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CENOZOIC GEOLOGY IN THE VICINITY OF CARLIN, NEVADA

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ABSTRACT

The Cenozoic section in the vicinity of Carlin, northeastern Nevada, comprises the following units, separated by erosional or slight angular unconformities: (1) several thousand feet of volcanic rocks ranging from rhyolite to basalt; diorite and granodiorite intrusive rocks (early Tertiary ?); (2) Rand Ranch formation (new name): 1700 feet of Paleozoic-pebble conglomerate and sandstone (Oligocene?); (3) Safford Canyon formation (new name): 700 feet of volcanic conglomerate and sandstone, rhyolitic tuff, and limestone (late Oligocene, early Miocene?); (4) Raine Ranch formation (new name): 2000 feet of pumice lapilli tuff, volcanic breccia, lava flows, conglomerate, rhyolitic tuff, diatomite, shale, and limestone (late Miocene); (5) 500 feet of rhyolite; (6) Carlin formation (new name): at least 600 feet of tuffaceous conglomerate and sandstone, rhyolitic and basaltic tuffs, diatomite, shale, and limestone (early Pliocene); (7) Hay Ranch formation (new name): several thousand feet of lacustrine clay, limestone, and rhyolitic ash with basin-border facies of conglomerate and fanglomerates (middle Pliocene–middle Pleistocene); (8) thin welded tuff (Pleistocene). Units 4, 6, and 7 are dated by vertebrate fossils.

Basin and Range faulting was active from late Miocene to Pleistocene and may have begun in Oligocene time.

Rhyolitic tuffs are extensively altered to zeolites. The transformation seems to have taken place under the influence of the water of the lakes in which the volcanic glass was deposited.

CONTENTS

TEXT

	Page
Introduction	1189
General statement	1189
Geography of the area studied	1189
Geologic setting	1190
Previous work	1190
Acknowledgments	1191
Stratigraphy and structure	1191
Outline of Cenozoic stratigraphy	1191
Structural framework	1192
Volcanic rocks of the Cortez Mountains	1192
Rand Ranch formation	1193
Safford Canyon formation	1193
Raine Ranch formation	1195
Palisade Canyon rhyolite	1198
Carlin formation	1198
Basalt plugs	1199
Hay Ranch formation	1199
Welded tuffs	1203
Pediments and recent warping	1203
Structure of Pine Valley	1204
Summary of geologic history	1204
Alteration of vitric tuffs	1205
Introduction	1205
Alteration to montmorillonite	1205
Alteration to zeolites	1205
Silicification	1208
References cited	1210

ILLUSTRATIONS

Figure	Page
1. X-ray-diffraction patterns of heulandite	1206
2. X-ray-diffraction patterns of erionite	1208
3. X-ray-diffraction patterns of altered vitric tuff	1209

Plate	Facing page
1. Geologic map and cross sections, near Carlin, Nevada	1189
2. Alteration of vitric tuffs	1204

INTRODUCTION

General Statement

This paper presents the stratigraphy and structure of a particularly complex section of Cenozoic rocks which is well exposed in the vicinity of Carlin in northeastern Nevada (Pl. 1). The alteration of vitric ash beds to clay, chert, and zeolites has been studied in detail.

Geography of the Area Studied

The described area covers three physiographic units: the northern half of Pine Valley, the broad basin in which lies the town of

Carlin, and the southern portion of the valley of Susie Creek.

(1) Pine Valley is a north-south depression with the Piñon Range (elevation 8700 feet) to the east and the Cortez Mountains (elevation 7200 feet) to the west. The floor of the valley is about 5000 feet above sea level.

(2) The Carlin Basin is a broad depression with Marys Mountain (elevation 7500 feet) to the west and the West Elko Hills (elevation 6500 feet) to the east. It is separated from Pine Valley by thick rhyolite flows, through which the Humboldt River has cut the impressive Palisade Canyon. The basin is drained by Maggie Creek, Susie Creek, and the Humboldt River.

(3) The valley of Susie Creek lies between the West Elko Hills to the east and Swails Mountain—the southern termination of the Independence Range—to the west. Swails Mountain rises to more than 8000 feet, and the valley floor is 5000–5500 feet above sea level.

Geologic Setting

The published information on the Cenozoic of Nevada has been summarized and interpreted by Nolan (1943) and Van Houten (1956), whose paper also includes much original information. The following summary has been abstracted from these papers.

Continental rocks, from early to late Tertiary age, are widespread in Nevada and consist of volcanic rocks and stream and lake sediments. They fill the basins and underlie the lower parts of some of the ranges. The upper Tertiary formations are accurately dated by numerous assemblages of fossil vertebrates, whereas the lower Tertiary formations, which have yielded only fossil plants and fresh-water mollusks and ostracods, are dated in fewer places and with less precision and certainty.

Lower Tertiary formations of eastern Nevada consists of Eocene (?) limestones and mudstones, which are associated with volcanic rocks and Paleozoic-pebble conglomerates. In northeastern Nevada, in the vicinity of Elko, oil shales and limestones are probably Oligocene. In western and central Nevada, lower Tertiary rocks are represented chiefly by thick sequences of volcanic flows and pyroclastic rocks, ranging in composition from rhyolite to basalt. In places they are referred to early Tertiary solely because they underlie upper Tertiary sediments. They are as old as Eocene (?) in the Silver City district of western Nevada (Gianella, 1936, p. 50–52).

Upper Tertiary sediments, which range from upper Miocene to Pliocene, are very widespread and are known chiefly under the names of Truckee, Esmeralda, Humboldt, and Panaca formations. In contrast to the lower Tertiary formations, these deposits have a fairly uniform lithofacies which consists of fine vitric tuffs and ashes interbedded with mudstones, sandstones, diatomites, and limestones. For that reason they have been called collectively the "vitric tuff unit" by Van Houten (1956). There are also basin-margin conglomerates, and, locally, coarse pyroclastic rocks and lava flows are present.

Pleistocene lake beds exhibiting shore features are widespread; most authors refer them to the Wisconsin stage. Dissected early Pleistocene or Plio-Pleistocene deposits are also known. Basalt flows and small volcanic cones in several localities have been referred to the Pleistocene.

Early Tertiary (?) thrusting has been recognized at Pioche, and in the Jackson Mountains (Willden, 1957). Later Tertiary orogeny seems to have been chiefly normal faulting and minor gentle folding (except in southern Nevada, where late Tertiary thrusting has taken place). The dominant process is the block faulting which produced the Basin and Range structure. This faulting began as early as Oligocene and has continued intermittently to the present. The last period of large-scale faulting, responsible for the present-day topography, has generally been referred to the late Pliocene to early Pleistocene.

Previous Work

The area of this study is included in the geologic maps of the Exploration of the Fortieth Parallel (King, 1876, Atlas Pls. 4–5), which afford a rough delimitation of the Tertiary outcrops. The Tertiary was subdivided into volcanic rocks and sediments. All the Tertiary sediments of the area of this study were referred to the Humboldt group, which was considered to be Pliocene.

Emmons (1910) presented a geologic map of the area, which is a simplified version of that of the Exploration of the Fortieth Parallel, and a brief description of the geology of the Safford district, which lies 3 miles southwest of Palisade. Lee, Stone, and Gale (1915) gave some observations on the Palisade Canyon.

Van Houten (1956), in the course of a general study of the Cenozoic of Nevada, briefly described some of the formations in Pine Valley. He indicated the fossil localities with their age determinations and correlated the formations with the rest of the Cenozoic of Nevada. Reeves and Shawe (1956) described the lithology and the structure of the volcanic rocks of the Cortez Mountains, south of Palisade.

Acknowledgments

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Stratigraphy and Structure

Outline of Cenozoic Stratigraphy

The Cenozoic in the vicinity of Carlin, Nevada, can be subdivided into nine mappable units:

Alluvium Pediment gravels and deposits of the present drainage	Late Pleistocene to recent
Welded tuffs 30 feet	Late Pleistocene
Erosional unconformity	
Hay Ranch formation Possibly several thousand feet of fanglomerates, conglomerates, sandstones, clays, and limestones. Some vitric ash beds mostly altered to zeolites	Middle Pliocene to Middle Pleistocene
Carlin formation At least 600 feet of tuffaceous sandstones and conglomerates, vitric tuffs, shales, limestones, and diatomite	Early Pliocene
Palisade Canyon rhyolite 500 feet	Late Miocene or early Pliocene
Slight angular unconformity	
Raine Ranch formation 2000 feet of lapilli tuff, volcanic breccia, lava flows, vitric tuffs, diatomites, shales, and limestones	Late Miocene
Slight angular unconformity	
Safford Canyon formation 700 feet of tuffs, tuffaceous conglomerates, and sandstones	Late Oligocene (?) or Early Miocene (?)
Slight angular unconformity	
Rand Ranch formation 1700 feet of sandstones and conglomerates	Oligocene (?)
Erosional unconformity	
Volcanic rocks of the Cortez Mountains Two sequences of flows and pyroclastic rocks separated by an angular unconformity. The total thickness is at least 3500 feet.	Early Tertiary (?)

The suggested age for the three older formations is inferential, whereas the others are dated by vertebrate fossils or by their stratigraphic relations. In addition to the units listed above, some small olivine-basalt plugs cut through the Raine Ranch formation and may be contemporaneous with the Carlin formation.

New names are proposed for the formations described in the present paper. The term Humboldt is not used on account of its imprecision: King (1877, p. 540; 1878, p. 392–393) considered that Tertiary sedimentary rocks in northeastern Nevada consisted of an Eocene and a Pliocene group. The Eocene group was represented by the well-known Elko oil shale (Winchester, 1923, p. 91–103), and the Pliocene group was named by King the "Humboldt group." Sharp (1939) redescribed the Tertiary rocks in the Elko area. He concluded that all belong to the same formation, which he named the "Humboldt formation" and considered to be late Miocene. According the Sharp the formation consists of three members, the Elko oil shale being part of the lower member. The age determination was based on plant remains collected from the Elko oil shale (Sharp, 1939, p. 152–154) and on fossil vertebrates from the McKnight locality on the North Fork of the Humboldt River (Merriam, 1914).

However, more recent work in the area indicates that Sharp's views may have to be revised. The Elko oil shale has yielded snails, which suggest Eocene or Oligocene age, and fossil leaves which are late Oligocene or early Miocene; petroliferous limestones, which are part of the lower member of the "Humboldt formation," overlie the Elko oil shale south of Elko and contain snails of early Cenozoic (pre-Miocene) age (Van Houten, 1956, p. 2812). According to Axelrod (1956, p. 64), fossil leaves from the middle member of the "Humboldt formation" are early Pliocene. The age determination of the fossils from the McKnight locality has been revised by Stirton (1940, p. 634) who concludes: "The geologic age of the material is uncertain. As Merriam has suggested it is probably in the later Miocene." The stratigraphic relationship of the type section of the "Humboldt formation" to the beds of the McKnight locality, 50 miles to the northeast, has not been described.

Late Miocene (or early Pliocene) and also early Pliocene vertebrate-fossil localities are indicated by Van Houten (1956, p. 2805) in the Elko area where the stratigraphy is probably more complicated than Sharp envisioned.

Structural Framework

Only Cenozoic structures are within the scope of this paper. Basin and Range faulting, which is accompanied by minor folding and small-scale faulting, is dominant (Pl. 1).

Pine Valley is a trough filled with Cenozoic sediments. This trough was formed through the elevation of the Piñon Range along a normal fault and the eastward tilting of the Cortez Mountains. The fault can be traced along the western edge of the Piñon Range from the northern end of Pine Valley to the southern end of the area. Its presence is indicated by the regularity and smoothness of the western edge of the Piñon Range, its independence from the internal structure of the range, and the presence of thick Plio-Pleistocene fanglomerates at the foot of Pine Mountain. Springs, some of them hot, tufa deposits, and oil seeps occur along the trace of the fault. The nature of the fault is evidenced by a fault breccia at Red Springs which dips 60° W. and by closely spaced, steeply west-dipping joints along Trout Creek in the Paleozoic outcrops of the footwall of the fault. Wells drilled through the Cenozoic sediments, a short distance west of the fault (sec. 11, T. 27 N., R. 52 E.), penetrated into the Paleozoic rocks at a depth of a few hundred feet. Evidence discussed below indicates that the fault originated in Oligocene (?) time and was active intermittently through late Cenozoic time. The trough becomes narrower and shallower toward the north, and the fault, which is hidden by rhyolite flows at the northern end of Pine Valley, seems to die out in that direction.

The upper part of the valley of Susie Creek is also a structural basin created by faulting, but the structure is the reverse of that of Pine Valley, in that faulting took place along the western edge of the basin. The evidence for a fault is presented below. Faulting took place in late Miocene and does not seem to have been renewed. The fault becomes hidden by lower Pliocene sediments and dies out toward the south.

The Carlin basin was created by warping in late Miocene and is probably fairly shallow.

Cenozoic formations, except the latest Pleistocene deposits, were tilted during the Basin and Range faulting. Dips do not exceed 35°. In Pine Valley, where faulting took place from Oligocene (?) to Pleistocene, the older formations are the more tilted.

The only large folds are those that affect rhyolite flows southwest of Carlin.

Volcanic Rocks of the Cortez Mountains

DESCRIPTION: Reeves and Shawe (1956) described the volcanic rocks of the Cortez Mountains as follows:

> "The northern part of the Cortez Mountains, extending 20 miles south from Palisade, is composed of a thick sequence of flow and pyroclastic rocks of Tertiary age. These include at least 2500 feet of an older sequence of Eocene or Oligocene age and at least 1000 feet of a younger sequence of late Miocene and early Pliocene age that unconformably overlies the older rocks.
>
> "Rocks of the older sequence range from andesite to latite. They are folded into north-trending open folds and are cut and metamorphosed by intrusive rocks of Oligocene (?) age ranging from diorite to granodiorite. The older volcanic rocks are extensively altered with enrichment in K and Fe.
>
> "The younger sequence of rocks ranges from andesite to rhyolite. They dip from a few degrees to 40° E. and interfinger with the Humboldt formation on the eastern edge of the range."

A study of the eastern edge of the Cortez Mountains has shown that the "younger sequence" also contains abundant basalt and does not interfinger with the "Humboldt formation" but underlies pre-upper Miocene sediments.

AGE: The age of the volcanic rocks of the Cortez Mountains is not certain. Three miles northwest of Palisade they overlie vertical silicified Paleozoic conglomerates, and, along the eastern edge of the range, the rocks of the "younger sequence" underlie the upper Miocene Raine Ranch formation and the pre-upper Miocene Safford Canyon and Rand Ranch formations.

Fresh-water gastropods of Cretaceous or early Tertiary age (Van Houten, 1957, personal communication) have been found west of Carlin (NW¼, sec. 13, T. 32 N., R. 50 E., in a road cut on the south side of U. S. Highway 40), in a thin bed of clay and angular volcanic gravel interbedded with the volcanic rocks of the "older sequence" defined by Reeves and Shawe. In the absence of evidence of Cretaceous volcanism in Nevada, the volcanic rocks of the Cortez Mountains are here referred to the early Tertiary.

Rand Ranch Formation

LITHOLOGY: The Rand Ranch formation, named after the Rand Ranch (SW¼ T. 30 N., R. 52 E.), consists of 1700 feet of sandstones and conglomerates which rests on the volcanic rocks of the Cortez Mountains along the eastern edge of that range and dips 15°–30° E. The thickest section of the formation is exposed in secs. 9 and 10, T. 29 N., R. 51 E.

The basal 450 feet consists of gray volcanic-pebble conglomerates and gray and yellow volcanic sandstones. The conglomerates are composed of subrounded to rounded andesite and basalt pebbles up to 8 inches in diameter. The sandstones are well sorted and comprise poorly rounded fragments of very weathered basic lava.

The upper part of the section consists of 1250 feet of interbedded white, yellow, and red sandstones and Paleozoic-pebble conglomerates. The conglomerates are composed of subrounded to rounded pebbles of chert, quartzite, and sandstone in a sandy matrix. The maximum diameter of the pebbles is 1 foot, but the most common diameter is 1–2 inches. The conglomerates form beds and lenses up to 25 feet thick; in places they are well indurated. Cross-bedding on a large scale and scour-and-fill channels are common features. The sandstones are fine-grained and are composed of quartz and less than 1 per cent chert, feldspar, and heavy minerals. They are thinly bedded and cross-bedded. These beds are conformable with the volcanic conglomerates and sandstones of the basal portion of the section.

LOWER CONTACT: The Rand Ranch formation rests conformably on the volcanic rocks of the Cortez Mountains.

AGE AND CORRELATION: The Rand Ranch formation has yielded only some very poor plant remains and some silicified and hematitized wood which are valueless for age determination. It is tentatively referred to the Oligocene on account of its stratigraphic position between the volcanic rocks of the Cortez Mountains and the pre-upper Miocene Safford Canyon formation. Van Houten (1956, p. 2812) suggested that the Rand Ranch formation might be equivalent to Paleozoic-pebble conglomerates in northwestern Utah and adjacent Nevada, which are unconformably overlain by upper Tertiary tuffaceous units. Lower Tertiary (?) conglomerates have also been described in the Jackson Mountains (Willden, 1957).

PHYSICAL SETTING: The sedimentary features indicate that the Rand Ranch formation is an alluvial deposit. The coarseness and the thickness of the sediments indicate that high relief existed at the time. The present site of the Cortez Mountains was a low area.

Safford Canyon Formation

LITHOLOGY: The Safford Canyon formation was named after a tributary of the Humboldt River southwest of Palisade. It consists (Section 1) of 700 feet of water-laid vitric tuffs and tuffaceous volcanic sandstones and conglomerates which form an open, north-plunging syncline at the northern end of Pine Valley.

The lower part of the formation is a 50-foot bed of coarse volcanic-pebble conglomerate which rests in sedimentary contact on the volcanic rocks of the Cortez Mountains. The rest of the formation consists of interbedded vitric tuffs, conglomerates, and sandstones, and a 20-foot bed of limestone.

Conglomerates and sandstones consist predominantly of volcanic detritus derived from the volcanic rocks of the Cortez Mountains and a small amount of Paleozoic material. Cross-bedding and scour-and-fill channels occur in many places.

Most of the vitric tuffs are altered to heulandite and to green chert. Both types of alteration occur in the same beds. Fresh volcanic glass in two beds has an index of refraction which indicates a rhyolitic composition. Fine bedding, *Section 1. Safford Canyon Formation*

Section measured from the NE¼ sec. 11, T. 31 N., R. 51 E., toward the center of sec. 1, same township

		Thickness (In feet)	
Top: eroded			
D.10	Light-gray to white vitric tuff, well bedded and cross-bedded, alternating with tuffaceous sandstone and conglomerate; tuff friable with colorless glass shards having incipient alteration to montmorillonite; some tuff beds with fresh glass shards (n = 1.496 ± 0.002), small amount of quartz, feldspar, biotite, green hornblende	150	681
D.9	Green, dark-brown-weathering volcanic conglomerate and sandstone, well bedded, cross-bedded, and with scour-and-fill channels; green siliceous cement	211	531
D.8	White, hard, massive calcilutite having veinlets of white opal, insoluble residue of colorless glass shards (n = 1.496 ± 0.002), angular fragments of quartz, feldspar, biotite, altered lava; in E½, sec. 12, T. 31 N., R. 51 E., same bed has algal structures and is partly oölitic	20	320
D.7	Green silicified tuff (*cf.* D.5)	30	300
D.6	Green, dark-brown-weathering volcanic sandstone and conglomerate, well bedded and cross-bedded	68	270
D.5	White and green altered vitric tuff; top half thinly bedded, bottom half an intraformational conglomerate with rounded fragments of tuff up to 1 foot in diameter in matrix of similar tuff; white tuff soft with about 20 per cent grains of sanidine, orthoclase, plagioclase, quartz, altered lava, green hornblende in cryptocrystalline matrix of heulandite with vitroclastic texture; green tuff compact and flinty, with same grains in matrix, with vitroclastic texture, of heulandite, opal, celadonite (?); both types of alteration occur in the same beds	29	202
D.4	Green altered volcanic tuffaceous volcanic sandstone; about 60 per cent somewhat rounded grains of altered lava and silicates of volcanic origin; matrix of heulandite, opal, and celadonite (?) has indistinct vitroclastic texture; few volcanic conglomerate interbeds	24	173
D.3	White and green altered vitric tuff; similar to D.5	31	149
D.2	Green, medium-hard, porous, altered vitric tuff, thinly bedded, cross-laminated; about 60 per cent glass shards and small pumice fragments replaced by heulandite and coated with celadonite (?); somewhat rounded fragments of altered lava and silicates of volcanic origin; scattered volcanic pebbles	62	118
D.1	Volcanic-pebble conglomerate, well bedded, with green tuffaceous cement; angular to subrounded pebbles and boulders of weathered basalt, andesite, and rhyolite	56	56
Bottom: sedimentary contact on the volcanic rocks of the Cortez Mountains			

cross-lamination, and intraformational conglomerates indicate that the tuffs are waterlaid. They are mixed with up to 20 per cent volcanic sand.

The limestone bed can be traced more than 2 miles along a semicircular belt of outcrop. It ranges from a white calcilutite to an oölitic and algal limestone.

LOWER CONTACT: The Safford Canyon formation rests on the volcanic rocks of the Cortez Mountains with a slight angular unconformity. In NE¼ sec. 35, T. 31 N., R. 51 E., the beds dip 25° E. and rest on flows that dip 35° E. In sec. 2, T. 31 N., R. 51 E., the formation strikes N. 10° W. and dips 15° E., whereas the volcanic rocks strike N. 20° E. and dip 20° E.

AGE AND CORRELATION: No fossils have been found in the Safford Canyon formation. It occupies the same stratigraphic position as the Rand Ranch formation, between the volcanic rocks of the Cortez Mountains and the upper Miocene Raine Ranch formation. It is not a facies of the Rand Ranch formation because, although formed in the same area and by the same agents, one formation is very tuffaceous and the other is entirely lacking in pyroclastic elements. The Safford Canyon formation is believed to be younger than the Rand Ranch formation. The Rand Ranch formation lies conformably on the volcanic rocks of the Cortez Mountains, whereas the Safford Canyon formation lies unconformably on them. This indicates that deposition of the Rand Ranch formation, tilting, erosion, and deposition of the Safford Canyon took place in succession.

The Safford Canyon formation might be the equivalent of a tuffaceous Oligocene (?) formation described by Van Houten in northeastern Nevada (1956, p. 2813).

PHYSICAL SETTING: The presence of an angular unconformity at the base of the Safford Canyon formation and the abundance of locally derived volcanic detritus throughout the section indicate a volcanic highland mass, presumably at the site of the Cortez Mountains. Alluvial and lacustrine sedimentation alternated. There is no evidence of local volcanic activity.

Raine Ranch Formation

LITHOLOGY: The Raine Ranch formation (named for a ranch in sec. 6, T. 31 N., R. 52 E.) is a thick tuffaceous unit which crops out in the northern part of Pine Valley and in the valley of Susie Creek. The best exposures are found in Pine Valley, where the formation is not faulted and dips uniformly 15° E.

A 1500-foot section was measured west of Pine Creek (sec. 2) and a shorter section east of the creek (sec. 3). The formation can be subdivided into two members. The lower member consists of a thick lapilli tuff, a volcanic breccia, and a basalt flow. The lapilli tuff, which is up to 400 feet thick, forms a continuous outcrop from the northern end of Pine Valley to Devils Gate. It is a soft, massive, white to cream-colored rock, composed of rounded pumice fragments up to 6 inches in diameter, embedded in a matrix of smaller pumice fragments, glass dust, and crystals of labradorite, sanidine, quartz, biotite, hornblende, and pyroxene. The tuff contains also some angular fragments of lava ranging from rhyolite to basalt. The volcanic breccia, which overlies the lapilli tuff, is as much as 100 feet thick in some places. It is composed of unsorted gray and red quartz andesite blocks, up to 3 feet in diameter, in a tuffaceous matrix. In secs. 13 and 24, T. 31 N., R. 51 E., a thin flow of scoriaceous hypersthene basalt overlies the volcanic breccia.

In places a slight erosional unconformity separates the lower member of the formation from the upper member, which consists of water-laid sediments among which vitric tuffs predominate. In the lower beds, the vitric tuffs are interbedded with coarse detrital material which, on the west side of the valley, was derived from the volcanic rocks of the Cortez Mountains and on the east side was derived from Paleozoic outcrops. The coarseness of the detrital elements, well-defined bedding, and scour-and-fill channels indicate alluvial deposition. The upper beds which consist of very pure vitric ash, interbedded with diatomites, shales, and fossiliferous limestones, are lacustrine. The ash has been slightly reworked; it displays fine lamination, cross-bedding, and ripple marks.

Throughout these water-laid beds the volcanic glass is colorless and consists of shards and pumice fragments smaller than 2 mm. The index of refraction varies within narrow limits (1.497 ± 0.002 to 1.508 ± 0.002) and incidates a rhyolitic composition. In some beds, however, there is a small amount of brown glass of basaltic composition. The lake-laid ash beds contain less than 5 per cent quartz and feldspar and a negligible amount of dark minerals. The tuffs that are interbedded with volcanic conglomerates contain up to 20 per cent quartz, feldspar, and dark minerals which are probably detrital. Most of the tuff and ash beds are fresh, but some are altered to heulandite and green chert.

The section in the valley of Susie Creek is substantially the same, except that the volcanic breccia is overlain by approximately 200 feet of basalt and andesite flows.

LOWER CONTACT: In Pine Valley, the Raine Ranch formation rests unconformably on the older Tertiary formations. A normal fault separates the Raine Ranch formation from the Paleozoic rocks of the Piñon Range. The fault has topographic expression, and at Red Springs a silicified fault breccia dips 60° W.

In the valley of Susie Creek, the Raine Ranch formation rests in sedimentary contact on the Paleozoic rocks of the West Elko Hills. It is faulted against the Paleozoic along the eastern edge of Swails Mountain. The contact is hidden by pediment gravels. The lower beds of the Raine Ranch formation, however, are missing near the contact, and the beds dip toward it.

AGE AND CORRELATION: The Raine Ranch formation is dated as late Miocene by vertebrate fossils found at three localities in stream-laid tuffs and conglomerates which lie a few hundred feet above the base of the upper member of the formation.

(1) Camp Creek locality, near the junction with Susie Creek (NE¼ sec. 2, T. 35 N., R. 53 E.). Fossils from this locality were collected by Lovejoy (1959, p. 557) during the summer of 1956 and donated to the American Museum of Natural History (AM-45823 to AM-45827): *Merychippus* sp., resembling forms in the Lower

Section 2. Raine Ranch Formation

Section measured in secs. 35 and 36, T. 31 N., R. 51 E., and sec. 31, T. 31 N., R. 52 E.

	Thickness (In feet)	
Hay Ranch formation		
Light-gray vitric ash with clear colorless glass shards (n = 1.502 ± 0.002), thinly laminated and cross-bedded; reedlike plant remains	2	1477
Greenish-brown vitric tuff with volcanic gravel interbeds	27	1475
White, thinly laminated diatomite with light-gray volcanic-ash interbeds which contain clear colorless glass shards (n = 1.500 ± 0.002)	71	1448
Light-gray clayey diatomaceous vitric ash which contains clear colorless glass shards (n = 1.502 ± 0.002) and trace of quartz and feldspar; thinly laminated	13	1377
White massive diatomite	2	1364
Light-gray vitric ash with clear colorless glass shards (n = 1.502 ± 0.002); thinly laminated, cross-bedded	23	1362
White massive diatomite	14	1339
Light-gray vitric ash	2	1325
White massive diatomite	1	1323
Light-brown vitric tuff composed of about 95 per cent clear colorless glass shards (n = 1.502 ± 0.002), 5 per cent brown glass shards (n = 1.565 ± 0.005), and traces of quartz and feldspar	23	1322
White diatomite with light-gray vitric-ash interbeds	14	1299
Light-gray vitric ash composed of clear colorless glass shards (n = 1.507 ± 0.002) and traces of quartz and feldspar	8	1285
Yellow limy shale	2	1277
White vitric tuff composed of clear colorless glass shards (n = 1.500 ± 0.005) and less than 5 per cent quartz and feldspar, traces of biotite, thinly bedded	18	1275
Light-gray vitric ash composed of about 90 per cent colorless cloudy glass shards (n = 1.508 ± 0.002), some brown glass shards, and less than 5 per cent quartz and feldspar, thinly bedded	10	1257
White massive diatomite	2	1247
Brownish and greenish vitric tuff and volcanic conglomerate, thickly bedded	50	1245
White massive diatomite	11	1195
Vitric tuff and volcanic conglomerate, thickly bedded	39	1184
Light-blue vitric ash composed of clear colorless glass shards (n = 1.505 ± 0.005), less than 1 per cent quartz and feldspar, and traces of dark minerals; thinly bedded, cross-bedded	30	1145
Gray, light-brown-weathering vitric tuff having about 70 per cent glass shards and small pumice fragments, mostly colorless (n = 0.507 ± 0.003), some brown glass (n = 1.575 ± 0.005), and about 30 per cent feldspar, quartz lava fragments, biotite, green hornblende, pyroxene; beds of tuff up to 20 feet interbedded with beds and lenses of conglomerate, which contain angular to subrounded pebbles up to 15 inches, ranging from rhyolite to basalt; cross-bedding on a grand scale, scour- and fill-channels; some tuff beds cemented by calcite forming prominent ledges; upper Miocene camelids	390	1115
Light-tan sandy mudstone; mostly covered	50	725
Greenish altered tuffaceous sandstone; mostly covered	102	675
White and green vitric tuff altered to clay, calcite and opal	47	573
Volcanic conglomerate and sandstone; pebbles up to 4 inches ranging from rhyolite to basalt; well bedded, cross-bedded, calcite cement	16	526
White vitric tuff containing colorless glass shards (n = 1.497 ± 0.002) with incipient alteration to montmorillonite and less than 1 per cent feldspar and quartz and traces of biotite, green hornblende, magnetite, apatite, zircon; bottom thinly laminated and cross-bedded; top an intraformational conglomerate composed of angular fragments of underlying tuff in gravelly tuffaceous matrix grading into overlying conglomerate	14	510
Volcanic conglomerate and sandstone	20	496
Gray volcanic sand composed of fragments of lava and water-worn grains of quartz and feldspar; some glass shards and pumice fragments; thinly bedded, cross-bedded	91	476

	Thickness (In feet)	
Slight local erosion		
White, massive lapilli tuff	15	385
Dark-red-weathering breccia having unsorted angular fragments and blocks up to 3 feet in diameter of light-gray and pink quartz andesite; tuffaceous cement; in places overlain by a thin flow of scoriaceous hypersthene basalt	50	370
White to cream, light-tan-weathering, soft, massive pumice lapilli tuff composed of angular to rounded pumice fragments up to 6 inches in matrix of smaller pumice fragments and glass dust ($n = 1.505 \pm 0.005$) and crystal fragments of labradorite, sanidine, quartz, biotite, green hornblende, hypersthene, augite; scattered angular lava fragments up to 4 inches ranging from rhyolite to basalt; black silicified wood	320	320

Bottom: sedimentary contact on the Rand Ranch formation.

Section 3. Raine Ranch Formation

Section measured in the NE¼ sec. 20, T. 31 N., R. 52 E. This section seems to be the upper continuation of section 2, but a slight gap or some repetition may be present.

		Thickness (In feet)	
Hay Ranch formation			
B.14	Light-gray vitric ash; thinly bedded, cross-bedded; some beds opalized (gray chert)	15	336
B.13	Vitric tuff altered to heulandite (white) and silicified (green)	20	321
B.12	Light-gray shale; chert concretions; abundant pelecypods, gastropods, ostracods; poorly preserved plant remains; some fish bones	13	301
B.11	Blue, sandy vitric ash, containing clear colorless glass shards (n close to 1.50); thinly bedded, cross-bedded	21	288
B.10	White slabby tuffaceous limestone	15	267
B.9	White massive diatomite	16	252
B.8	Vitric tuff partly silicified	7	236
B.7	Light-gray vitric ash composed of clear colorless glass shards (n close to 1.50); thinly bedded, cross-bedded, ripple marks	103	229
B.6	Light-gray vitric tuff and yellow silicified tuff; poorly exposed	26	126
B.5	Greenish vitric tuff, thinly bedded	9	100
B.4	Light-gray vitric ash, ostracods, thinly bedded, cross-bedded	29	91
B.3	White tuffaceous limestone; chert concretions; abundant pelecypods, gastropods, ostracods; at bottom tuffaceous shale rich in matted reed and 1-foot bed of peat, partly silicified	25	62
B.2	Gray rhyolite breccia containing angular blocks of flow-banded rhyolite in siliceous matrix	2	37
B.1	Greenish vitric tuff composed of clear colorless glass shards (n close to 1.50), small amounts of feldspar, quartz, and dark minerals; interbeds of coarse sand and gravel, mostly volcanic	35	35

Bottom: not exposed

Snake Creek of Nebraska (identification by M. F. Skinner); camelids of late Miocene age (identification by C. H. Falkenbach); turtle (not identified).

(2) Five miles south of Palisade (NE½ sec. 36, T. 31 N., R. 51 E.), camelids of late Miocene age (identification by C. H. Falkenbach). These fossils are also in the American Museum of Natural History (AM-44991 and AM-44993).

(3) Five miles southeast of Palisade (NE¼ sec. 20, T. 31 N., R. 52 E.), *Merychippus* sp., of Barstovian age (Van Houten, personal communication).

An isolated patch of tuffaceous sediments in the Carlin Pass (SE¼ sec. 15 or N½ sec. 22, T. 32 N., R. 52 E.) yielded a jaw of *Tomarctus*-like canid, which resembles a form in the Lower Snake Creek fauna of Nebraska, and a large camel. These fossils suggest a Barstovian age but may be slightly older (Van Houten, personal communication).

The upper beds of the Raine Ranch formation in Pine Valley (sec. 20, T. 31 N., R. 52 E.) yielded gastropods of Oligocene or Miocene age (Van Houten, personal communication).

Numerous late Miocene and late Miocene or early Pliocene fossil localities are known in Nevada (Van Houten, 1956). The thick lapilli tuffs and lava flows described in the Roberts Mountains (Merriam and Anderson, 1941) 25 miles south of the map area may be correlative with the lower member of the Raine Ranch formation. The Raine Ranch formation may be present northeast of Lone Mountain, 15 miles north of the map area, where late Miocene vertebrate fossils have been collected from vitric tuffs (Lovejoy, 1959, p. 557).

PHYSICAL SETTING: The nature of the beds of the lower member of the Raine Ranch formation indicates the presence of volcanic centers in the area; no evidence of their presence has been found within the map area. Granitic bodies and felsitic dikes occur at Swails Mountain, and granodiorite and quartz porphyry occur in the Piñon Range, east of Pine Mountain (Emmons, 1910). The age of these intrusive bodies, which are not in contact with the Tertiary formations, is not known. However, on the basis of potassium-argon dating, the quartz monzonite intrusive body of Nannie's Peak, 15 miles north of the map area, is Cenozoic and probably Miocene. This dated intrusive body is part of a complex of stocks and dikes which range from diorite to quartz porphyry (Lovejoy, 1959).

The distribution of pebbles in the Raine Ranch formation (volcanic rocks on the west side of Pine Valley, Paleozoic rocks on the east side) is identical to that of the present drainage. This fact suggests that the present distribution of highlands and basins was in existence when the Raine Ranch formation was deposited.

Palisade Canyon Rhyolite

LITHOLOGY: Extensive flows of rhyolite form a major element of the landscape southwest of Carlin. They separate the Carlin basin from Pine Valley; they are folded into an open syncline in which flows the Humboldt River and an anticline that determines a ridge 1000 feet high west of the river. In Palisade Canyon, the rhyolite forms cliffs 500 feet high.

The rhyolite consists of several flows; three are exposed in Palisade Canyon. Some of the flows are more than 200 feet thick and can be traced for several miles. The rock is brownish red and weathers dark brown. It is very strongly flow-banded. It contains phenocrysts of sanidine, quartz, biotite, and pigeonite in a groundmass crystallized in small spherulites. The base of each flow is a glassy, black to dark-blue rock which is also flow-banded. It contains the same phenocrysts as the top of the flows in a glassy groundmass with abundant trychtites and perlitic cracks.

The thickness of the rhyolite varies greatly from place to place. The maximum thickness observed, in the Palisade Canyon, is 500 feet. Toward the east the flows thin out and disappear. According to the maps of the Exploration of the Fortieth Parallel (King, 1878), the rhyolite covers a large territory toward the northwest.

LOWER CONTACT AND AGE: At the northern end of Pine Valley, the Palisade Canyon rhyolite overlies the Raine Ranch formation unconformably (Pl. 1, cross section). A zone of slumping has developed at the contact.

The Palisade Canyon rhyolite is upper Miocene or lower Pliocene because it overlies the Raine Ranch formation and is overlain by the lower Pliocene Carlin formation.

Carlin Formation

LITHOLOGY: The beds of the Carlin formation fill the Carlin basin. Good exposures are found only 5 miles southwest of Carlin and in area along and east of Susie Creek. The beds in most places show small faults and gentle folds; the dips rarely exceed 15°.

The formation is composed chiefly of soft, tan to reddish, muddy, tuffaceous sandstones and siltstones which are interbedded with conglomerates. Good exposures in the road cuts on U. S. Highway 40 display well-defined bedding, cross-bedding, and scour-and-fill channels. The sandstones and siltstones contain some intermixed fine gravel. Other rock types present in the formation are vitric tuff and ashes, diatomite, limestone, and limy shales, all of which, with the exception of basaltic tuffs, are very similar to the lake beds of the upper part of the Raine Ranch formation.

Section 4, 625 feet thick, was measured by correlating outcrops southwest of Carlin. At the bottom of the section is 225 feet of lacustrine fine vitric tuffs and ashes which are interbedded with diatomite and limestone beds. The vitric tuffs contain a small amount of quartz and feldspar and a negligible amount of dark minerals. The index of refraction of the glass indicates a rhyolitic composition. Some of the tuff beds are fresh; some are altered to montmorillonite, heulandite, and green chert. These beds are overlain by 400 feet of tan siltstones, sandstones, and conglomerates. The conglomerates are of poorly rounded elements up to 1 foot in diameter, most of which are derived from the volcanic rocks of the Cortez Mountains and the Palisade Canyon rhyolite. Their size decreases within a short distance toward the northeast.

Section 5 was measured east of Carlin. It has 175 feet of lake beds overlain by 225 feet of tan sandstones and conglomerates. The lake beds consist of interbedded white shaly limestones, light-gray rhyolitic ashes, blue and yellow basaltic tuffs, and diatomite. This is the only section within the map area in which basaltic tuffs are present. They consist of brown glass shards and scoria fragments up to 10 mm in diameter, accompanied by some fragments of basalt and some crystals of labradorite, orthoclase, augite, and olivine. The index of refraction of the glass indicates a basaltic composition. The conglomerates that overlie the lake beds contain angular to subrounded pebbles and boulders of limestone, chert, and siltstone that are identical to the Paleozoic rocks that crop out in the West Elko Hills immediately to the east. Boulders and pebbles decrease in size within a short distance toward the west.

LOWER CONTACT: The contact of the Carlin formation with the underlying Palisade Canyon rhyolite is well exposed 7 miles west-southwest of Carlin. The contact is sedimentary with an angular unconformity of 10°–15°. The surface of contact is very irregular.

The Carlin formation laps onto the Paleozoic rocks of the West Elko Hills over a surface of gentle relief. A red conglomerate is present in places at the contact.

The Carlin formation rests with a slight angular unconformity on the Raine Ranch formation. The contact is well exposed on the south bank of Middle Susie Creek (sec. 1, T. 34 N., R. 53 E.). The basal beds of the Raine Ranch formation, dipping 15° NW., are overlain by tan tuffaceous conglomerates containing angular pebbles of volcanic rocks derived from the Raine Ranch formation and dipping 10° S.

AGE AND CORRELATION: The Carlin formation is dated as early Clarendonian by vertebrate fossils found 3 miles northeast of Carlin, at the base of the sandstones that overlie the diatomite bed of the Triolite mine (section 5, bed I.24). The following forms have been found (Van Houten, 1958, personal communication): SW¼ sec. 7, T. 33 N., R. 53 E.: *Protolabis* (late Barstovian or early Clarendonian); NE¼ NW¼ NE¼ sec. 19, same township: *Aphelops* (middle Miocene to early Pliocene); area of the Triolite mine: *Merychippus* sp. and camelid (Clarendonian). Another locality, west of Carlin (SW¼ sec. 31, T. 33 N., R. 52 E.), yielded a *Merychippus* of late Miocene to early Pliocene age (E. R. Larson, 1958, personal communication).

A large number of early Pliocene and late Miocene or early Pliocene fossil localities are known in Nevada (Axelrod, 1956; Van Houten, 1956). In particular, the Carlin formation is correlative with the middle member of the "Humboldt formation," which has been described by Sharp (1939) in the Elko region, and the rhyolite at Jarbridge (Schrader, 1923), in both of which early Clarendonian floras have been found (Axelrod, 1956, p. 64).

PHYSICAL SETTING: The Carlin formation laps over the edges of the Carlin basin. It contains locally derived pebbles whose size decreases basinward. This indicates that the Carlin formation was laid in a basin shaped substantially like the basin in which it is now contained. There is no evidence that this basin was formed by faulting; it is probably fairly shallow, as indicated by the presence of small hills of the basement rocks which crop out in several places of the basin through the beds of the Carlin formation. The basin at times contained a lake in which vitric tuffs, shales, limestones, and diatomites were deposited; at other times, meandering streams deposited sandstones and conglomerates. Local volcanic activity is indicated by the coarse basaltic tuffs and by the presence of a thin basalt flow which crops out in the northeast part of the basin.

Basalt Plugs

A number of small basalt plugs have been mapped in Pine Valley. The rock consists of crystals of labradorite, olivine altered to bowlingite, augite, quartz, and magnetite in a glassy groundmass.

The youngest beds cut by the plugs are upper Miocene. They may be correlative with the basalt tuffs and flow of the Carlin formation.

Hay Ranch Formation

DESCRIPTION: The Hay Ranch formation, named after a ranch in NW¼ T. 29 N., R. 52 E., covers most of the floor of Pine Valley. It

Section 4. Carlin Formation

Section measured by correlating outcrops in secs. 1, 2, and 3, T. 32 N., R. 51 E.

Top: eroded

		Thickness (In feet)	
G.20	Tan to reddish tuffaceous siltstone, sandstone, and conglomerate; little rounded pebbles and cobbles up to 1 foot in diameter, mostly derived from Palisade Canyon rhyolite and volcanic rocks of the Cortez Mountains, some Paleozoic; size decreasing toward the northeast; well bedded, cross-bedded	400	614
G.19	Light-gray vitric ash composed of about 95 per cent clear colorless glass shards (n = 1.500 ± 0.002) and about 5 per cent feldspar and quartz; thinly bedded, cross-lamination	63	214
G.18	Vitric tuff altered to heulandite (white) and silicified (green), poorly exposed	32	151
G.17	Light-gray tuffaceous limestone; insoluble residue of clear colorless glass shards (n = 1.502 ± 0.002)	1	119
G.16	Diatomite	0.2	
G.15	White, slabby calcilutite	1	118
G.14	White diatomite, thinly bedded; interbeds of light-gray vitric ash composed of clear colorless glass shards (n = 1.505 ± 0.002) and trace of feldspar and quartz	23	117
G.13	Diatomaceous clayey vitric ash	5	94
G.12	Light-gray vitric ash; incipient devitrification	1	89
G.11	White massive diatomite	23	88
G.10	Light-gray vitric ash composed of colorless glass shards (n = 1.510 ± 0.005) and traces of feldspar and quartz; incipient alteration to montmorillonite	20	65
G.9	Diatomite	5	45
G.8	Light-gray vitric ash composed of clear colorless glass shards (n = 1.502 ± 0.002)	18	40
G.7	Diatomite	2	22
G.6	Gray vitric tuff composed of glass shards altered to montmorillonite	1	20
G.5	Diatomite	3	19
G.4	Dark-green chert	0.1	
G.3	Light-gray vitric tuff composed of colorless glass shards (n = 1.510 ± 0.005), incipient alteration to montmorillonite; about 5 per cent quartz and feldspar	1	16
G.2	Green silicified mudstone	0.1	
G.1	Yellow vitric ash composed of glass shards (n = 1.504 ± 0.002), mostly altered to montmorillonite; about 5 per cent quartz and feldspar	15	15

Bottom: sedimentary contact on the Palisade Canyon rhyolite

Section 5. Carlin Formation

Section measured in secs. 18 and 19, T. 33 N., R. 53 E.

Top: not exposed

		Thickness (In feet)	
I.24	Tan to reddish tuffaceous siltstone, sandstone and conglomerate; pebbles and boulders derived from the West Elko Hills	325	501
I.23	Light-gray, calcite-cemented, ledge-forming vitric tuff composed of clear, colorless glass shards (n = 1.502 ± 0.002); interbeds and lenses of Paleozoic-pebble conglomerate	10	176
I.22	White diatomite with interbeds of light-gray vitric ash composed of clear colorless glass shards (n = 1.607 ± 0.002) and traces of feldspar and quartz; large flat opal concretions	12	166
I.21	Green silicified tuff	6	154
I.20	Light-gray vitric ash composed of clear colorless glass shards (n = 1.515 ± 0.005) and about 10 per cent quartz and feldspar; thinly bedded	24	148

		Thickness (In feet)	
I.19	Green silicified tuff	3	124
I.18	Light-gray vitric ash composed of cloudy colorless glass shards (n = 1.510 ± 0.005); thinly bedded, cross-laminated, contorted bedding	38	121
I.17 I.16	White limy shale	13	83
I.15	Light-gray vitric ash composed of clear colorless glass shards (n = 1.510 ± 0.002) and about 5 per cent quartz and feldspar	13	70
I.14	White limy shale	2	57
I.13	Light-gray vitric ash composed of clear colorless glass shards (n = 1.512 ± 0.002) and traces of quartz and feldspar	2	55
I.12	White limy shale	3	53
I.11	Yellow altered basaltic tuff composed of scoria fragments up to 10 mm, which show labradorite laths intergrown with augite	12	50
I.10	Basaltic tuff similar to 1.5	1	38
	White limy shale	1	
	Basaltic tuff similar to I.5	1	
	White limy shale	2	
I.9	Light-gray vitric tuff composed of clear colorless glass shards (n = 1.503 ± 0.002) and traces of quartz and feldspar	2	33
I.8	White limy shale	8	31
I.7	Yellow altered basaltic tuff composed of scoria and basalt fragments up to 10 mm, and crystals of labradorite, orthoclase with black glass inclusions, augite, olivine	2	23
I.6	White limy shale	4	21
I.5	Blue basaltic tuff composed of brown glass shards and scoria fragments (n = 1.570 ± 0.005); color due to coating of montmorillonite (?) on glass particles	2	17
I.4	White limy shale; 6-inch interbed of blue basaltic tuff similar to I.5 (n = 1.580 ±0.002)	7	15
I.3	Light-purple-gray vitric tuff composed of clear colorless glass shards (n = 1.505 ± 0.005) and about 5 per cent quartz and feldspar	1	8
I.2	White limy shale	7	7

Bottom: in fault contact on 400 feet of tan tuffaceous sandstone and conglomerate

consists of lake deposits of clay, vitric tuffs (mostly altered to zeolites), limestones and tan tuffaceous siltstones, and sandstones, which interfinger with conglomerates and fanglomerates. Except for the northern part of the valley, where it dips up to 15° E., the formation lies essentially undisturbed. It is overlain by an extensive, deeply dissected pediment, so that outcrops are present along the tributaries of Pine Creek, but no thick section can be measured. Structural evidence suggests that the formation is thick.

By correlating outcrops in the southern part of the area, it is possible to measure a 420-foot section (section 6), which consists of green clays overlain by limestones. Excellent exposures to the south (sec. 4, T. 27 N., R. 52 E.) provides a better section of the upper part of the clay beds (section 7). The clays are pale green and massive. They contain a very minor amount of silt and, in some zones, disseminated clusters of small gypsum crystals, but no beds of evaporites. Interbedded with the clay are beds of erionite and another zeolite (?) and stringers of limonite-stained rhyolitic vitric ash. The zeolite beds range from 1 inch to 25 feet in thickness. They are uniform in thickness and cover several square miles. The limestone, which overlies the clay beds, forms prominent bluffs east of the Slagowski Ranch (sec. 16, T. 28 N., R. 52 E.). It is a white, massive, hard, thickly bedded calcilutite which contains, sparingly some tiny gastropod shells. The insoluble residue, which represents about 20 per cent by weight, is composed of clay and a little sand. Toward the middle of the limestone section, a 2-foot bed of light-gray, thinly bedded vitric ash can be traced over 12 square miles. All these features indicate that the limestone is an indurated impure lime mud deposited in a lake.

Toward the east, this section of lake sediments grades into tan sandstones and conglomerates. The limestone becomes progressively

Section 6. Hay Ranch Formation

Section measured by correlating outcrops in secs. 16, 20, and 21, T. 28 N., R. 52 E.

		Thickness (In feet)
Top:	eroded	
E.8	White, massive, hard calcilutite; insoluble residue (about 20 per cent) of clay and little silt and sand; small gastropods; thickly bedded	30
E.7	Light-gray vitric ash; clear colorless glass shards; index of refraction close to 1.50	2
E.6	White calcilutite; similar to E.8	140
E.5	Green clay; stringers of vitric ash stained by limonite, composed of clear colorless glass shards (n = 1.505 ± 0.005) and traces of quartz and feldspar; Interbeds of white altered vitric ash better exposed farther south (section 7)	170
E.4	White vitric tuff altered to zeolite (?)	15
	Green clay, clusters of small gypsum crystals	5
E.3	White vitric tuff altered to zeolite (?)	1
E.2	Green clay	33
E.1	White massive porous altered tuff; 99 per cent erionite and 1 per cent angular quartz and feldspar	25
	Total:	421
Bottom: not exposed		

Section 7. Hay Ranch Formation

Section measured in sec. 4, T. 27 N., R. 52 E.

		Thickness (In feet)
Top: eroded		
J.11	Green clay	1
J.10	White vitric tuff altered to zeolite (?)	0.2
J.9	Green clay	21
J.8	White vitric tuff altered to zeolite (?)	0.2
J.7	Green clay	9
J.6	White vitric tuff altered to zeolite (?)	0.2
J.5	Green clay	13
J.4	White vitric tuff altered to zeolite (?)	0.1
J.3	Green clay	7
J.2	Vitric tuff altered to zeolite (?), stained by limonite	0.3
J.1	Green clay	21
	Total:	72
Bottom: not exposed		

loaded with sand and fine gravel; within half a mile from the contact with the Paleozoic rocks of the Piñon Range, it has given way to reddish sandstones and conglomerates composed of angular to subrounded cobbles up to 6 inches in diameter, which were derived from the nearby Paleozoic outcrops. The same kind of facies variation can be observed on the west side of Pine Valley, opposite the Slagowski Ranch: white limestones overlie green clays toward the middle of the valley and grade progressively westward into conglomerates composed of volcanic pebbles derived from the Cortez Mountains.

Thus, the Hay Ranch formation was deposited in a basin which had the same boundaries as the basin in which it occurs today. The basin was created by normal faulting along the west side of the Piñon Range and by eastward tilting of the Cortez Mountains block. The fault is lined by a series of hot springs and oil seeps. The influence of the faulting on the sedimentation is shown by the presence of a thick alluvial fan at the foot of Pine Mountain. The fanglomerate is well exposed in the canyon of Mill Creek. At the head of the canyon, the fanglomerate consists of thick beds of angular blocks up to 5 feet in diameter derived from the limestones that make up the west face of Pine Mountain, from the black argillites and sandstones that crop out at the head of Mill Creek, and from a white quartz porphyry that forms dikes in the same area. Westward, this coarse deposit grades laterally into interbedded tan sandstones and gravel beds. Southward the fanglomerate grades into lake deposits of tan siltstones, green clay, and white limestone.

CONTACTS: The Hay Ranch formation rests with a slight angular unconformity on the older Tertiary formations. Northwest of Pine Mountain and at the head of Mill Creek, nearly flat-lying conglomerates and fanglomerates override the border fault of the Piñon Range and rest on an eroded surface cut on the Paleozoic rocks. South of Pine Mountain the Hay Ranch formation is faulted against the Piñon Range. Best evidence is found along Willow Creek where the pediment, which is cut on the beds of the Hay Ranch formation and extends somewhat over the Paleozoic rocks, is cut by the border fault with the formation of an eroded scarp about 80 feet high. This recent faulting appears to have everywhere a small displacement.

AGE AND CORRELATION: The Hay Ranch formation is dated as middle Pliocene to middle Pleistocene by vertebrate fossils. The following forms have been found:

(1) Near the base of the formation, in tan to reddish tuffaceous conglomerates and sandstones (NE¼ NE¼ sec. 20, T. 31 N., R. 52 E.), one molar of a small equid referable to the *Hipparion gratum* group of Leidy, 1869, currently allocated to the *Griphippus gratus* group Quinn, 1955, middle Pliocene (identification by M. F. Skinner). This fossil is in the American Museum of Natural History (AM-45819).

(2) White tuff bed, sec. 7, T. 29 N., R. 52 E.; fragmentary horse material referable to *Pliohippus astrohippus*, late Hemphillian or early Blancan (Van Houten, personal communication)

(3) Tan tuffaceous mudstone near the top of the formation in sec. 7, T. 29 N., R. 52 E.; astragalus of *Equus* sp., Pleistocene

(4) Twelve miles south of Palisade, a quarter of a mile east of the highway (probably sec. 21, T. 30 N., R. 52 E.); *Equus* sp., middle Pleistocene (Van Houten, personal communication)

The Hay Ranch formation is correlative in part with beds of rhyolite tuffs, pumice, diatomite, sands, and gravel in Mason Valley, Nevada, which contains the Wichman fauna of Blancan age (Stirton, 1940; Axelrod, 1956); with the Morgan formation, which ranges from Hemphillian to Blancan; and with the "Truckee formation", which ranges from late Clarendonian to Blancan (?) (Axelrod, 1956). A few other middle Pliocene to Pleistocene fossil localities are listed by Van Houten (1956) and Stirton (1940). Pleistocene mammals have also been reported from the Manhattan district, Nevada (Ferguson, 1924), and Carson, Nevada (Hay, 1927).

Late Pleistocene lake deposits, such as the higher stages of Lake Bonneville and Lake Lahontan, which are characterized by well-preserved shore features and are generally referred to the Wisconsin stage (Hubbs and Miller, 1948), are not present in Pine Valley.

Welded Tuffs

LITHOLOGY: Small patches of welded tuffs occur in three widely separated localities: northeast of Carlin (sec. 12, T. 34 N., R. 53 E.); in the northernmost part of Pine Valley; and near Devils Gate (secs. 2 and 11, T. 30 N., R. 51 E.). The most extensive exposures are those of the northern end of Pine Valley where a salmon-colored tuff overlies a gray tuff. The aggregate thickness is not more than 100 feet. The gray tuff is a medium-hard, porous rock in which flattened pieces of pumice up to 1 inch in length and broken crystals of quartz, sanidine, plagioclase, and some biotite flakes are imbedded in a matrix composed of plastically deformed glass shards and pumice fragments. The salmon-colored tuff is a hard rock composed of slightly flattened pumice pieces, angular lithic fragments, and some quartz and feldspar in a matrix composed of welded and devitrified glass shards and pumice fragments.

AGE: Northeast of Carlin, the welded tuff rests horizontally on eroded beds of the Carlin formation. At the northern end of Pine Valley, it rests on a very irregular erosion surface and overlies unconformably the basal beds of the Raine Ranch formation. Near Devils Gate, it lies on a pediment, which farther south extends over the Hay Ranch formation. The welded tuff, which is assumed to be contemporaneous at the different localities, is consequently late Pleistocene or Recent.

Pediments and Recent Warping

Extensive pediment gravels occur throughout the area. They are so extensive that it was impractical to represent them on the geological map (Pl. 1).

A very extensive dissected pediment occurs along the eastern edge of Swails Mountain. It is cut on the tuffaceous sediments of the Raine Ranch formation and extends 1–2 miles over the Paleozoic rocks. The other side of the valley is not pedimented because most of the outcrops on the east side of the creek are the lava flows of the base of the Raine Ranch formation. Many workers have observed that pedments do not develop over lava flows (Bryan, 1923; Gilluly, 1937).

There are remnants of two pediments in Pine Valley. The most extensive one is well developed on both sides of the valley. It forms the spectacular Evans Flat southwest of Pine Mountain. On the west side of the valley, it is developed only on the Cenozoic sediments and does not encroach on the volcanic rocks of the Cortez Mountains. On the east side, in places it stops at the contact of the Cenozoic sediments with the Paleozoic rocks of the Piñon Range, but north and northeast of Pine Mountain, it extends widely over Paleozoic argillites and sandstones.

Restored profiles of this pediment show that it is approximately 700 feet above grade at the northern end of Pine Valley, where Pine Creek is entrenched in the Cenozoic sediments, and 200 feet above grade at the southern end of the map area, where Pine Creek meanders in a wide flood plain. The general slope of the restored pediment is toward the south. Pine Valley, however, is presently drained toward the north. This can be explained in one of two ways: (1) When the pediment formed, Pine Valley drained to the south and was later captured from the north. (2) The pediment was tilted southward. The first hypothesis is untenable, because the divide between Pine Valley and adjoining valleys to the south is everywhere above 5900 feet, whereas the restored profiles indicate that a stream draining the pediment southward could not have had an outlet above 5200 feet. The second hypothesis explains the entrenchment of Pine Creek northward and the superimposed course of the Humboldt River in Palisade Canyon.

In the area of the Rand Ranch are small remnants of a lower pediment which are 120 feet above grade.

Structure of Pine Valley

Evidence indicates that the Pine Valley half graben does not have a simple structure and that more than one major longitudinal fault is present:

Tan silicified chert-pebble conglomerate and sandstone from a small outcrop at the northern end of Pine Valley and seem to be partlv burried under the Raine Ranch formation. They resemble both the Oliogocene (?) Rand Ranch formation and fossiliferous Paleozoic conglomerates 2 miles to the east. They have been mapped as Paleozoic because they dip west, as do the Paleozoic conglomerates, whereas all the Tertiary formations in Pine Valley dip east. For that reason, the generalized structure section of the northern end of Pine Valley (Pl. 1) has a concealed normal fault with a large stratigraphic throw. Four miles south of the map area, in the Hay Ranch formation, there is a north-trending monocline whose limb dips 10°–15° W. It is probably a late surface manifestation of a normal fault in depth, parallel to the border fault of the Piñon Range.

Summary of Geologic History

The Cenozoic geologic history of the area can be deciphered in detail from the sedimentary record. It is characterized by repeated tectonic and volcanic activity.

This history begins with the outpouring of the older volcanic rocks of the Cortez Mountains (Paleocene ?) and then their folding and intrusion by diorites and granodiorites (Eocene ?). This episode was followed by erosion and the formation of the younger volcanic rocks (Oligocene ?).

A new period of tectonic activity, probably

Plate 2.—ALTERATION OF VITRIC TUFFS

Figure 1.—Photomicrograph of erionite from the Hay Ranch formation (sample E-1, section 6). Natural light, ×100.

Figure 2.—Hay Ranch formation, green clay with stringers of vitric ash altered to zeolite (sec. 4, T. 27 N., R. 52 E.).

Figure 3.—Vitric ash altered to heulandite and silicified (Raine Ranch formation, sample B-13, section 3).

Figure 4.—Fresh, water-laid vitric ash for comparison, Raine Ranch formation.

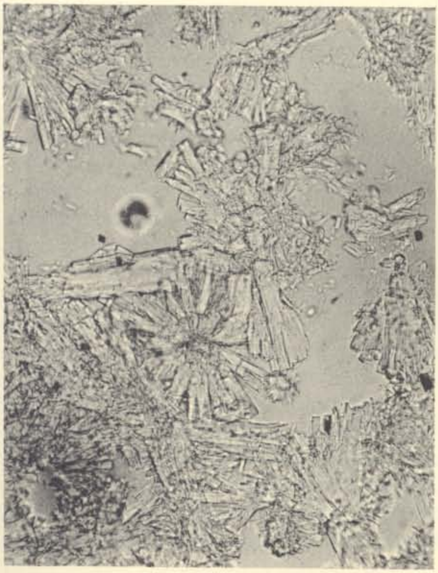

Figure 1

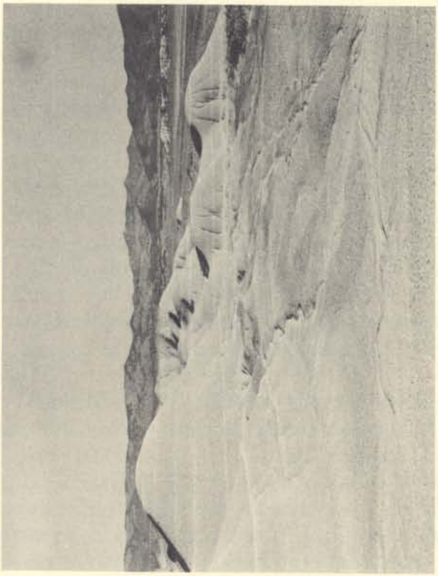

Figure 2

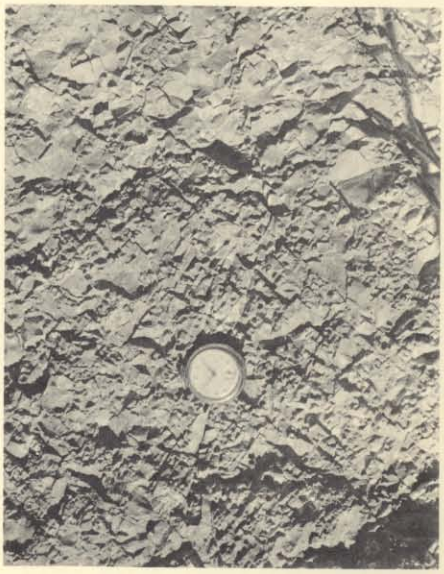

Figure 3

Figure 4

ALTERATION OF VITRIC TUFFS

faulting, must account for the deposition by streams of the Rand Ranch formation. Highlands on the order of several thousand feet were created. The present site of the Cortez Mountains was a low area. This is the only sedimentary episode that records no volcanic activity. The present pattern of Basin Range topography may have originated before the next episode of sedimentation: the volcanic rocks of the Cortez Mountains were tilted east and supplied much detritus to the Safford Canyon formation (Late Oligocene, early Miocene ?). Volcanic activity was resumed, but the fineness of the pyroclastic material indicates that it may have originated in remote volcanic centers. Alluvial and lacustrine deposition alternated.

Deposition of the Safford Canyon formation was followed by renewed tilting eastward of the Cortez Mountains block and erosion. Local volcanic activity was renewed in upper Miocene time and resulted in the deposition of the lower member of the Raine Ranch formation. After a very minor period of erosion, the streams and lake sediments of the upper member of the formation were deposited. The pebble content of these deposits suggest a topography similar to that of today.

The first evidence of Basin and Range faulting is provided by the contact of the Raine Ranch formation with the Paleozoic of the Piñon Range. In Pine Valley, the fault is overlain by the Palisade Canyon rhyolite and is consequently late Miocene. In the valley of Susie Creek, the fault, which is overlain by the Carlin formation (early Clarendonian), probably has the same age. This faulting was followed by erosion and outpouring of the Palisade Canyon rhyolite.

The nature and distribution of the lower member of the Raine Ranch formation indicates that it was deposited over the area which is now the Carlin basin; it has been recognized underneath the Carlin formation only in the valley of Susie Creek. This indicates that the area was high for some time after the deposition of the Raine Ranch formation so that it was removed by erosion. Then warping created the basin—similar in shape to the present-day depression—in which the Carlin formation was deposited. This explains the eastward dip of the Palisade Canyon rhyolite west of Carlin and its angular relationship with the overlying Carlin formation. Stream and lake deposition alternated; large amounts of fine acidic ash were mixed or interbedded with detrital sediments. The relatively coarse basaltic tuffs and a basalt flow may have had their source in Pine Valley where basalt plugs occur.

Next events are renewed faulting along the western edge of the Piñon Range and the correlative steepening of the eastward tilt of the Cortez Mountains block and deposition of the Hay Ranch formation in the basin thus created (middle Pliocene-middle Pleistocene). Local volcanic activity during the deposition of the Hay Ranch formation is not recorded; the fine rhyolitic ash the formation contains probably drifted from remote volcanic centers; a local volcanic outpouring in late Pleistocene time resulted in the formation of small welded tuff patches.

The dominant geological process since the deposition of the Hay Ranch formation has been erosion, which has led to the formation and later dissection of extensive pediments. Recent warping is responsible for the entrenchment of Pine Creek and the Humboldt River.

Alteration of Vitric Tuffs

Introduction

All the tuffaceous formations that have been described contain beds of water-laid vitric tuffs which are extensively altered to montmorillonite, zeolites, and silica.

Alteration to Montmorillonite

Alteration to montmorillonite is relatively rare and incomplete. The clay was identified by the benzidine staining test, the reliability of which was verified for one sample with the X-ray diffractometer.

In most cases, the glass shards are cloudy and take a weak blue coloration in the benzidine solution. In more advanced stages of alteration, the glass shards are opaque and milky, but their shape is not altered. X-ray-diffraction measurements indicate montmorillonite as the only alteration product.

Alteration to Zeolites

HEULANDITE: Vitric-ash beds altered to heulandite are present in the Safford Canyon, Raine Ranch, and Carlin formations. This identification is based on comparison of X-ray-diffraction data with heulandite from Cape Blomidon, Nova Scotia, and Patterson, New Jersey (Fig. 1; Table 1).

Heulandite occurs in several beds of the Safford Canyon formation (section 1). Sample

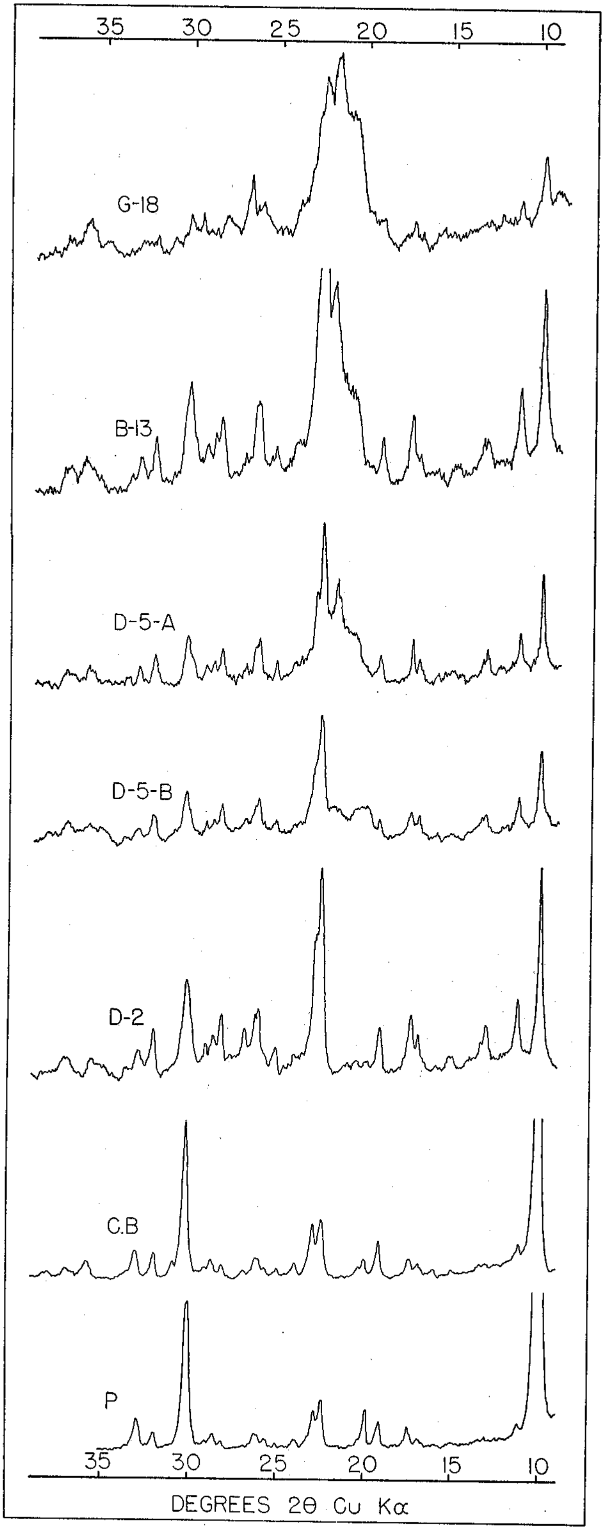

FIGURE 1.—X-RAY-DIFFRACTION PATTERNS OF HEULANDITE

P. Patterson, New Jersey; C.B. Cape Blomidon, Nova Scotia; D. Safford Canyon formation (section 1); B. Raine Ranch formation (section 3); G. Carlin formation (section 14). Supplementary reflection at 2Θ = 21.7–21.9 on curves D-5-A, B-13, and G-18 is probably the strongest reflection of cristobalite

TABLE 1.—X-RAY DIFFRACTION OF HEULANDITE DIFFRACTOMETER MEASUREMENTS

(Cu rad., Ni fil.)

Cape Blomidon, Nova Scotia		Sample D.2	
dÅ	I	dÅ	I
8.93	10	8.93	10
7.96	1	7.89	4
7.13	½	7.24	1
6.80	½	6.75	2
6.60	½	6.60	1
5.90	½	5.82	1
5.54	½	5.54	1
5.24	½	5.21	2
5.06	1	5.09	3
4.62	1	4.62	3
4.44	1	4.46	1
4.37	½	4.33	1
4.19	¼	4.23	1
3.97	2	3.95	10
3.88	2	3.90	6
3.72	½	3.69	1
3.56	½	3.55	2
3.46	½		
3.42	1	3.41	3
3.40	1	3.39	2
3.32	½	3.31	2
3.22	¼	3.22	1
3.17	½	3.16	3
3.11	½	3.11	2
3.07	¼	3.07	1
2.96	4	2.96	5
2.89	½		
2.80	1	2.78	3
2.71	1	2.71	1
		2.66	1
2.51	1	2.52	1
2.43	½	2.43	1

D.2 exhibits minute acicular and prismatic crystals of the mineral replacing glass shards. Sample D.5 has an indistinct vitroclastic texture, and the zeolite is cryptocrystalline.

Sample G.18, from the Carlin formation (section 4), is a massive white rock through which are disseminated small crystal molds of an unidentified mineral filled with calcite. The zeolite is cryptocrystalline, and no trace of vitroclastic texture is visible.

Where exposures are good these heulandite beds can be traced for more than a mile.

ERIONITE AND OTHER: Beds of erionite and another zeolite (?) are present in the Hay Ranch formation (sections 6, 7).

The lowermost of these beds, 25 feet thick, is a white massive rock stained by limonite and composed almost entirely of minute prismatic crystals of erionite which are arranged in spheroidal aggregates (Pl. 2, fig. 1). The identification of the mineral is based on comparison of X-ray-diffraction data with erionite from the type locality, Durkee, Oregon (Fig. 2). It agrees optically in index of refraction, birefringence, and orientation with the description of erionite given by Staples (1957). In addition to erionite the rock contains less than 1 per cent angular fragments of quartz and feldspar.

Higher in the section, similar beds are composed of an unidentified mineral (Pl. 2, fig. 2). It is a massive, white, porous, exceedingly fine-grained rock. In some of the beds thin sections reveal an indistinct vitroclastic texture; the glass shards are replaced by a colorless cryptocrystalline mineral. One of the beds has no vitroclastic texture, and the mineral is better crystallized in the form of minute acicular crystals arranged in spheroidal aggregates. A trace of angular fragments of quartz and feldspar occurs in all the beds. The optical properties of the mineral are: parallel or low-angle extinction, positive elongation, indices between 1.480 and 1.490, birefringence less than 0.005. Qualitative chemical and spectroscopic analyses indicate a hydrated silicate of Al, Ca, Mg, and Na (not tested for K). X-ray-diffraction measurements (Fig. 3) indicate that the mineral has large interplanal spacings. It has been tentatively referred to the zeolite group.

ORIGIN: The vitric-tuff beds altered to heulandite of the Raine Ranch and Carlin formations are interbedded with diatomite, fossiliferous fresh-water limestone and shale, and thinly bedded unaltered vitric ash which in many places contain ostracods. They appear to be lacustrine.

Altered vitric ash beds in the Hay Ranch formation, which are interbedded with plastic green clays and are remarkably uniform in thickness over several square miles, also appear to be lacustrine.

The lateral gradation of altered vitric tuff into unaltered vitric tuff has never been observed; altered beds cover several square miles; the alteration is controlled rigidly by the bedding, even where altered beds are overlain and underlain by fresh, porous vitric ash. Thus alteration apparently took place under the influence of the waters of the lakes in which the ash fell.

The alteration of volcanic glass to various zeolites, in some cases at low temperature, has been reported by several investigators. Harris and Brindley (1954) report the alteration of a pitchstone dike to mordenite, and Kerr *et al.* (1957) report a similar occurrence of ptilolite; Needham (1938) describes thomsonite, analcite, and natrolite as the alteration of andesite flows by either meteoric or hydrothermal waters, and thomsonite also as the alteration of white acidic tuffs under hydrothermal conditions. Coombs (1952) describes the replacement of crystal-vitric tuffs by heulandite and analcite during diagenesis and their transformation to laumontite by incipient metamorphism. Tyrell and Peacock (1926) report the partial alteration of a palagonite tuff to faujasite and analcite and consider that the transformation took place at low temperature. Murray and Renard (1891) found abundant phillipsite in red deep-sea ooze and consider that it was formed by slow transformation on the ocean floor of glassy basalt lapilli and palagonite. Bramlette and Posnjak (1933) and Kerr and Cameron (1936) report the presence of clinoptilolite in bentonite beds from California, Wyoming, and Arizona, in which partly altered glass shards are still visible. Bradley (1929) and Ross (1928; 1941) describe analcite beds interbedded with lake or playa sediments and show that the zeolite was formed by the interaction of volcanic ash with mineralized lake waters. Erionite and heulandite are abundant in altered vitric tuffs of Central Nevada (K. S. Deffeyes, personal communication).

The only occurrence of erionite that has been reported in the literature is from Durkee, Oregon, where the mineral, which has a woolly texture, is found in the cavities and fissures of a rhyolitic tuff (Eakle, 1898; Staples, 1957).

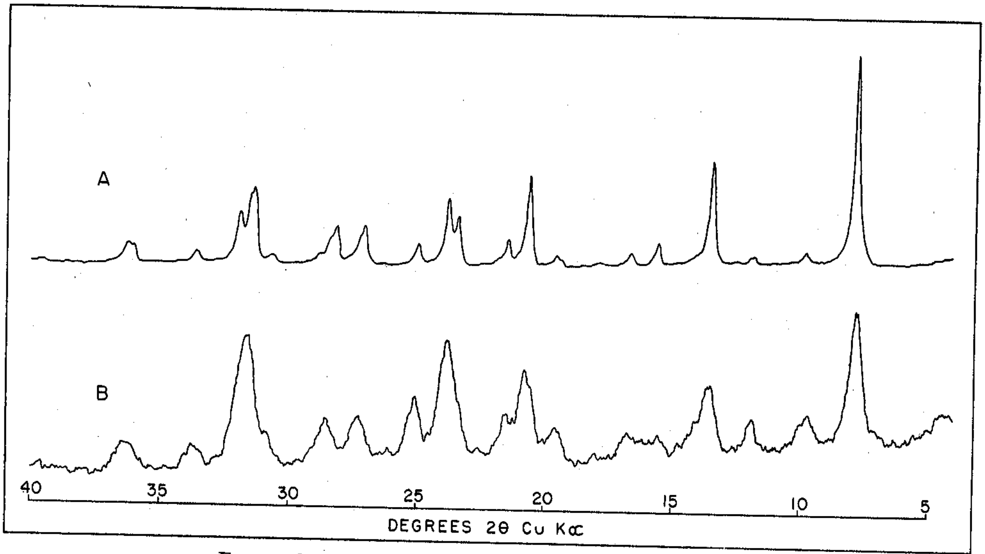

FIGURE 2.—X-RAY-DIFFRACTION PATTERNS OF ERIONITE
A. Sample E-1, Hay Ranch formation (section 6); B. Durkee, Oregon

Silicification

Silicification of water-laid ash beds is observed in many places and results in the formation of gray and green chert which is typically very brittle (Pl. 2, fig. 3).

At several horizons in a thick ash bed of the Raine Ranch formation gray chert forms beds, 1 inch to 2 feet thick, traceable for several hundred feet. Thin sections and X-ray-diffraction data indicate that the silicification consists of the cementation of the ash by colorless opal. The glass shards are not altered.

Green chert has been found in all the heulandite beds previously described. The coloration is caused by an earthy green mineral (celandonite ?). Much opal can be seen in thin section. X-ray-diffraction patterns have been obtained (Fig. 1) for unsilicified (D-5-B) and silicified (D-5-A) material from a heulandite bed of the Safford Canyon formation. The only difference between the two patterns is the presence in the silicified material of a supplementary peak that

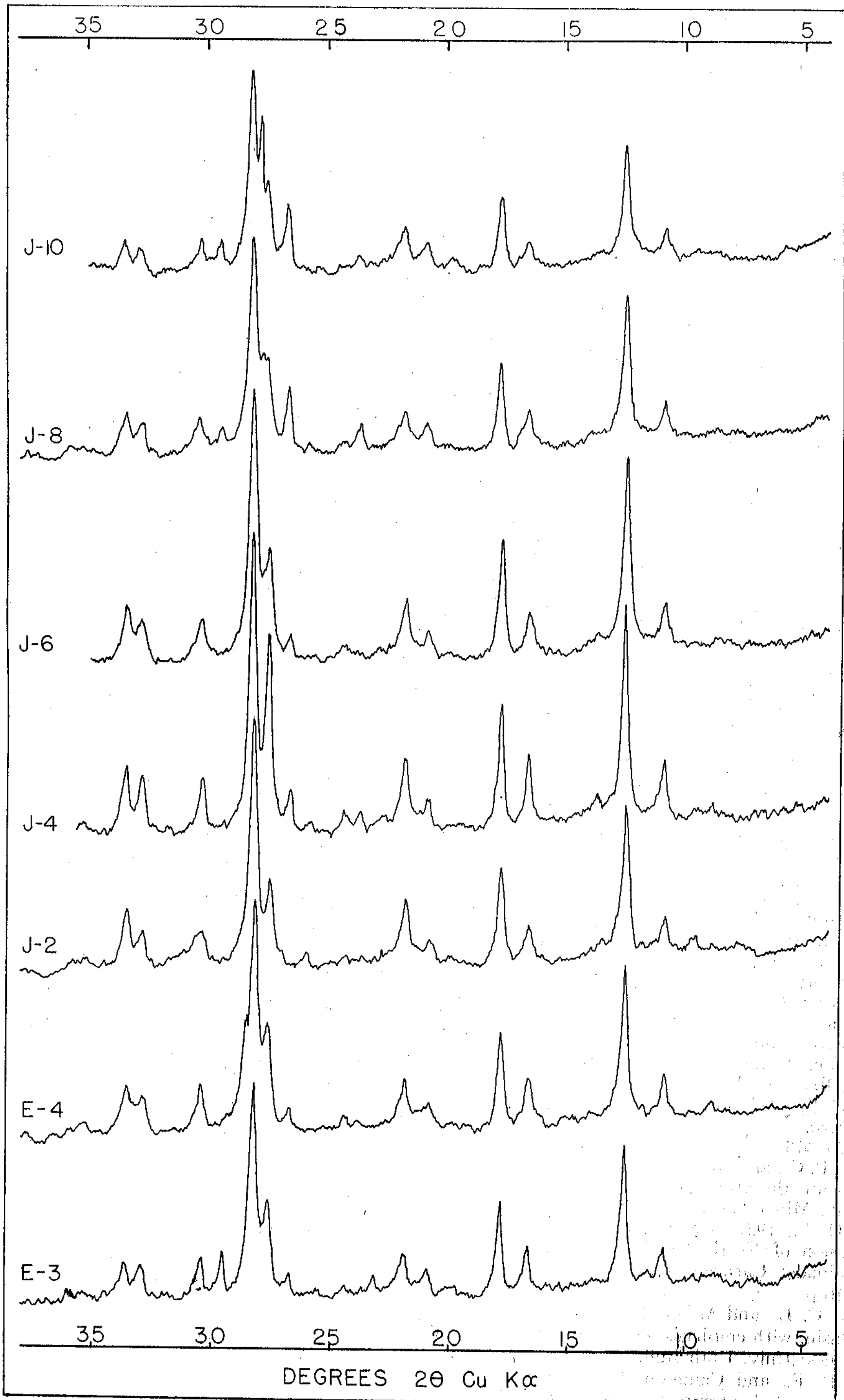

FIGURE 3.—X-RAY-DIFFRACTION PATTERNS OF ALTERED VITRIC TUFF
Hay Ranch formation (sections 6 and 7)

has been referred to the strongest reflection of cristobalite. Heulandite samples B-13 and G-18, which present incipient silicification, also show the same supplementary reflection (Fig. 1). These green cherts can be traced continuously in the same beds for more than a mile.

The great lateral extent of these chert beds and their rigid conformity to the bedding suggest that they formed on the bottom of the lakes in which the vitric ash accumulated. Thick diatomite beds in the same sections indicate that the waters of the lakes were rich in silica.

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