel which caps the surface and the underlying rocks. This has been done, because in nearly all places the overlying gravel has slumped down so extensively that the contact between the gravel and the underlying rock has been entirely buried. Thus, the heights of the surfaces as listed include from 5 to 25 feet of gravel. The figures are given in groups corresponding to the four areas outlined above. The streams within any one area are listed from north to south. The figures represent height in feet of the surfaces above present stream level and are arranged in vertical columns; the column for surface #1 is at the left, and the columns for lower surfaces are progressively

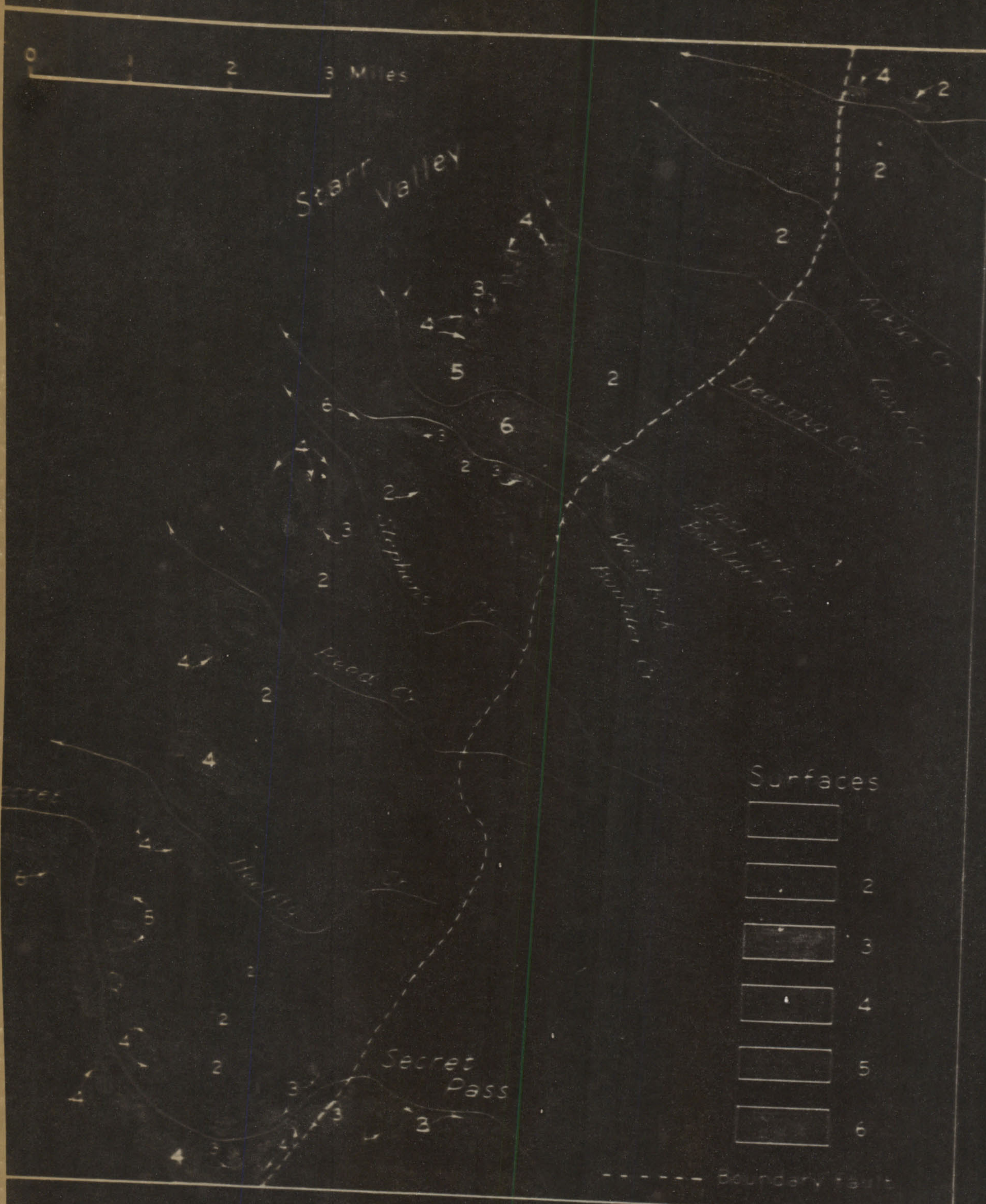


Figure 1[illegible]

[illegible]ap of a series of pediments and terraces in the [illegible] er Creek area on the west side of the [illegible] Humboldt [illegible] untains. The surfaces are cut largely on soft Tertiary basin deposits, but in places they cross the boundary fault and cut across the hard, pre-Tertiary rocks of the mountain block. See figure 1[illegible] for exact location.

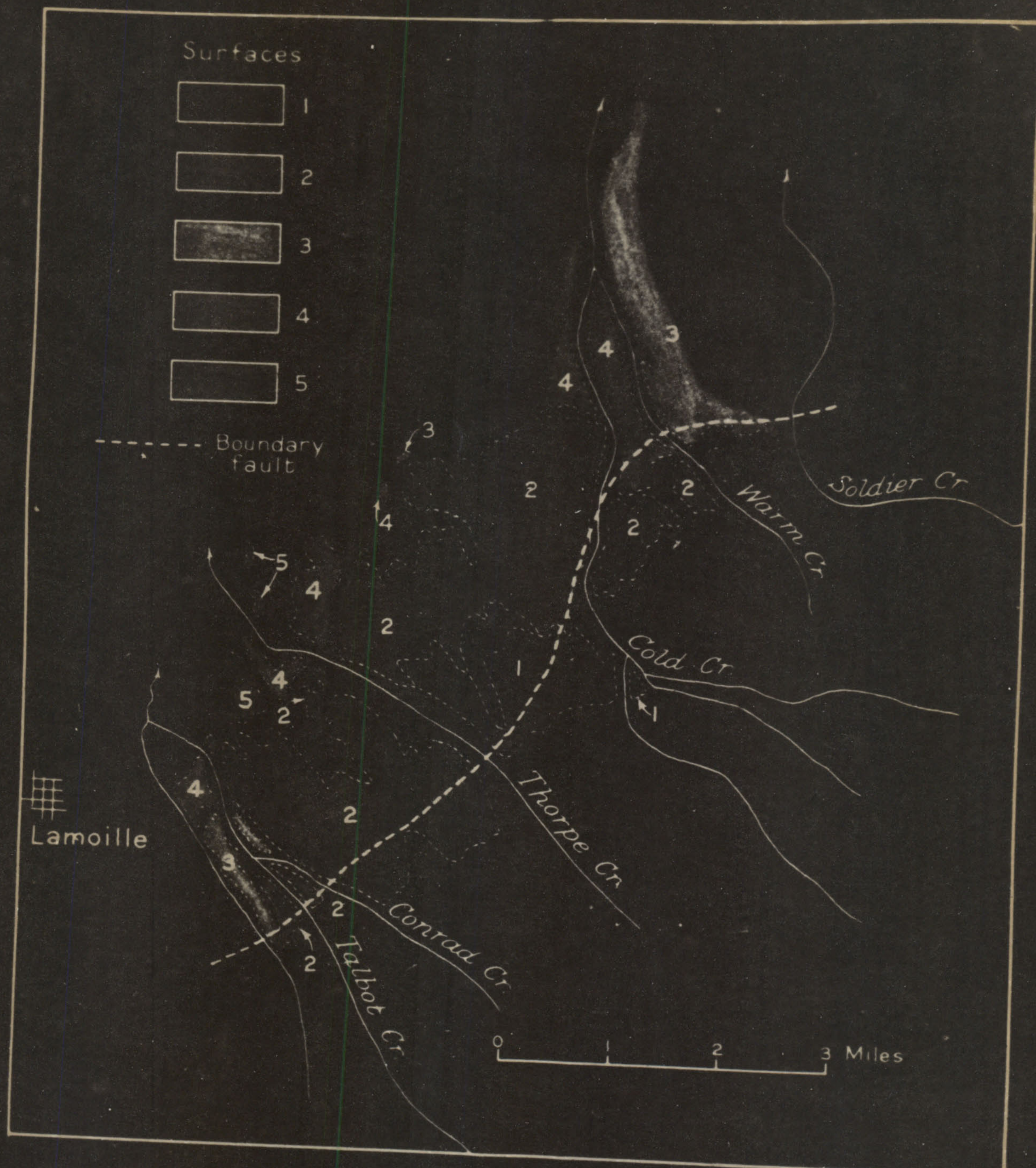


Figure 21

Map of a series of pediments and terraces in the Thorpe Creek area on the west side of the Ruby Mountains. The surfaces are cut largely on soft Miocene basin deposits, but in places they cross the boundary fault and cut across the hard, pre-Tertiary rocks of the mountain block. See figure 18 for exact location.

Figure 22

Map of a series of pediments and terraces in the South Fork area on the west side of the Ruby Mountains. The surfaces have been mapped from the base of the mountain block on the east to the gorge of the South Fork on the west. See figure 18 for exact location.

Figure 23

Map of a series of pediments and terraces in the Smith Creek area on the west side of the Ruby Mountains. The surfaces are cut largely on soft Miocene basin deposits, but in places they cross the boundary fault and cut across the hard, pre-Tertiary rocks of the mountain block. See figure 18 for exact location.

GEOMORPHIC FEATURES OF THE EAST FLANK OF THE RANGE

General Statement

The surfaces, mostly pediments, on the east flank of the range differ in several respects from those on the west. They are cut largely on pre-Tertiary rocks. They have been developed under a régime of interior drainage, and, hence, have been formed in part at least with respect to a rising baselevel. The climatic conditions under which they were formed are more arid than those on the west, for the high crest of the range casts a rain shadow over the area immediately to the east.

Description of Surfaces

A broad, gently sloping pediment along Willow and Clover Creeks at the north end of the East Humboldt Mountains is an exception to the general rule outlined above; for it is cut on soft Miocene basin deposits, and at the present time, at least, Willow and Clover Creeks drain into the Humboldt River. This pediment extends from Willow Creek south to Ralph Creek. It is now dissected to a depth of 100 feet by streams which emerge from the east face of the East Humboldt Mountains. In a number of places, remnants of a thin gravel mantle rest on this surface.

From Ralph Creek south to the Polar Star mine the East Humboldt Mountains are flanked by alluvial slopes which extend up to the base of the mountains. In one or two places, outcrops of pre-Tertiary rocks a short distance in front of the base of the mountains suggest that the upper one-half mile of this slope, which appears to be the upper part of an alluvial fan, may actually be a gravel-mantled pediment. Near the Polar Star mine a dissected pediment, roughly 100 feet above present stream grade, is cut across folded Carboniferous limestone beds. In places, remnants of a well-cemented gravel composed of subangular limestone fragments lie on this surface.

The southern end of the East Humboldt Mountains is encircled by a broad pediment, slightly dissected to a depth of 5 to 20 feet, and cut across Carboniferous limestone and Pliocene(?) lavas.

The west side of the southern projection of the East Humboldt Mountains, the west flank of the Valley Mountains, and the east flank of the Ruby Mountains are bordered by alluvial-covered slopes which do not have the undulatory cross section parallel to the mountain front which is so typical of a piedmont slope formed by coalescing alluvial fans. The reasonable interpretation is that these slopes are actually gravel-mantled pediments, cut largely on the pre-Tertiary rocks which make up the mountain block. In a few places, notably south of Sharps Creek, streams have cut through this alluvial mantle and have exposed a gently sloping surface cut on pre-Tertiary rocks. The alluvial cover in these places is not over 20 feet thick.

On the east side of the Ruby Mountains from Smithers Creek south to Battle Creek is exposed a dissected pediment which is of particular interest, figure 24. This pediment is cut on pre-Tertiary limestone and igneous intrusives. It is bounded on the east by a fault scarp, 150 to 200 feet high, and on the west by the face of the range, Plate XXXV. Careful study disclosed no fault between the pediment and the mountain face to the west. The pediment is an erosional surface left in the wake of the mountain face as it retreated more or less parallel to itself. This pediment is 1½ miles wide along Thompson and Moore Creeks and narrows progressively to the north and south. On the whole, it is a moderately smooth surface with here and there a residual hill projecting 50 to 100 feet above the general level. The residuals are composed of resistant intrusive igneous rock. The gradients on the remnants of this surface average between 400 to 500 feet per mile. If the surface has been tilted westward during the uplift along the fault to the east, the original gradients must have been somewhat steeper.

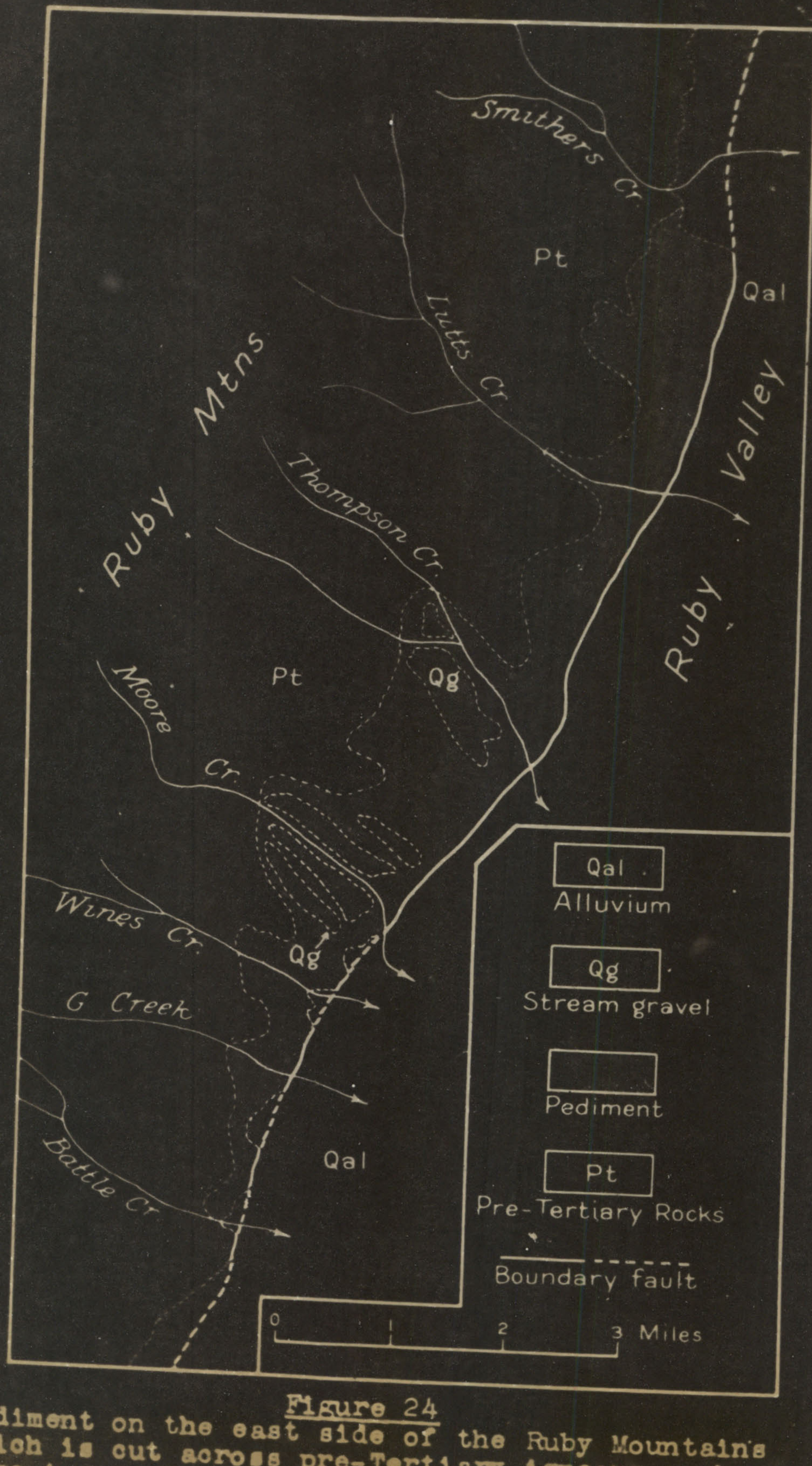


Figure 24

Pediment on the east side of the Ruby Mountains which is cut across pre-Tertiary igneous rocks and limestone. The pediment is bounded on the east by a piedmont scarp known

The surface has been dissected to a depth of 200 feet along Lutts Creek where the scarp bounding it to the east is highest. The depth of dissection decreases as the height of the scarp decreases, and the dissection of the pediment is clearly related to the uplift which formed the scarp.

The gravel remnants on the surface near Thompson and Moore Creeks suggest that at least part of the surface has been covered by a thin mantle of gravel. These gravel remnants are located immediately adjacent to some of the largest streams which cross the surface, and it seems likely that, if the entire surface had been mantled by gravel, the remnants would be found in the inter-stream areas and not on those parts of the surface immediately adjacent to the streams where the potential for removing the gravel cover is the greatest.

It seems clear that this pediment has been exposed only because of renewed fault movement on the boundary fault in this particular section. The exposition of such a surface indicates that the mountain block has moved relatively upward more rapidly than the valley is being filled with detritus.

Farther south, near Dawley Creek, renewed faulting on the boundary fault has brought to view a relatively narrow pediment, one-fourth mile wide, cut on granitic rocks. This surface is probably merely another section of the pediment which flanks the entire east face of the Ruby Mountains. Presumably, faulting along other sections of the boundary fault would expose other parts of this same pediment.

Other small pediment remnants are scattered along the east face of the Ruby Mountains from Battle Creek south to Harrison Pass. These remnants are from 50 to 125 feet above present stream grade. In most places, they are bare, rock surfaces not mantled by gravel, and they may or may not be parts of one and the same surface. The remnants are too small and scattered for any correlations to be attempted, and their dissection seems to be related to changes of baselevel caused by acceleration in the upward movement of the mountain block and by changes in stream courses.

Terraces are few and of local extent on the east side of the Ruby-East Humboldt Range. A terrace at 33 feet and another at 66 feet have been mapped along Overland Creek. A terrace 25 feet above stream grade has been noted on Moore Creek, and terraces at 50 and 100 feet above stream level on Lutts Creek indicate that the dissection of the pediment in that vicinity has been by stages.

Terraces 50 to 75 feet above stream level have been observed on Robinson Creek, and at 25 to 50 feet above stream level on Pole, Hunneman, Johnson, and Steels Creeks. These terraces are all on the mountain block. In every case, the terraces are probably related to local changes caused by faulting, glaciation, capture, shifting of stream courses, or sinking of the water level of the Pleistocene lakes which filled the basins east of the range.

GRAVEL COVER ON SURFACES

Practically all the surfaces on the west side of the range and part of those on the east side are covered by a thin alluvial mantle. This mantle is composed of stream gravel and slope-wash detritus. The stream gravel is made up of rounded to subangular pebbles, cobbles, and boulders, a few inches to several feet in diameter, composed of pegmatite, granite, gneiss, quartzite, schist, and limestone, the rock types which make the mountain block. These roundstones are set in a sandy to gravelly matrix, and the whole is usually loose and incoherent, unless considerable limestone is present, in which case the gravels may be well cemented and resistant. As a rule, gravel is poorly bedded.

APPENDIX A

PETROGRAPHY OF THE TERTIARY LAVAS

Miocene Lavas in the Vicinity of the Ruby-East Humboldt Range

The Tertiary lavas in the immediate vicinity of the Ruby-East Humboldt Range can be divided into two series on structural and petrographic bases. Rhyolite flows are interbedded in the Miocene sediments. Andesitic and basaltic flows overlie unconformably the Miocene sediments.

The rhyolite flows are gray to light brown on fresh fractures and weather dark reddish brown. The groundmass in most specimens is aphanitic, and large, clear, vitreous crystals of feldspar and quartz are set in this groundmass. Some specimens contain crystals of a second, white feldspar. No indications of flow alignment or vesicules have been noted in these rocks.. Some specimens are cut by moderately irregular, thin (0.5 mm.) veinlets of finely crystalline quartz, chalcedony, and opal.

Thin sections of these rhyolites show that they are composed of rounded crystals of quartz and orthoclase (0.5 to 5 mm. in diameter), and euhedral crystals of oligoclase nearly as big, set in a microcrystalline groundmass of quartz, and feldspar. The quartz phenocrysts are slightly biaxial. The texture of the groundmass is not strictly rhyolitic in all specimens, for a tendency to form tabular feldspar laths in the groundmass has been noted in several specimens. The quartz and orthoclase phenocrysts are markedly rounded and resorbed, as though to indicate that at some time during their history they were out of equilibrium with the magma. These resorbed phenocrysts may be foreign crystals picked up by the magma on its way to the surface, or they may have separated from the magma at depth under favorable physical-chemical conditions. When these conditions were disturbed by further intrusion, or extrusion, the quartz and orthoclase crystals were thrown out of equilibrium with the magma and were resorbed.

Not all the rhyolite flows interbedded with the Miocene sediments exhibit all the features noted above. However, most are characterized by a great abundance of quartz; extensive alteration of the groundmass and feldspar crystals; large, resorbed crystals of quartz and orthoclase; and many do show a notable tendency to form tabular feldspar crystals in the groundmass.

The greatest extent and thickness of these rhyolite lavas in the vicinity of the Ruby-East Humboldt Range is at the north end of the East Humboldt Mountains. Here they cover an area of approximately 8 square miles and are about 500 feet thick. At other localities, only small outcrops of flows not over 100 feet thick, as far as can be told, have been mapped.

Pliocene? Lavas in the Vicinity of the Ruby-East Humboldt Range

The Pliocene? lavas are black to dark gray on fresh fractures and weather a dark brown. The groundmass in hand specimen appears to be either aphanitic or glassy, and lath-shaped feldspar crystals, up to 2 to 3 mm. long, are set in this groundmass. In some specimens, crystals of a pyribole are also easily identified. Small vesicules and some alignment of the feldspar laths are common features of the Pliocene(?) lavas.

In thin section, the groundmass is seen to be most commonly hypocrystalline or hypohyaline. Holocrystalline or holohyaline groundmasses are less common. Euhedral crystals of labradorite, andesite, bytownite, hypersthene, and augite are all common. Hornblende crystals are sparse. Olivine appears in one or two of the basaltic lavas. Pyroxene andesites are the most common, though olivine basalt is not unknown. One specimen of an olivine basalt studied (S 107)* contained about 2 percent of rounded, resorbed quartz crystals. These quartz crystals appear to be foreign to the rock, as they are surrounded by a reaction rim of small pyroxene crystals. Zoning of the feldspars in the Pliocene? lavas is particularly notable. Nearly all zoning noted was progressively toward the sodic end, outward toward the borders of the crystals. One or two cases of what looked like repeated zoning were noted. Many of the feldspar crystals are beautifully twinned on the Carlsbad and albite laws; some pericline twinning was also noted.

In the Ruby-East Humboldt region, all the lavas which overlie unconformably the Miocene deposits are either pyroxene andesite or olivine-pyroxene basalt. No rhyolitic flows have been mapped as overlying the Miocene basin deposits in this region.

Lavas of Northernmost Nevada and Southern Idaho

Specimens have been collected from a series of lava flows in northernmost Nevada and southern Idaho, 50 to 75 miles north of the Ruby-East Humboldt Range. These flows are part of the great series of Tertiary lavas

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*See table at the end of Appendix A.

of southern Idaho and Oregon. These lavas are also separated into two groups, one of which is thought to be Pliocene (?), and the other of which is thought to be Miocene (?). Schrader (38, Chapter II). In the field, the Pliocene(?) lavas can be seen to overlie the Miocene(?) lavas, though the nature of this contact has not been determined. It may be conformable or unconformable.

The Miocene? lavas of this northern region are rhyolites, which strongly resemble the rhyolite flows interbedded in the Miocene sediments on the flanks of the Ruby-East Humboldt Range. They contain large (5 mm.) phenocrysts of quartz and feldspar, rounded and resorbed. The groundmass in the Miocene(?) rhyolite (S 67) near Jarbidge in northernmost Nevada shows the same tendency toward formation of feldspar laths as did the groundmass in some of the rhyolite in the Ruby-East Humboldt region.

The Pliocene(?) lava flows immediately overlying the Miocene(?) flows in this northern region are tridymite rhyolite. Two (S 68, S 63) of the three specimens of this rock which were studied show well developed eutaxitic structure. The flow lines are marked by greatly elongated clusters of tridymite crystals. These tridymite rhyolites also contain sparse crystals of quartz orthoclase, and plagioclase (albite-oligoclase) set in a glassy groundmass. The structural relations and petrographic character of these tridymite rhyolite lavas (S 68, S 63, S 62) are so striking as to suggest that they are members of the same series, though widely separated geographically. Associated with the rhyolitic lavas, for the most part overlying them, are some augite andesite and olivine-augite andesite flows (S 66, S 65, S 65).

Near Jarbidge, the Miocene(?) lavas are considerably more altered than the so-called Pliocene(?) lavas from the same region. Alteration is no certain crigerion of age, but other relations suggest that at least some of the rhyolite flows of northernmost Nevada are Miocene, regardless of what may be the age of the finer-grained rhyolite flows higher in the section (see Chapter II, pp. 35-37).

APPENDIX C

LATE PLEISTOCENE OR RECENT VERTEBRATE REMAINS IN CLOVER VALLEY

Introduction

Early in August, 1936, the Nevada State Highway Department uncovered some elephant teeth in the course of dredging a water hole in Clover Valley east of the East Humboldt Mountains. Some of these teeth were collected by Al Kinne of the Highway Department, by his father, R. A. Kinne of the Elko Municipal Water Department, and by David Dotta, Mayor of Elko. Report of this discovery came to hand August 24, 1936, and with directions graciously furnished by Mr. R. A. Kinne, the locality was visited, and a large part of that day was spent in collecting material and studying the geological relations. Mr. Seneca Weeks of Clover Valley is reported to have dug elephant teeth out of this same water hole in either 1929 or 1930. By the time I was able to visit the locality, water had seeped into the hole and so nearly filled it that observations were made with difficulty. Fortunately, Mr. R. A. Kinne made complete and intelligent observations before the hole filled up with water. Various bits of information collected by Mr. Kinne are included herein.

Location

The vertebrate material was collected from a water hole in a low drainage channel, locally known as Clover Slough, in Clover Valley on the east side of the East Humboldt Mountains. The locality is in the SE. 1/4 of section 8, T. 35 N., R. 62 E. This area can be reached by taking U. S. Highway #93 south from its intersection with U. S. Highway #40 near Wells. The water hole is approximately 16 miles south of this intersection and is not over 50 yards east of the highway. It is marked by a clump of green grass and weeds and is clearly visible from the road.

Geological Relations

The banks of the water hole expose the following section. Uppermost is a black, loamy-soil layer 4 feet thick. This layer contains a number of large boulders up to one foot in diameter. These boulders have been hauled in by Seneca Weeks in order to give his stock a firm foot around the hole, so they may be excluded from further consideration. The black soil layer has been considerably disturbed by trampling of domestic stock at times when it was soft and wet. Below the black soil layer is a blue-green clay layer which contains lenses of sand. The blue-green clay turns white on drying. Below the clay is a layer of unknown thickness composed of sand and gravel. The vertebrate remains occur in this blue-green clay layer and in the sandy lenses within the clay.

Nine miles to the south is a playa known as Snow Water Lake. Lake beaches of Snow Water Lake at least 100 feet above its present level have been noted farther south. Al Kinne states that the water hole in which the vertebrate remains have been collected is not over 30 feet above the present level of Snow Water Lake as shown by highway surveys. The area of the water hole was covered during a former high level of Snow Water Lake. The exact date of the last high-level stage of Snow Water Lake is not known, but it was associated with or closely followed the Wisconsin glaciation. The blue-green clay layer probably represents the deposits of this lake. The black soil layer has been developed since the lake withdrew from this area.

The following sequence of events is pictured. The withdrawal of the lake probably left something of a water hole in Clover Slough. Old-time residents in this region recall that the present water hole and vicinity were wet and swampy ever since they can remember. Animals gathered at this water hole, and some of them died there; for a sick or dying animal often seeks water. The remains of these animals were trampled in the wet, and still soft, lake deposits of blue-green clay by other animals which frequented the water hole. It is not impossible that the vertebrate remains were washed into the lake and embedded in the blue-green clay when it was being deposited. However, the great abundance of remains at this spot indicates that it is an exceptional accumulation and not just a few stray remains washed in from some place else.

Vertebrate Material

Elephant, horse, and camel teeth have been collected from this locality. Loose, friable fragments of skeletal material and pieces of elephant tusk have also been found, but they were too poorly preserved to be collected. The remains are all composed of original material, for no petrification has taken place. The teeth are in moderately good condition, simply because enamel is a resistant substance. Extensive collections could be made here if some means of draining the pool in the water hole could be found.

Age of the Remains

All the material collected in this study has been turned over to Dr. Chester Stock of the California Institute of Technology. Dr. Stock has not studied the remains completely enough yet to be able to give any statement as to their age. The lack of petrification indicates that they are relatively recent. Furthermore, the geological relations as outlined above, suggest that they are late glacial or post-glacial. They may be late Pleistocene or Recent.