General Geology of the Jackson Mountains Humboldt County, Nevada

By RONALD WILLDEN

CONTRIBUTIONS TO GENERAL GEOLOGY

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

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By RONALD WILLDEN

ABSTRACT

The rocks exposed in the Jackson Mountains, a prominent range near the center of Humboldt County, Nev., record the effects of a Late Cretaceous to early Tertiary orogeny. Such an orogeny has been assumed to have affected all of the Great Basin, but the rock record is sufficiently complete to provide positive dating in only a few areas, such as the Jackson Mountains.

The oldest rocks in the range are the Permian or earlier volcanic rocks of the Happy Creek volcanic series, which make up most of the northern half of the range. In a few places the Happy Creek volcanic series grades upward into undivided Permian and Triassic rocks, which consist of interbedded clastic sedimentary rocks, mafic volcanic rocks, and some shaly and siliceous limestone. The Happy Creek volcanic series is also overlain by an unnamed predominantly limestone unit of Triassic age. A phyllite and slate unit of probable Triassic age is in fault contact with the Permian and Triassic undivided rocks. At several other localities the Happy Creek volcanic rocks are overlain by the King Lear formation of Early Cretaceous age or by the Pansy Lee conglomerate of Cretaceous or Tertiary age; these two units are of chief importance in dating the Cretaceous and possibly early Tertiary orogenic events.

The King Lear formation consists of locally derived pebble and boulder conglomerate and interbedded siltstone and graywacke, and lenses of limestone.

The Pansy Lee conglomerate is a pebble conglomerate with considerable interbedded coarse-grained sandstone. The pebbles consist of chert and quartzite completely unlike rocks now exposed in the Jackson Mountains.

Dioritic rocks were intruded both before and after the King Lear formation was deposited. Granodioritic intrusive bodies in the range cut rocks no younger than Triassic, but the granodiorite is believed to be of Late Cretaceous or early Tertiary age.

Tertiary intrusive and extrusive volcanic rocks and sedimentary rocks are widely distributed along the east side and south end of the range.

The most extensive tectonic feature of the Jackson Mountains is the Deer Creek thrust, which is discontinuously exposed from Rattlesnake Canyon northeastward to the north side of Deer Creek Peak. The thrust has brought the Happy Creek volcanic series over the King Lear and Pansy Lee formations, and is thus of Late Cretaceous or early Tertiary age.

An earlier period of possible Cretaceous deformation is shown by a northeastward-plunging syncline in the King Lear formation on the southeast side of King Lear Peak.

Pre-Cretaceous deformation is shown by a tight fold in limestone of the undivided Permian and Triassic unit beneath the King Lear formation at the mouth of Rattlesnake Canyon.

The late Tertiary deformation was almost exclusively a response to vertical stresses, which generally produced high-angle faults rather than folds. The range has probably been uplifted principally by displacement on faults that are buried beneath the alluvium some distance to the east and west of the range.

Ore deposits in the range include some small but high-grade iron deposits, some low-grade quicksilver deposits, and some small copper prospects.

The iron occurs in veins that cut the Happy Creek volcanic series or as replacement bodies near the contact between diorite and the Happy Creek. Bleached volcanic rocks that are cut by numerous closely spaced joints contain films of hematite on either side of the joints and suggest that the iron of the iron deposits has been derived from the Happy Creek volcanic rocks. The diorite intrusive rocks may have provided heat and solutions to mobilize the iron of the volcanic rocks.

INTRODUCTION

The Jackson Mountains in Humboldt County, Nev., are interesting for several reasons. The chief reason is the presence of Cretaceous rocks in the range, one of only three areas known in Nevada where Cretaceous rocks record the late Mesozoic and early Tertiary orogenic history of the region. A second reason is that some of the intrusive rocks appear to have had their composition controlled to some degree by Permian or older volcanic rocks, which are the predominant pre-intrusive country rocks. The range also contains workable iron and quicksilver deposits. In spite of its interesting geologic problems, the area was largely a geologic terra incognita in 1956 when I began to map the range as part of a cooperative reconnaissance mapping project of Humboldt County between the U.S. Geological Survey and the Nevada Bureau of Mines. This report is based on field work in 1956 and additional work in 1957 and 1958.

LOCATION AND ACCESSIBILITY

The Jackson Mountains lie between long. 118°15′ W. and 118°45′ W. and extend about 7½ miles south of the 41st parallel and about 3 miles north of lat. 41°30′ N. The location of the range with respect to other geographic features in Humboldt County is shown in figure 1. This report deals only with that part of the range north of the 41st parallel.

The region is sparsely populated. Settlements are limited to the small village of Jungo at the southeast end of the range, the smaller settlement of Sulphur southwest of the range, and a mining camp at the Iron King mine in the north-central part of the range. There are several ranches along the east side of the range, one at Quinn

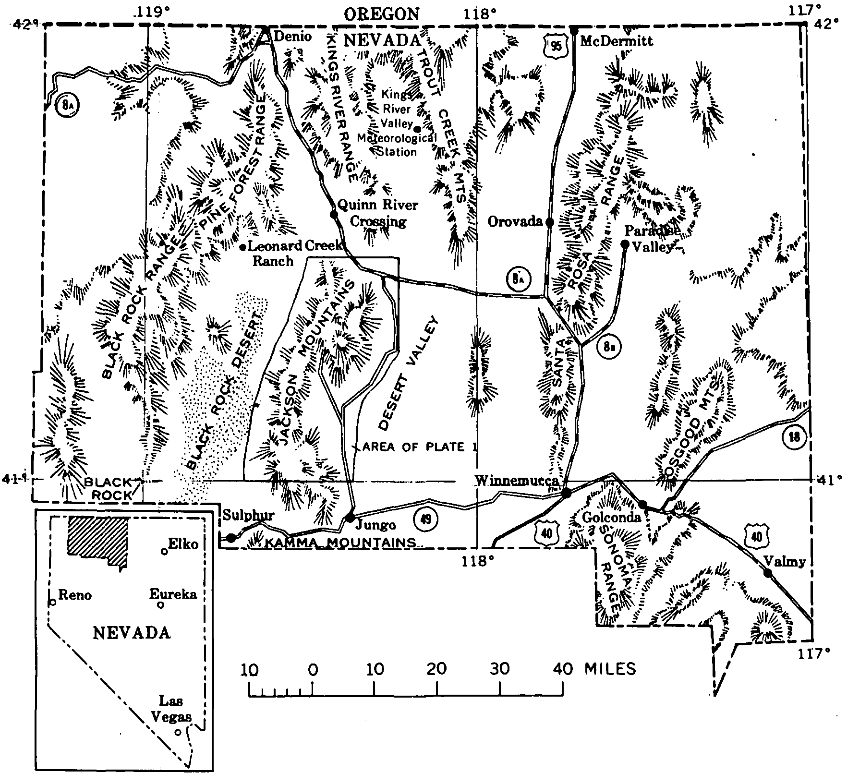

FIGURE 1.—Index map showing location of Jackson Mountains and other physiographic features in Humboldt County.

River Crossing about 2 miles north of the range, and two on the west side.

Jungo and Sulphur are on State Highway 49, a graded gravel road that extends eastward to Winnemucca, 35 miles from Jungo. A graded gravel road, maintained by the A. and B. Mining Co., connects the Iron King mine with Jungo, which is on the Western Pacific Railroad and is the shipping point for the iron mines in the range. Most of the ranches are connected by county-maintained gravel roads. Several of these gravel roads extend northward to State Highway 8A, a paved road, and provide the best access to the range. Most of the interior of the range and the west side south of Jackson Creek are accessible by rather poor dirt roads..

PHYSICAL FEATURES

The Jackson Mountains are one of the prominent ranges of northwestern Nevada. King Lear Peak, which rises to 8,910 feet, is a conspicuous landmark visible for many miles. Much of the northern part of the range is more than 8,000 feet high and some summits rise to 9,000 feet and higher. Desert Valley on the east side of the range lies at 4,000 to 4,100 feet altitude and the Black Rock Desert on the west lies at about 4,000 feet. Low relief and subdued topography characterize the southern third of the range, whereas the northern two-thirds is characterized by rugged topography and high relief. Shore features of the Pleistocene Lake Lahontan, especially wave cut terraces, spits, and bars, are abundant along both flanks of the range, especially at the north end and surrounding the low detached hills on the southeast side of the range.

The high northern part of the range is drained by four perennial streams: Trout Creek, which flows south, Bottle Creek, which flows east, Happy Creek, which flows north, and Jackson Creek, which flows west. Intermittent streams occupy most of the other large canyons. Springs are numerous; a notable one is the excellent spring in limestone at the mouth of the unnamed canyon between Elbow and Alaska Canyons.

Vegetation consists mainly of sagebrush and other desert shrubs, but junipers are abundant throughout the range, cottonwood and aspen grow in the canyon bottoms, and aspens are found in protected places at higher altitudes in the northern part of the range. The several ranches in the area graze cattle throughout the range.

CLIMATE

The Jackson Mountains are in an area of semiarid climate. Most of the precipitation occurs from October to June with approximately equal amounts during each month. The summer months are dry except for sporadic thunder showers. The winter temperatures are mild except at the higher altitudes, and the summer temperatures are high but not unpleasantly hot except at low altitudes in the valleys on either side of the range.

There are no climatological stations in the range but the data from five stations in valleys of the surrounding area are summarized in the following tables:

Average precipitation, in inches, at points near area

[Data from: U.S. Weather Bureau, 1959, Climatological data, Nevada, annual summary 1958, v. 73, no. 13]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Altitude (feet)
Denio [1]	0.64	2.06	0.76	0.47	0.51	2.14	0.18	0.27	0.02	0.28	0.90	0.42	8.65	4,185
Kings River Valley.[1]	.43	1.53	1.18	1.10	.10	2.85	.15	.32	Trace	.13	.19	.23	8.21	4,240
Leonard Creek Ranch.[1]	.43	1.94	1.23	.84	.24	2.60	.08	.24	.12	.19	.11	.09	8.11	4,225
Orovada [2]	1.14	1.14	1.04	1.25	1.51	1.21	.26	.11	.40	1.05	.96	1.21	11.28	4,300
Winnemucca [3]	.96	1.01	.86	.83	.84	.79	.31	.18	.34	.79	.84	1.00	8.75	4,299

[1] Figures for 1958 only.
[2] Long-term mean, 1931–55.
[3] Long-term mean, 1921–50.

Average temperatures for 1958 in degrees Fahrenheit at points near area

[Data from: U.S. Weather Bureau, 1959, Climatological data, Nevada, annual summary 1958, v. 73, no. 13]

	Annual average	Average maximum		Average minimum		Maximum		Minimum	
		Temperature	Month	Temperature	Month	Temperature	Month	Temperature	Month
Denio	50.2	71.2	August	32.6	January	103	July	−3	November
Kings River Valley		73.4	do	31.1	do	101	August	−5	Do
Leonard Creek Ranch	53.4	76.5	do	32.8	do	101	July	6	Do
Orovada		75.2	do	33.4	do	100	August		
Winnemucca	49.8	72.7	do	31.6	do	100	do	2	November

ACKNOWLEDGMENTS

I am indebted to many residents of the area and to mine operators for information and assistance. C. J. Rowe, mine superintendent, and W. G. Austin, President, both of A. and B. Mining Co., and Ray R. Whiting, Jr. of Humboldt Metals Co. deserve special thanks. W. J. O'Toole and H. V. W. Donohoo, the latter now with Texas Gulf Sulfur Co., contributed much information through discussions.

I am indebted to K. B. Krauskopf, R. R. Compton, and G. A. Thompson of Stanford University for many stimulating discussions of numerous problems concerning geologic interpretations. F. R. Shawe, during part of 1956, and D. H. Whitebread, in the spring of 1957, capably assisted with the mapping. D. R. Mabey furnished much geophysical data.

PREVIOUS WORK

The earliest reference to the geology of the Jackson Mountains is in the reports of the Fortieth Parallel Survey, although the range was not referred to by name. King (1878, p. 565, 601, 648) described the volcanic rocks along the west side of the range north of the Kamma Mountains, and Hague and Emmons (1877, p. 789–790) briefly described the geology of the southern part of the range. Russell (1885, p. 27, 38), in his monograph on Lake Lahontan, described a fault along the west side of the Jackson Mountains and briefly mentioned the vegetation and physiography of the area.

Substantial contributions to the geology of the range or parts of it were made during the Geological Survey's examination of mining districts in the area. The first such examination was that of the Red Butte district, which is on the west side of the range about 7 miles north of the south boundary of the map, by Ransome in 1908. His report (1909, p. 27–30) gives a brief, but good, general account of the geology of the southwest part of the range. Roberts'

662098 O—63——2

report (1940) on the Bottle Creek quicksilver district gives an excellent description of the geology of an area in the northeast part of the range.

During the Second World War the U.S. Geological Survey and the U.S. Bureau of Mines examined and sampled the quicksilver deposits in the Bottle Creek district as part of a statewide investigation of quicksilver deposits. The two publications resulting from this work (Bailey and Phoenix, 1944, p. 80–90; Benson, 1956, p. 19–24, 38–40, 42–49) contain much information about the mines but little about the geology of the range.

The iron deposits were examined in 1954 by F. R. Shawe, R. G. Reeves, and V. E. Kral (1962) as a cooperative program between the U.S. Geological Survey and the Nevada Bureau of Mines.

The Jackson Mountains and their mining districts are also mentioned in publications by Hill and Lindgren (1912, p. 213–214), Schrader, Stone, and Sanford (1917, p. 190–199), Lincoln (1923, p. 98–99, 102), Vanderburg (1938, p. 17, 41–42), and Gianella (1941, p. 52, 57); these reports are essentially catalogues of mining districts or mineral occurrences.

The reconnaissance study of Humboldt County undertaken in cooperation with the Nevada Bureau of Mines has resulted in two short accounts of the geology of the Jackson Mountains (Willden, 1958; 1962) and a reconnaissance map (Willden, 1961).

GEOLOGIC SETTING

The Jackson Mountains lie just east of what might be considered the east margin of the Sierra Nevada batholith; that is the range is east of a line of which more than 50 percent of the pre-Tertiary rocks are granitic (fig. 2). The Jackson Mountains are made up principally of Permian or older rocks and all the surrounding ranges are made up mainly or entirely of Mesozoic or younger rocks (fig. 2). This evidence and the thick Triassic section on both the east and west sides of the Jackson Mountains, suggest that the range is part of a northward-trending regional uplift. The uplift can be assigned a post-early Mesozoic and pre-late Tertiary age on the basis of the distribution of Paleozoic and Mesozoic rocks and the unconformable relation of the late Tertiary rocks to all older units. A similar and parallel upwarp can be postulated to extend from the Osgood Mountains to the Humboldt Range. Recognition of additional warps has been hampered in eastern Nevada by the absence of Triassic rocks and in western Nevada by the extensive volcanic cover and the difficulty of recognizing warps in the batholithic rocks.

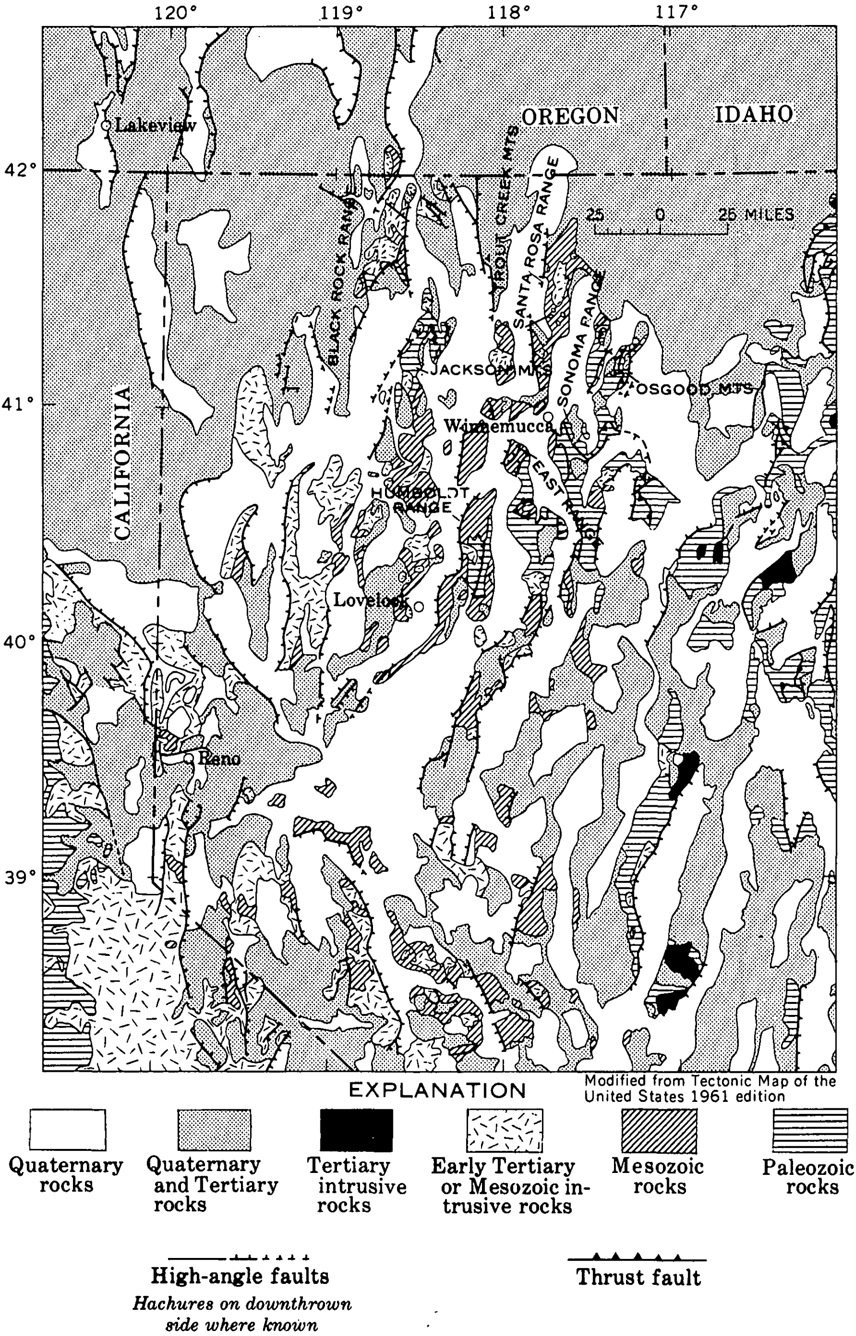

FIGURE 2.—Generalized geology of northwestern Nevada and parts of adjacent States showing regional structural and stratigraphic setting of the Jackson Mountains.

Twenty mappable units have been recognized in the Jackson Mountains and are shown on the geologic map (pl. 1). These units represent all the systems from Permian to Quaternary, but a single unit of Permian or possibly older age makes up most of the bedrock in the range. Rocks of the younger systems occur on the flanks of the range, as intrusive bodies within the range, and are locally infolded with Permian or older rocks.

PERMIAN OR OLDER ROCKS

HAPPY CREEK VOLCANIC SERIES

The Happy Creek volcanic series, named for exposures along Happy Creek in the northern part of the range (Willden, 1962), is the only unit assigned a Permian or older age. The Happy Creek is by far the most extensive unit in the range. It extends from one end of the range to the other and has been recognized in the south end of the Kings River Range and in the Pine Forest Range where it has been mapped as an unnamed andesitic and basaltic volcanic unit of Permian age (Willden, 1961).

The base of the Happy Creek volcanic series is not exposed and the internal stratigraphy is poorly known. A tuff and breccia unit probably more than 1,500 feet thick (fig. 3) is present within the formation along Happy Creek and on King Lear Peak. At both

FIGURE 3.—Happy Creek volcanic series in the headwaters of Happy Creek. Looking east. Rocks in center foreground consist of interlayered tuffs, agglomerates, and graywackes. Light-colored rocks on left skyline are Tertiary rhyolites.

localities the tuff and breccia unit is part of the upper plate of an extensive thrust, so that its exact stratigraphic position is not known. Much thinner tuff units are present elsewhere but they are not laterally continuous and have not been useful in deciphering the stratigraphy of the Happy Creek volcanic series or the internal structure of the Jackson Mountains.

The Happy Creek volcanic series grades upward into an unnamed unit assigned a Permian and Triassic age. This gradation begins with the appearance of pillow lavas; then shaly and cherty beds interbedded with volcanic units, which are usually pillow lavas but include fragmental volcanics and nonfragmental flow units, and ends with graywacke, pebble conglomerate, and limestone interbedded with flow units. The contact on the map is somewhat arbitrary but is generally located at the base of a coarse graywacke composed of volcanic debris, above which the section is predominantly nonvolcanic clastic rocks. Fragmental volcanic rocks occur lower in the section, and at some localities it is quite possible that the contact has been placed on a fragmental volcanic rock (breccia) rather than the graywacke.

The thickness of the Happy Creek volcanic series is unknown because the base is not exposed and the internal stratigraphy is uncertain. A thickness of about 20,000 feet is not unreasonable, and is indeed required by the outcrop widths unless the formation is tightly folded or much repeated by faults.

The rocks of the Happy Creek volcanic series are predominantly volcanic but graywackes are found at places associated with tuffs. The volcanic rocks are principally andesitic; basaltic rocks are of secondary but minor importance, and trachytic to dacitic rocks are of infrequent occurrence. Rhyolitic rocks have not been observed.

The andesites, which are commonly flow breccias, are generally light-gray to dark reddish-gray aphanitic to porphyritic rocks. The porphyritic rocks usually have an aphanitic groundmass and small phenocrysts; the plagioclase phenocrysts are rarely longer than 2 mm, and the mafic phenocrysts, which are either clear, nearly colorless augite or chlorite relicts of pyroxene, seldom exceed 5 mm in longest dimension. The andesites contain 60 to 80 percent plagioclase, which is usually considerably altered to sericite and clay in some specimens, and to epidote and clinozoisite in others; 10 to 20 percent pyroxene, which is altered to chlorite in most specimens but is quite fresh in some; 5 to 10 percent black-opaque minerals; 5 to 20 percent microcryptocrystaline material between grains; and in a few specimens about 5 percent brown-bordered olivine grains.[1]

[1] In this report, where percentages for mineral constituents of a rock are not given, the most abundant mineral is listed first with the following minerals in the order of decreasing abundance.

The plagioclase is generally unzoned but some specimens show faint zoning. The unzoned plagioclase is albitized and the zoned plagioclase has an average composition from sodic andesine to sodic labradorite. The albitization of the plagioclase and the clinozoisite, epidote, and chlorite in these rocks are probably products of the low-grade regional metamorphism that has affected most of the pre-Cretaceous rocks in northern Nevada. The metamorphic minerals in these rocks and the few specimens of andesine and labradorite show that the Happy Creek volcanic series was not originally a sodic-rich (spilitic) suite of rocks; however, I have no specimens of the pillow lavas and these may be spilites.

The basalts are generally strongly altered but relict pyroxene phenocrysts can be recognized in a chlorite and serpentine matrix. A few specimens contain scattered plagioclase phenocrysts altered to clinozoisite, calcite, and white mica, and a few specimens contain relict labradorite phenocrysts.

The trachytes contain scattered plagioclase phenocrysts in a groundmass of crudely oriented lathlike sanidine grains. The plagioclase is generally so altered to clay and white mica that its composition can not be determined; clay has formed extensively in the groundmass.

Dacitic rocks have been recognized only as flow breccias. These rocks contain abundant plagioclase, minor quartz, and in some specimens biotite in a microcryptocrystalline matrix. The plagioclase shows faint zoning and is usually partly altered to clay; its composition is usually near sodic andesine.

The Happy Creek volcanic rocks have been the host rock for at least part of the iron deposits of the range. Figure 4 shows a breccia of andesite cemented with hematitic jasper that contains about 45 percent iron.

The age of the Happy Creek volcanic series is not definitely known because it lacks fossils, but it grades upward into a unit that contains Permian fossils. Thus it can be assigned a Permian or older age.

The uncertain age of the Happy Creek volcanic series makes correlation with rocks in surrounding areas difficult. A possible correlative unit might be the lower part of the Koipato group of the Humboldt Range, which consists of andesitic rocks with an exposed thickness of about 4,000 feet (Tatlock and others, 1960). The Koipato had long been considered to be of Permian age and the lower part is still so considered (Tatlock and others, 1960; Wallace and others, 1959), but the upper part, which is dominantly rhyolitic, has been shown to be at least in part of Triassic age (Roberts and others, 1958, p. 2849; and Wallace and others, 1959). Another pos-

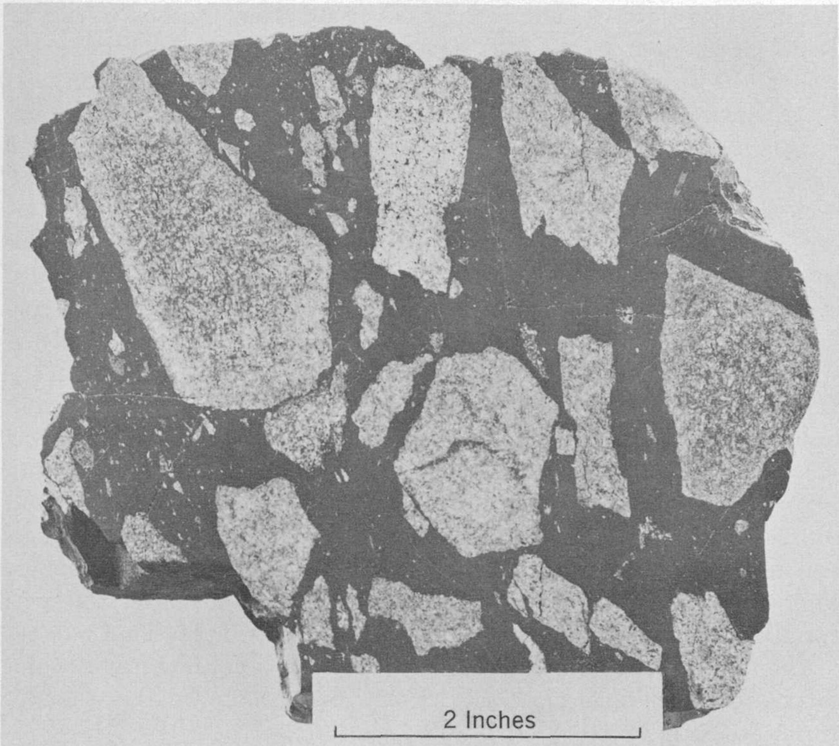

FIGURE 4.—Breccia of andesite from the Happy Creek volcanic series cemented by hematitic jasper.

sible correlation is with the basic volcanic rocks in the Pablo formation in the Toyabe Range (Ferguson and Cathcart, 1954), but this is a distant area and there are few or no data on the intervening area to support such a correlation. Perhaps the best correlation is with the marine Permian section at Black Rock, Nev., recently discovered by Gianella and Larson (1960), which consists mainly of augite andesite breccia. The Black Rock section should probably also be correlated with the lower part of the next younger unit in the Jackson Mountains, the unnamed unit of Permian and Triassic age described below. It is unlikely that the Happy Creek volcanic series correlates with any of the older Paleozoic basic volcanic rocks because the older volcanic rocks are associated with shale and chert, both of which are lacking in the Happy Creek.

PERMIAN AND TRIASSIC ROCKS UNDIVIDED

A single unnamed unit of probable Permian and Triassic age occurs along the west side of the Jackson Mountains at the south boundary of the map (pl. 1), through the central part of the range south of Post Creek, along the east front from the south end of Trout Creek Spur to the northeast side of Buff Peak, and along the west front from just south of Jackson Creek to just east of Buckbrush Spring.

This unnamed unit overlies the Happy Creek volcanic series, and the contact is gradational. The rocks of the unit, which have all been metamorphosed, consisted originally of a lower part of interbedded graywacke, mafic volcanic rocks, silty cherty shale, pebble conglomerate, and some silty and siliceous limestone. They graded into an upper part that consisted predominantly of shale but contained thin beds of chert, limestone, and dolomite. Secondary cleavage has been formed in most of these rocks; the shale beds are phyllitic and in places schistose; the chert and limestone are recrystallized; and stretched pebbles in the conglomerates show the effect of dynamic metamorphism. The upper predominantly shale unit just south of the area shown on plate 1 grades upward into a unit consisting of thick carbonate beds and interbedded phyllitic shale and numerous thin cherty beds. This carbonate unit is probably equivalent to the unnamed Triassic limestone shown on the west front of the range in the vicinity of McGill and Alaska Canyons.

The thickness of the Permian and Triassic unit is uncertain due to possible structural complexities but an estimate on the order of 10,000 feet is required by the outcrop width.

The Permian age of the lower part of the unit is based on one collection of fusulinids from a limestone exposed at the south end of Trout Creek Spur that has been assigned a Permian age by L. G. Henbest (written communication, 1957). The Triassic age for the upper part of the unit has been assigned principally on the basis of lithologic correlation with known Triassic rocks in the surrounding areas. However, a single specimen of a radially ribbed pelecypod, which belongs either to the genus *Daonella* or *Halobia* and indicates a Middle or Late Triassic age, was collected from a limestone fragment in a dacite flow breccia at the base of the Tertiary sequence in the Bottle Creek quicksilver district (specimen identified by N. J. Silberling, oral communication, 1960). Most of the material in the dacite breccia seems to have been derived from the immediately underlying rocks, and I believe that the fossil also is from the underlying rocks.

The incomplete fossil record and the heterogeneous lithology in this unit handicap attempts to correlate it with units of known age in nearby areas. The lower part might be a correlative of the upper part of the Havallah formation which contains Early Permian (Leonard) fossils (Roberts and others, 1958, p. 2848), but the lithology is strikingly different. Some of the phyllite with interbedded chert and limestone in the upper part probably correlates with the Quinn River formation of Middle Triassic age (Willden, 1962) exposed a few miles to the north.

The most probable correlation of this unit and the other Triassic rocks of the Jackson Mountains with the stratigraphic section in nearby areas is shown on plate 2.

TRIASSIC ROCKS

Two unnamed units in the Jackson Mountains have been assigned a Triassic age on the basis of lithologic correlations with known Triassic rocks in nearby areas. These units are a predominantly limestone section exposed on the west side of the range and a metamorphosed fine-grained clastic unit, herein designated phyllite, exposed in the southeast part of the range. The two units are not in contact with the map area, but from a study of somewhat similar rocks in the Pine Forest Range to the northwest, it is reasonably certain that the limestone is the older of the two.

UNNAMED LIMESTONE

The limestone unit is exposed on the west side of the range from just south of Elbow Canyon southward to about 1½ miles south of Alaska Canyon, and in a small area on the west side of the north end of the range. The limestone rests on the Happy Creek volcanic series at the north end of the range and south of Elbow Canyon, but in the vicinity of Alaska Canyon the limestone rests on the undivided Triassic and Permian rocks, although this contact was not observed. No upper contact of the limestone is exposed in the Jackson Mountains but in the Pine Forest Range a similar limestone unit is overlain by a phyllite, slate, and fine-grained quartzite unit.

The maximum thickness of the limestone in the Jackson Mountains is between 1,000 and 1,500 feet. The thickness of the similar limestone in the Pine Forest Range is 1,700 feet.

The following four members can be recognized in the limestone unit at its exposures in the Jackson Mountains and are especially well developed in the limestone unit in the Pine Forest Range: (1) a thin basal unit of dark-gray carbonaceous and sandy limestone, overlain by (2) a thick unit (about 500 feet) of calcareous siltstone, overlain by (3) a somewhat thinner unit of buff to dark-gray crystalline limestone interbedded with black argillite, overlain by (4) a thick section of buff to gray crystalline limestone and limestone-pebble conglomerate with occasional shale and mudstone beds. Chert-pebble conglomerate occurs in the lower part of the section in the Pine Forest Range.

662098 O—63——3

The section in the Pine Forest Range has yielded one collection of poorly preserved fossils that N. J. Silberling has assigned an early Mesozoic age, possibly Late or late Middle Triassic (written communication, 1956).

Without precise dating and with only a general knowledge of the stratigraphy, absolute correlations are not possible, but the limestone unit probably correlates best with the Natchez Pass formation exposed in the East Range (Ferguson and others, 1951). The suggested correlations are shown on plate 2.

UNNAMED PHYLLITE

The unnamed phyllite unit is exposed in several small isolated areas in the southeastern part of the range and on some low hills about 3 miles southeast of Roberts Ranch.

The unit consists mainly of light-gray to light greenish-gray phyllite but also includes slate and fine-grained quartzite, and contains hornfels near the diorite intrusive on the low hills southeast of Roberts Ranch. Characteristically, the unit lacks coarse-grained rocks. The coarsest grained rocks are fine- to medium-grained quartzites.

The unit is too restricted within the map area to warrant an estimate of its thickness, but it is probably part of a much thicker section of fine clastic sedimentary rocks exposed south and east of the area.

Fossils have not been found in these rocks. The rocks have been assigned to the Triassic on the basis of the lithologic similarities with Upper Triassic rocks exposed in the East Range to the southeast. In particular, the phyllite unit resembles the Raspberry formation which is the youngest recognized Triassic unit in the East Range (Ferguson and others, 1951). The most plausible correlation of these rocks with the sections in other areas is shown in plate 2.

JURASSIC ROCKS

DIORITE

Three diorite bodies, which have been assigned a Jurassic age, are exposed at the north end of the range, along Bobs Canyon near the south end of Trout Creek Spur, and in the low hills about 3 miles southeast of Roberts Ranch. Two of these bodies intrude the Happy Creek volcanic series and one intrudes the Triassic phyllite. Other small diorite bodies intrude the Happy Creek northeast of DeLong Peak and in the vicinity of the Iron King mine, but these have not been mapped. The large body at the north end of the range is overlain by basalt, the Bobs Canyon body is in fault contact with younger rocks, and the southern body is overlain by Lake Lahontan sediments. Several other small masses of diorite, which have not been shown on the map, are present within the Happy Creek volcanic series in the north part of the range.

The contacts of these diorite bodies with the rocks they intrude have been studied in detail at only a few places, but at these places the diorite becomes progressively finer grained near the contacts. Where the intruded rock is andesitic material of the Happy Creek volcanic series the contacts are generally indistinct, owing to the similarity of the chilled diorite and the andesite. In the low hills southeast of Roberts Ranch, where the intruded rock is phyllite, the diorite is fine grained near contacts, but the contacts are sharp where they are exposed. A few dikes of diorite can be traced from the stocks into the country rock for a short distance, but, in general, the dikes observed cutting the pre-Jurassic rocks could not be related to larger intrusive bodies. Inclusions of the intruded rock were not observed in the diorite bodies, but at one locality on the southern contact of the intrusive body at the north end of the range blocks of volcanic material are partly surrounded by diorite. This relationship can be interpreted as an indication of piecemeal stoping, and if exposures were somewhat better inclusions of volcanic rock might be found in the diorite.

The metamorphic effect of these diorite bodies on the rocks they intrude has been largely obscured by the later regional metamorphism. Rocks of the phyllite unit in the hills southeast of Roberts Ranch have been converted to hornfels along the contact with the diorite, but metamorphic effects in the volcanic rocks directly attributable to the diorites have not been identified.

These intrusive bodies are made up largely of diorite but locally the composition changes to syenodiorite, quartz diorite, and gabbro. These compositional variations seem to be internal features of the individual bodies rather than separate intrusions. The diorites contain from 60 to 80 percent plagioclase, 15 to 35 percent mafic minerals (probably nearly all pyroxene prior to metamorphism but now including considerable hornblende, chlorite, and some biotite), and 5 to 10 percent black opaque minerals. The syenodiorites contain 15 to 20 percent potassium feldspar, 50 to 65 percent plagioclase, 10 to 30 percent mafic minerals (which include either pyroxene and hornblende, or hornblende and biotite), and up to 5 percent black opaque minerals. The gabbros are much like the diorites except that they contain 50 percent or more dark minerals. A single specimen of quartz diorite contained 20 percent quartz, 72 percent plagioclase, 7 percent biotite, and 1 percent black opaque minerals.

The plagioclase grains in all these rocks now consist of twinned albite or sodic oligoclase rims surrounding aggregates of sericite, clay, and some epidote. Clinozoisite commonly occurs on the borders of grains and in veinlets that cut the plagioclase. The pyroxenes are commonly partially altered to chlorite or hornblende or, in some specimens, to both.

The clinozoisite associated with epidote, albite (and sodic oligoclase), sericite, and chlorite is characteristic of the green-schist facies of metamorphism. This metamorphic assemblage in the diorites and related rocks is the same as that developed in the Happy Creek volcanic series and is compatible with the metamorphic grade of the Triassic rocks.

The Jurassic age of these diorites is based on: (a) their intrusive relations to probable Upper Triassic rocks, (b) the metamorphism shown by the diorites which is lacking in the Cretaceous rocks, (c) the presence of abundant diorite boulders in the locally derived King Lear formation, and (d) one absolute lead-alpha age determination of 135 $\pm$ 15 million years made on zircon in boulders from the basal conglomerates of the King Lear (T. W. Stern, written communication, 1959).

The rocks on which the absolute age determination was made look much like the diorites described above but in thin section they are very different. They contain 60 to 80 percent plagioclase (An_{35-40}), 10 to 30 percent original mafic minerals, and up to 5 percent black opaque minerals. These percentages are all close to those listed for the intrusive bodies, but they also contain a small percentage of interstitial quartz and some zircon and sphene. The mafic minerals are nearly completely altered to chlorite, and the chlorite is distinctive in that it is crowded with red iron oxide dust. This red oxide was probably produced as a surface-weathering phenomenon from free magnetite produced along with chlorite during the alteration of the mafic minerals. The plagioclase in these rocks has not been albitized as it has been in the intrusive diorites, although sericite and clay and occasionally some epidote have developed within plagioclase grain boundaries. The absence of clinozoisite and albitized plagioclase in these rocks suggests that they have not been subjected to the low-grade regional metamorphism that has affected the intrusive diorites. The alteration shown by the diorite clasts in the King Lear formation may well be explained as a combination of deuteric alteration of the mafic minerals and perhaps of the plagioclase with later weathering to produce the clay, red iron oxide, and perhaps the sericite.

REGIONAL METAMORPHISM

All the pre-Cretaceous rocks in the Jackson Mountains contain mineral assemblages characteristic of the greenschist facies of regional metamorphism. The Happy Creek volcanic rocks and the Jurassic diorites contain albite or sodic oligoclase, chlorite, epidote, clinozoisite, and sericite. Original shales in the undivided Permian and Triassic unit and in the Triassic phyllite unit are now generally phyllites or phyllitic shales. They contain chlorite and sericite as newly formed minerals and, in a few specimens, sodic plagioclase which may or may not represent albitized calcic material.

Metamorphic structures include: (a) cleavage that cuts the bedding of the fine clastic rocks at a small angle, (b) boudinage structures, and (c) flattened elongated pebbles in the pebble conglomerates. The boudinage structures have developed in what was probably originally an interbedded sequence of shale and fine-grained quartzite with some limestone beds. The quartzite and limestone beds have been disrupted and ellipsoidal fragments of quartzite and limestone are now surrounded by phyllite. The fragments are elongated parallel to the intersection of the cleavage and bedding. The flattening of the pebbles in the conglomerates took place in the plane of the cleavage and the pebbles are elongated parallel to the intersection of the cleavage and the bedding.

The Triassic rocks throughout central Humboldt County and as far east as the Santa Rosa Range, except those at the south end of the Kings River Range, show the same metamorphic structures and contain the same metamorphic minerals of the green-schist facies as those in the Jackson Mountains (Compton, 1960; Willden, 1962). The widespread Tertiary volcanic rocks west of the Jackson Mountains and the Pine Forest Range limit determination of the western extent of the regional metamorphism, but the Permian rocks recently discovered by Gianella and Larson (1960) at the south end of the Black Rock Range do not exhibit metamorphic structures, and the limestones in the section are not recrystallized although the volcanic rocks contain chlorite. The rocks in the Jackson Mountains and the region to the east of the range have probably been subjected to more intense metamorphism of regional extent than those in eastern Humboldt County or the area southwest of the Jackson Mountains.

CRETACEOUS ROCKS

The King Lear formation is the only unit shown on the map as Cretaceous. Other units of possible Cretaceous age, which will be described in the next section on Tertiary and Cretaceous rocks, include the Pansy Lee conglomerate, the dioritic intrusive rocks in the southern part of the map area, and a single granodiorite intrusive.

KING LEAR FORMATION

The King Lear formation, which consists of locally derived clastic rocks, including pebble to boulder conglomerate interbedded with siltstone and graywacke and lenses of limestone, was named for exposures on the southeast side of King Lear Peak (Willden, 1958, p. 2382–2391). The King Lear formation is also exposed west of the crest of the Jackson Mountains in the vicinity of Deer Creek, Parrot, and DeLong Peaks; near the divide separating the Jackson Creek drainage area from the Trout Creek drainage area; along the east front of Trout Creek Spur south of Willow Creek; along the west front of the range northwest of the abandoned town of Red Butte; on the south side of Rattlesnake Canyon at the west front of the range; along the road to Navajo Peak just below the peak; and on the low hills about 3 miles south-southeast of Red Butte.

The formation is thickest at the exposure on the southeast side of King Lear Peak but at this locality a number of faults with small displacements offset the beds and this section is therefore incomplete. The section exposed along the road south of the Iron King mine is the only one that has been measured. The best preserved fossils come from the section exposed on Cedar Creek just east of Navajo Peak. At this locality exposures are poor and the beds are broken by several faults of uncertain displacement.

The King Lear formation rests on the Happy Creek volcanic series at all exposures except on the south side of Rattlesnake Canyon, where the formation rests on folded crystalline limestone of the undivided Permian and Triassic unit. The limestone has been folded into an almost isoclinal anticline and the axial plane is slightly overturned toward the west. Conglomerate and sandstone beds of the King Lear formation, which unconformably overlie the limestone, strike from N. 30° E. to N. 80° E. but dip fairly uniformly about 55° SE. At other localities where the King Lear formation overlies the volcanic series the structure of the volcanic rocks is poorly known.

The King Lear formation is overlain by dacitic flow breccias, rhyolite, and tuffs along the ridge southwest of the divide between Jackson Creek and Trout Creek. These volcanic rocks, which are assumed to be Tertiary in age, strike about N. 30° E., dip 10° to 30° SE., and are concordant with the underlying King Lear formation. The only other place where younger rocks overlie the

King Lear formation is on the north side of Deer Creek Peak where the Pansy Lee conglomerate rests on it with no apparent angular unconformity. At this locality the King Lear formation is represented by about 150 feet of coarse pebble to cobble conglomerate composed of andesitic material, and shows a marked contrast with the overlying Pansy Lee conglomerate, which is represented by 150 to 200 feet of pebble conglomerate and coarse sandstone composed entirely of quartzite and chert fragments.

The section described in the following three paragraphs is generalized and applies to the outcrop areas west of DeLong Peak, on the south side of Jackson Creek, and on the southeast side of King Lear Peak. At the other localities the section is less complete.

The basal part of the King Lear formation is invariably a poorly sorted conglomerate (fig. 5), composed almost entirely of subrounded to rounded clasts of the subjacent rock type overlain by pebble to cobble conglomerate with some interbedded red siltstone. The conglomerates, with the exception of the basal bed at some localities, are typically bimodal. This basal conglomerate unit is 200 to 300 feet thick and is overlain by 300 to 500 feet of dusky red and greenish-gray to brown siltstone interbedded with greenish-gray to brown sandstone and graywacke. Lenticular bodies of light to dark-gray finely crystalline dense limestone occur locally in the basal conglomerate and the overlying siltstone-sandstone unit. This siltstone-sandstone unit is overlain by about 200 feet of pebble to cobble conglomerate interbedded with sandstone, graywacke, and siltstone, which is in turn overlain by an upper unit of uncertain thickness, consisting of interbedded siltstone, graywacke, and sandstone. Although the major units of the King Lear formation persist over considerable distances, many individual beds within the four units are lenticular, especially the limestone and conglomerate beds, which in the lowest unit are abruptly lenticular.

The sandstone commonly contains subangular to rounded quartz, chert, feldspar, and volcanic rock fragments, a small amount (5 to 10 percent) of finely divided matrix material, and some detrital hematite grains. The graywacke contains the same constituents as the sandstone but the grains are commonly more angular and the matrix material is much more abundant (15 to 50 percent of the total rock). The red color of some siltstone and a few sandstone beds is due to hematite in discrete grains and as a coating on the other detrital particles.

Some beds in the basal conglomerate exposed on the east side of Navajo Peak contain abundant clasts of hematite and some magnetite; the lower conglomerates exposed on the southwest side of DeLong Peak contain a few scattered clasts of hematite and mag-

FIGURE 5.—Basal conglomerate of King Lear formation. Light clasts are diorite, remainder of material was derived from Happy Creek volcanic series.

netite. These clasts indicate a period of iron mineralization before deposition of the King Lear formation.

The King Lear formation probably was deposited in a fluviatile environment that was intermittently the site of fresh-water lakes. The lenticular, bimodal conglomerate beds containing subrounded to well rounded clasts are typical of channel deposits. The siltstone, sandstone, and graywacke units are probably flood-plain deposits in part deposited under oxidizing conditions as indicated by the red color of some beds, and in part under reducing conditions as indicated by the green and greenish-gray color of other beds. The limestone lenses containing the fresh-water fossils listed below were deposited in lakes.

J. B. Reeside, Jr., of the U.S. Geological Survey, identified the following fossils collected from a limestone lens exposed along Cedar Creek road, 6.6 miles west of the Jungo-Iron King mine road (written communication, 1955).

USGS Collection 25457:
Musculiopsis russelli MacNeil
Mesoneritina sp.
Physa aff. P. *prisca* Walcott
Valvata? sp.
Lioplacodes? sp.

Reeside said of the collection:

Though this collection lacks most of the species that at some localities mark the fauna, and though all of the gastropods were damaged in fossilization and are difficult to study, I consider the fauna Cretaceous and believe it to belong to the middle Lower Cretaceous fauna that has turned up at several places in Nevada and is widely known in the Kootenai and Cloverly formations of the Rocky Mountain region. The only description of it in Nevada was published by F. S. MacNeil (1939) for the Eureka area * * *. A much more remote possibility is the fauna and flora near the boundary between the Lower and Upper Cretaceous found by Longwell (1949, p. 931–933) in the Overton fanglomerate of the Muddy Mountains near Las Vegas.

USGS Collection 26616 from about 3 miles south of Jackson Creek and 1½ miles west of the Jungo-Iron King mine road, in sec. 15, T. 39 N., R. 31 E. (projected), has been reported on by Mr. Reeside as follows (written communication, 1957):

The only well-preserved fossils in this collection are the opercula of a viviparoid gastropod indistinguishable from those found at Eureka and called by MacNeil *Scales powelli* (Walcott) (Jour. Paleontology, v. 13, p. 355–360, 1939). A number of cross sections of gastropod shells show on surfaces but do not break out and are indeterminable. Some of the tiny blebs could represent oogonai of charophytes or ostracodes but do not show any diagnostic features. I would say the assemblage is definitely of fresh-water origin, and for the region, must represent the Lower Cretaceous fauna now known at several places beside Eureka.

A collection from about 0.6 mile northwest of the junction of the Jackson Creek-Iron King mine road, in sec. 35, T. 40 N., R. 31 E., has been reported on by Mr. Reeside as follows (written communication, 1957):

This material * * * shows cross-sections of gastropods, probable fragments of pelecypods, ostracodes, algal masses resembling *Stromatopora*, and ramose bodies suggesting a charophyte alga. It resembles, in the types of organisms present, associations at other places that are of Cretaceous age. I am not able, however, to identify any of the fossils closely enough to justify or to condemn such a judgment. It has to remain a guess, but I would guess the Cretaceous assignment to be correct.

The Cretaceous fauna found in the Eureka area (MacNeil, 1939) occurs in the Newark Canyon formation described by Nolan, Merriam, and Williams (1956, p. 69) as consisting "of fresh-water limestone, conglomerates that contain both siliceous and limestone boulders, silts, sandstones, and grits." As such it is lithologically similar to the King Lear formation as well as being a faunal equivalent.

The Cretaceous fossils from the Muddy Mountains area were collected from rocks originally mapped as Overton fanglomerate but since remapped and divided into two formations of Cretaceous age and the Overton fanglomerate of Cretaceous or Cenozoic age (Longwell, 1949, p. 931–933). The two Cretaceous formations are the Baseline sandstone and the Willow Tank formation, which consists of a basal conglomerate overlain by about 300 feet of fine-grained deposits that contain the Cretaceous fossils.

CRETACEOUS OR TERTIARY ROCKS

The Pansy Lee conglomerate, the dioritic intrusive rocks in the south part of the map area, and the granodiorite intrusive body have been assigned a Cretaceous or Tertiary age. The three units have no mutual contacts, so their relative ages are unknown.

PANSY LEE CONGLOMERATE

The Pansy Lee conglomerate was named for exposures in sec. 1, T. 36 N., R. 36 E., and sec. 6, T. 36 N., R. 37 E., just north of the Pansy Lee mine on the north side of the low hills about 10 miles west of Winnemucca (Willden, 1958, p. 2391–2394).

In the Jackson Mountains, the Pansy Lee conglomerate is exposed on the west side of Deer Creek Peak, on the northeast flank of King Lear Peak and on the east side of the south end of Trout Creek Spur. The Pansy Lee rests on the King Lear formation on the north side of Deer Creek Peak; it rests on the Happy Creek volcanic series on the northeast flank of King Lear Peak, and on the undivided Permian and Triassic rocks at the south end of Trout Creek Spur. The King Lear formation is absent at the last two localities. At the type locality the Pansy Lee conglomerate rests with angular unconformity on phyllitic shale correlated with the Raspberry formation of Late Triassic age (Ferguson and others, 1951). The top of the Pansy Lee conglomerate is not exposed in the Jackson Mountains, but at the type locality it is unconformably overlain by basalt flows and tuffaceous shale and sandstone that are thought to be late Tertiary in age.

The basal unit of the Pansy Lee conglomerate is a poorly sorted pebble to boulder conglomerate with about one-half to one-third locally derived material. At the type locality, the locally derived material consists of fine-grained feldspathic quartzite, slate, and shale derived from the underlying Raspberry formation. In the Jackson Mountains the locally derived material consists of andesitic to basaltic volcanic rocks, diorite, and sparse slate and feldspathic quartzite. The conglomerate becomes better sorted upward and the amount of locally derived material decreases to the point where it becomes difficult to find. Coarse-grained sandstone is interbedded with pebble conglomerate through most of the section.

The exotic chert and quartzite clasts are the most striking feature of the formation and they serve to differentiate it from all other conglomerates in the stratigraphic column. The chert clasts are mostly light to dark gray or green; a few are red or reddish brown. The quartzite clasts are dark gray to almost white, well sorted, fine to medium grained, and clean. These exotic clasts look very much like rocks of the Valmy formation of Ordovician age, the nearest exposure of which is in the north end of the Sonoma Range east of Winnemucca. According to R. J. Roberts (oral communication, 1958), the clasts resemble some light to dark well-sorted clean quartzite and dark chert in a unit mapped as the Leach formation in the East Range. Either of these units may have been the source of the Pansy Lee conglomerate.

The only fossils thus far obtained from the formation are some indeterminate rootlike impressions, so that no precise age can be assigned. The formation certainly predates the upper Tertiary volcanic rocks, which are thought to be no older than Miocene, and postdates the Lower Cretaceous King Lear formation. The apparent conformity between the King Lear formation and the Pansy Lee conglomerate in the northern part of the Jackson Mountains must be regarded as coincidence, because on the northeast slope of King Lear Peak the Pansy Lee conglomerate rests directly on the Happy Creek volcanic series with no intervening King Lear formation, and about 3 miles farther south the King Lear formation attains its greatest thickness. It seems unlikely that the King Lear formation could thin to zero thickness in 3 miles when the formation is present over a 25-mile length of the range. Also, the King Lear formation has been folded into a tight slightly overturned syncline on the southeast side of King Lear Peak, and the Pansy Lee conglomerate on the northeast side of the peak has a fairly uniform gentle eastward dip. The King Lear formation was evidently folded and in places completely eroded before deposition of the Pansy Lee conglomerate.

A contemporaneous unit may be the conglomerate comprised of Paleozoic pebbles unconformably overlain by the Miocene to Pliocene volcanic and sedimentary rocks of eastern Nevada and western Utah as reported by Van Houten (1956, p. 2806–2808). He suggests that the pebble conglomerate and associated rocks may be correlated with the "Wasatch" conglomerate of Paleocene or early Eocene age of north-central Utah and points out (p. 2807) that Christiansen had previously suggested that similar rocks in eastern Nevada and western Utah may be the result of an Early Cretaceous orogeny. The Rand Ranch formation of Regnier (1960, p. 1193), exposed on the east flank of the Cortez Mountains, has an upper part 1,250 feet thick that consists of "interbedded white, yellow, and red sandstones and Paleozoic-pebble conglomerates," and might be a correlative of the Pansy Lee conglomerate. Regnier tentatively assigned the Rand Ranch formation an Oligocene age although he found no datable fossils.

DIORITE

Dioritic rocks intrude the King Lear formation on the east side of Navajo Peak, west of the Red Butte mine, and along Rattlesnake and Shawnee Canyons. A dioritic intrusive body, exposed on the east side of the range along Post Creek, is mapped in this unit, although it does not cut the Cretaceous rocks. Interpretation of an aerial magnetic map of the range suggests that these bodies all connect at depth as three of them are shown to do on section C–C′, plate 1.

The contacts of the Cretaceous or Tertiary diorite bodies are well exposed at only a few places east of Navajo Peak, west of Red Butte, and south of Post Creek. The diorite generally is somewhat finer grained near intrusive contacts. This reduction in grain size (chilling) was not observed along the contact with the conglomerates of the King Lear formation southeast of Navajo Peak. Here the diorite is uniformly medium-grained for several hundred feet from its contact. Dikes have not been observed projecting into the country rock from these stocks except one large dike west of the Red Butte mine. Inclusions of country rock have not been observed in the diorite, but one large block of conglomerate, probably a roof pendant, is enclosed in the diorite south of the Cedar Creek road about one and a half miles southeast of Navajo Peak.

The Cretaceous or Tertiary diorites have produced only a minor metamorphic effect in the rocks they intrude. Mudstones of the King Lear formation are more indurated near intrusive contacts than elsewhere but they have not recrystallized. No metamorphic effects were observed in the King Lear conglomerates or graywackes. Limestone lenses in the undivided Permian and Triassic unit south of Post Creek have been recrystallized to medium and coarse-grained calcite aggregates near the diorite, and the phyllitic rocks in the unit have been converted to hornfels. The volcanic rocks of the Happy Creek series have not been obviously metamorphosed by the diorites.

The Cretaceous or Tertiary dioritic intrusive bodies have a mineral composition much like the premetamorphic mineralogy of the Jurassic diorites. They also show a wide variation in composition, but it is very different from the variation shown by the Jurassic diorites. Gabbroic facies are abundant in the Cretaceous or Tertiary dioritic intrusive bodies and varieties close to anorthosite are present. The rocks contain from 30 to 90 percent plagioclase, 10 to 65 percent mafic minerals (pyroxene in various stages of alteration to hornblende), and up to about 5 percent black opaque minerals; quartz and potassium feldspar are virtually absent.

In the gabbros and diorites the plagioclase is strongly zoned. The centers of the larger crystals are so completely altered to sericite and clay that the composition cannot be determined. The smaller crystals are generally fresher and show a composition range from about An_{25} on the rims to An_{55} in the centers. Some crystals show oscillatory extinction indicating reversals in the trend from calcic to sodic compositions outward. The pyroxene, which seems to be entirely augite, is nearly always partly altered to hornblende, and has a mottled appearance. Chlorite occurs in some sections but is not abundant in any.

In the anorthositic rocks the plagioclase is zoned, but not strongly, and the composition ranges from oligoclase to sodic andesine. The cores of the plagioclase grains are generally somewhat altered to clay and sericite. Orthopyroxene (probably hypersthene) is the only mafic mineral. These high-plagioclase rocks also contain about 1 or 2 percent potassium feldspar.

The general absence of definite metamorphic minerals in the Cretaceous or Tertiary diorites indicates they were intruded after the regional metamorphism. The nonmetamorphosed King Lear formation, which they cut, also stands as evidence that the metamorphism took place prior to the intrusion.

However, some specimens of rock collected from what were thought to be Cretaceous or Tertiary diorites in the field contain sericitized, albitic plagioclase and a small amount of clinozoisite. Such samples may represent unrecognized pendants of Jurassic diorite or they may be small parts of the Cretaceous or Tertiary diorites subjected to metamorphic stresses sufficiently high to produce this alteration.

The Cretaceous or Tertiary age of these diorites is determined on the basis of their crosscutting relation to the King Lear formation and the general absence of metamorphism in the diorites.

Apart from one small intrusive gabbro on the southeast side of Blue Mountain about 15 miles west of Winnemucca, all the quartz-free pre-Tertiary intrusive rocks in Humboldt County are in areas where the intermediate to basic volcanic rocks of the Happy Creek volcanic series and correlative units are widely exposed. The one area in the county where dioritic rocks are abundant, the Jackson Mountains, is also the only area where the Happy Creek volcanic series is by far the most abundant rock unit. The dioritic intrusive body in the Pine Forest Range cuts the Happy Creek volcanic series and is in turn cut by granodiorite.

The general restriction of the diorites to areas where the intermediate and basic volcanic rocks are exposed might be evidence that the diorites were formed from the volcanic rocks. Regional stratigraphic relations indicate that the 20,000 feet or more of Permian or older volcanic rocks in central and west central Humboldt County were buried by about 25,000 to 40,000 feet of Triassic and possibly Lower Jurassic sediments. Some of the volcanic rocks were conceivably buried deeply enough to have been recrystallized to rocks indistinguishable from diorite; some of the volcanic material may even have melted and then been intruded into higher parts of the section. However, it is much less conceivable that this process would have conveniently taken place sometime in the Jurassic and then again in the Cretaceous to account for the two ages of diorite in the range. It is particularly difficult to explain the Cretaceous or Tertiary diorites by this mechanism because at the time, or only shortly before, the Cretaceous or Tertiary diorites were intruded the Permian or older volcanic rocks were exposed at the surface and undergoing erosion to produce the King Lear formation.

GRANODIORITE

One fairly large granodiorite intrusive body is exposed on the west side of the range north of Jackson Creek. This body is about 3.5 miles long and 2.5 miles wide. It intrudes the Happy Creek volcanic series and is not in contact with the younger rocks.

The contact of the granodiorite and the Happy Creek volcanic series was examined in detail at the north end of the stock northwest of Parrot Peak and at the south end in the area north of Jackson Creek. The south end of the intrusive body is in fault contact with the Happy Creek. The fault is marked by a zone about 1 to 10 feet wide filled with crushed volcanic rocks and thin mylonite stringers. Granodiorite in the crushed zone forms sliverlike blocks, but is not intensely crushed. The amount of displacement on the fault is unknown but is probably small because granodiorite dikes from a few inches to several feet thick cut the volcanic rocks south of the fault. The granodiorite dikes south of the fault have fine-grained margins, except the thinner dikes which are uniformly fine grained. The dikes contain inclusions of volcanic rock, but the granodiorite immediately north of the fault lacks inclusions; however, some large boulders of granodiorite in the canyon bottom near the fault contain abundant inclusions. Granodiorite dikes are less abundant at the north end of the stock, but the stock contains abundant inclusions at places.

The metamorphic effect of the granodiorite on the Happy Creek volcanic rocks was much greater than that of the diorite intrusive bodies. The volcanic rocks at some places adjacent to the granodiorite have been recrystallized to biotite-quartz-plagioclase schists, but generally the metamorphic recrystallization has been on a microscopic scale. Biotite is commonly formed in the Happy Creek volcanic series near the contact and the plagioclase has been reconstituted to a more calcic variety. Epidote and clinozoisite almost disappear in the volcanic rocks, although chlorite, which was originally much more abundant, remains in considerable abundance. At places, epidote veins cut the rocks.

The granodiorite is highly varied in composition (fig. 6) and contains from 5 to 30 percent quartz, 2 to 30 percent potassium feldspar, 35 to 55 percent plagioclase (oligoclase and sodic andesine), 5 to 35 percent mafic minerals (biotite, hornblende, and chlorite as alteration products of both), and 1 to 5 percent black opaque minerals. Rocks in the interior of the stock, at the chilled margins of dikes, and in the narrow dikes have a high content of quartz and also contain large amounts of potassium feldspar. They contain only small amounts of mafic material that is locally biotite but elsewhere includes some hornblende. Rocks from the central parts of wide dikes and in a border zone of the stock several hundred yards wide contain abundant plagioclase and hornblende and only small amounts of potassium feldspar. Inclusions are commonly surrounded by material containing only plagioclase, hornblende, and biotite. Plagioclase aggregates are abundant in the granodiorite where inclusions are abundant. Some inclusions have sharp borders but the borders of others are indistinct.

Biotite, some of which is partly chloritized, is the only mafic mineral in rocks that contain 5 to about 10 percent mafic minerals. The increase in total mafic minerals beyond about 10 percent is accomplished by increase in the amount of hornblende. The hornblende is nearly always altered to some degree: some of it is completely

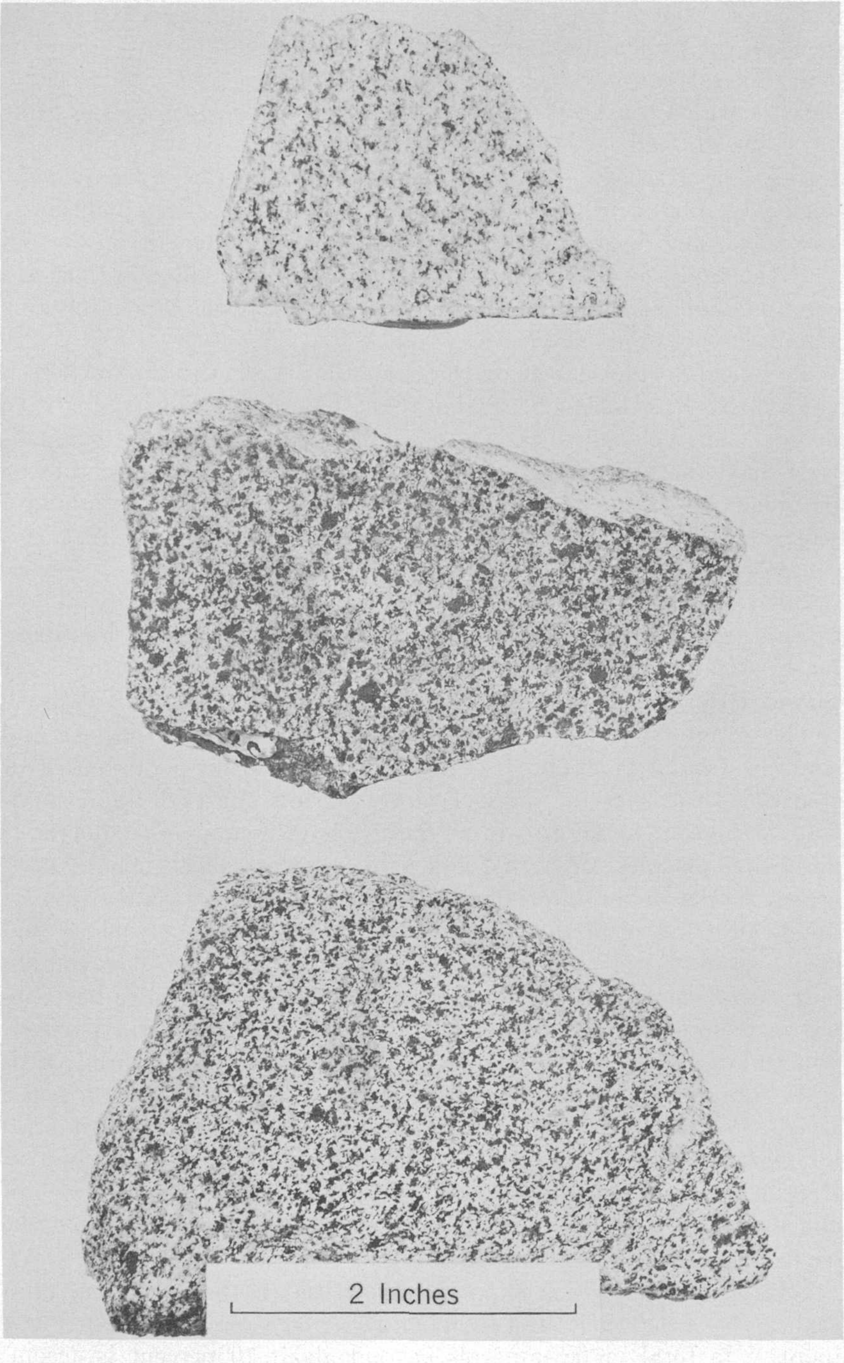

FIGURE 6.—Specimens of Cretaceous or Tertiary granodiorite north of Jackson Creek showing considerable variation in mineralogy.

converted to chlorite or to chlorite-magnetite aggregates, some has only the borders altered to chlorite, and some is merely mottled with non-pleochroic material that is otherwise apparently identical with the host hornblende.

The wide variation in composition of the granodiorite stock is probably due to reaction of the granodiorite with the intruded Happy Creek volcanic rocks. Evidence supporting this idea is: (a) the distribution of plagioclase and hornblende-rich material in the border zone of the stock and quartz and potassium feldspar-rich material in the chilled margins and in the interior of the stock; (b) plagioclase-rich material surrounding inclusions and as segregations in inclusion-bearing granodiorite; and (c) the indistinct borders of some inclusions.

The age of the granodiorite is speculative. The granodiorite has not undergone the regional metamorphism that has affected the Jurassic diorites or the rocks they intrude, and granodiorite clasts are not found in the King Lear formation of Early Cretaceous age or the Pansy Lee conglomerate. The granodiorite is exposed within about half a mile of the King Lear, and it seems likely that granodioritic clasts would have been contributed to the King Lear had the granodiorite been emplaced prior to the deposition of the King Lear. Thus a post-Early Cretaceous age for the granodiorite can be postulated. The possibility of an early Tertiary age for the granodiorite is based on five lead-alpha age determinations on zircons from five granodiorite intrusive bodies in eastern Humboldt County (Jaffe and others, 1959, p. 74–75; T. W. Stern, written communication, 1959). These lead-alpha ages range from 35 ± 10 to 65 ± 10 million years.

TERTIARY ROCKS

Tertiary volcanic, intrusive, and sedimentary rocks are widespread in the Jackson Mountains. These Tertiary rocks have been divided into a total of eight map units that include two intrusive, two sedimentary, and four volcanic units. The intrusive units are a dacite porphyry and a felsite of dacitic composition which is shown on the map as a microdacite. Diabase dikes occur in the Bottle Creek quicksilver district in the northeast part of the range (Roberts, 1940), but they have not been shown on the map (pl. 1). The sedimentary units are a silicified pebble conglomerate and a unit consisting of shale, water-laid tuff, shaly sandstone, and diatomaceous shale. The volcanic units include a predominantly dacitic series of flows and some tuffs, rhyolite tuff, basalt flows, and rhyolite flows.

The correlation of the various Tertiary units in the Jackson

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Mountains with units in other sections in Humboldt County is shown on plate 3.

DACITE PORPHYRY

Two intrusive bodies of dacite porphyry have been mapped. One small body intrudes the King Lear formation just south of Jackson Creek in the central part of the range. A larger body, to the southwest, cuts the Happy Creek volcanic series, and the King Lear and Pansy Lee formations. The large dacite porphyry intrusive is overlain by flows and tuffs of mainly dacitic composition that have been assigned to the oldest Tertiary extrusive unit in the range.

The dacite porphyry contains about 40 percent phenocrysts about 1 mm to 1 cm long and 60 percent matrix material. The phenocrysts are plagioclase, quartz, and chlorite-hematite relicts of amphibole. Under the microscope the rock can be seen to contain about 60 percent plagioclase (sodic andesine), 5 percent quartz, 10 percent relict amphibole, and about 25 percent finely divided low-birefringent matrix material. The plagioclase shows a nearly complete gradation in grain size from 0.05 mm to 1 cm in length. The larger phenocrysts have a narrow rim with lower extinction angles than the inner parts of the crystals, but most of the phenocrysts are unzoned. The larger crystals also show alteration of their centers to clay. The quartz phenocrysts, unlike the other crystals, are embayed and rounded.

The dacite porphyry has been assigned a Tertiary age because it intrudes the Pansy Lee conglomerate, and because dacitic rocks are abundant in the Tertiary section in most of Humboldt County (Willden, 1962). It is overlain by the dacitic flow unit which is believed to be the oldest Tertiary volcanic unit in the range.

MICRODACITE INTRUSIVES

The rocks shown on plate 1 as microdacite occur as dikes, sills, plugs, and small stocks intruding the Happy Creek volcanic series, the King Lear formation, and the Pansy Lee conglomerate. These rocks, which have been recognized only in the north half of the range, are nearly white and so fine grained that no minerals can be identified in hand specimens.

The dikes generally trend northward and several can be followed for more than a mile. Only the larger dikes are shown on the map; several smaller ones cut the King Lear formation north of Jackson Creek and one is present in the Happy Creek volcanic rocks just east of the Iron King mine.

Only one sill has been shown on the map, and this body intrudes the King Lear formation east of the mine symbol on the north fork of Jackson Creek.

The plugs and small stocks range from a quarter of a mile in length and an eighth of a mile in width to slightly more than a mile in length and half a mile in width. Dikelike apophyses extend south from the plug on the east side of Parrot Peak and the plug at the head of the north fork of Jackson Creek.

Even the largest of these intrusives has produced no noticeable metamorphic effect in the intruded rocks.

The microdacites contain about 70 to 80 percent plagioclase, 20 to 25 percent quartz, about 5 percent potassium feldspar, and virtually nothing else. The plagioclase was identified by staining techniques and was determined to have an index of refraction greater than balsam; the rock is so fine grained that further determinations could not be made.

The microdacite intrusives have been assigned a Tertiary age because one small plug cuts the Pansy Lee conglomerate. Their age with respect to the other Tertiary units is not known, but, because of their dacitic composition, they have been assigned the same age as the dacite porphyry intrusives.

DACITE FLOWS

The dacitic flow unit is exposed from Jackson Creek southward along the ridge west of the Jungo-Iron King mine road for about 4 miles. It rests on the King Lear formation, apparently conformably, and on the dacite porphyry intrusive. It is covered on the east by alluvium.

The unit consists mainly of dacite flows but also includes some flow-banded rhyolite, silicified tuff, and thin sandstone and mudstone beds. The tuffs and sedimentary rocks occur in the upper part of the exposed section. The unit is about 2,500 feet thick.

The volcanic rocks (flows and tuffs) generally contain between 30 to 70 percent identifiable crystals or foreign rock inclusions in a microcryptocrystalline matrix. The crystals include plagioclase (oligoclase and sodic andesine), quartz, hornblende, and biotite. The quartz crystals are usually rounded and embayed. The hornblende is a dark-brown strongly pleochroic variety. In some specimens the biotite or hornblende (the two rarely occur together) is partly altered to chlorite. The plagioclase commonly shows alteration of the central parts of the crystals to clay and some sericite. Rock fragments are abundant in the tuffs and are also found in some of the flows from the lower part of the sequence. These rock fragments include shale, basic volcanic rocks, glassy volcanics, some chert, and granodiorite.

The dacitic flow unit is probably the oldest of the Tertiary volcanic units because dacitic material much like that in the flow unit occurs in the lower part of the next younger map unit, the tuff, and the tuff unit is overlain elsewhere by basalt with intercalated sedimentary rocks that can be dated by means of fossils. The basalt and intercalated sediments are part of a fairly well established sequence.

The dacitic flow unit is probably of pre-middle Miocene age as indicated in the Tertiary correlation diagram (pl. 3).

TUFF UNIT

An unnamed tuff unit is exposed in a large area in the southeastern part of the Jackson Mountains and in a much smaller area in south-central part of the range. Within the area shown on plate 1 the only contacts of the tuff units with older rocks are faults, but about 1 mile south of the map area the tuff rests on the undivided Permian and Triassic unit. The tuff is overlain by basalt and the sedimentary rocks that are interlayered with the basalt in the central part of the south end of the range. The exposed section of the tuff is on the order of 1,200 feet thick.

Some dacitic rocks similar to those in the dacite flow unit are exposed in the lower part of the exposed section of tuff in the north part of the large outcrop area. The bulk of the tuff unit, however, is of quartz latitic to rhyolitic composition.

The few specimens of the tuff that were examined contain about 10 percent crystals and a few limy siltstone fragments in a microcryptocrystalline matrix in which a few shardlike structures can be seen. Most of the crystals were ground away in preparing the slides, but they include quartz, microcline, chlorite relicts of pyroxene or amphibole, and clay relicts of feldspar. Sodium cobaltinitrite staining indicated that much of the finely divided matrix material is potassium feldspar.

The tuff unit is believed to be younger than the dacite flow unit because of the dacitic material in the lower part of the tuff, and it is known to be older than the basalt unit, which lies stratigraphically higher. It can be assigned a Tertiary age rather confidently because of its stratigraphic position.

CONGLOMERATE

A silicified pebble conglomerate completely surrounded by alluvium is exposed on a low hill east of Trout Creek about 2 miles south of the junction of the Jackson Creek-Iron King mine road. This conglomerate is composed almost exclusively of rounded pebbles of dacitic and rhyolitic volcanic rocks, some of which are identical to rocks exposed in the dacite flow unit a short distance to the west (fig. 7). The pebbles have been firmly cemented together by

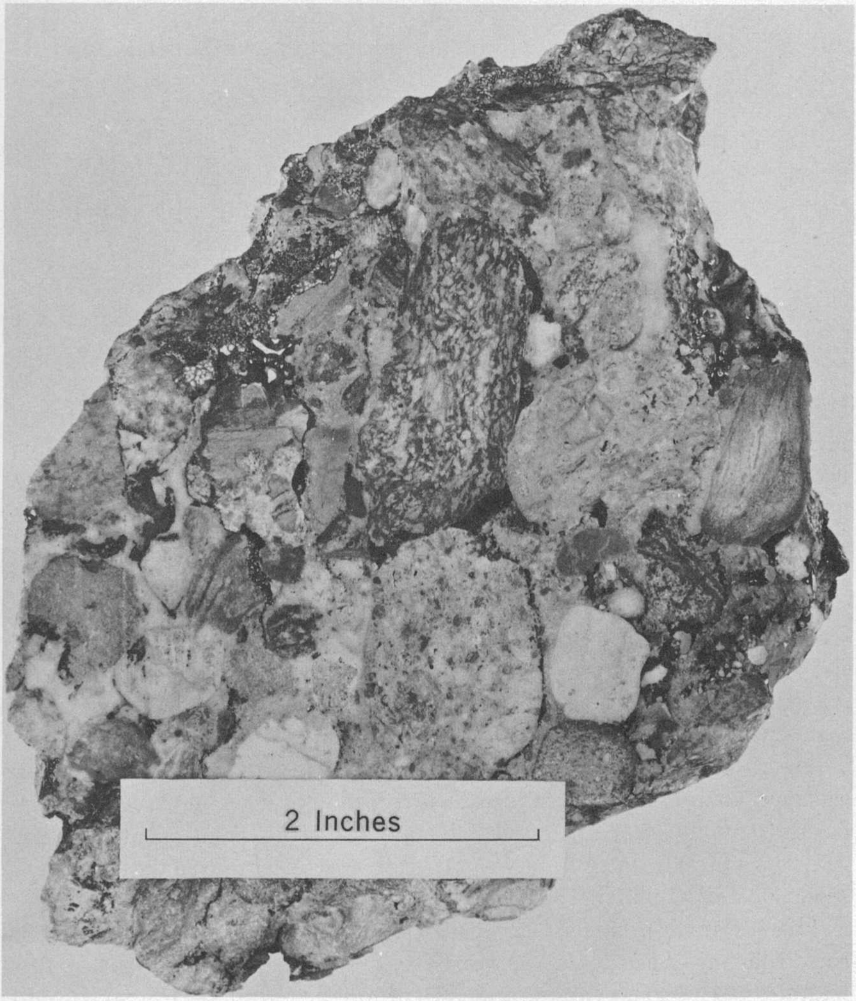

FIGURE 7.—Specimen of Tertiary conglomerate (shown on pl. 1) from hill east of Trout Creek. Most of the clasts have been derived from the dacite flow unit. Cement is secondary silica.

silica but not all the pore spaces have been filled. The high degree of sorting of the conglomerate suggests that it was deposited as a beach or offshore bar in a Tertiary lake.

The conglomerate would probably not merit designation as a separate map unit if it had not been recognized elsewhere, but it is much like some rocks exposed on the west front of the Kamma Mountains just south of the Jackson Mountains. The rocks at the west front of the Kamma Mountains consist of several hundred feet of pebble conglomerate, sandy pebble conglomerate, and conglomeratic sandstone, all of which are composed principally of volcanic clasts. The prominent cliff at the range front northeast of Sulphur is a silicified pebble conglomerate much like the one described above. The only currently mined sulfur deposits in Nevada have been developed in these conglomerates.

The conglomerate, because it contains material much like that previously assigned a Tertiary age, must be of Tertiary (or later) age; because it lacks basalt clasts, it is probably older than the basalt.

BASALT

Basalt extends in discontinuous patches along the east side of the range from one end to the other. On the west side of the range, it is not exposed north of two small hills about 2 miles north-northwest of the Red Butte mine, but is exposed in several low hills east of the range front and at the west front of a broad terrace in the southwestern part of the map area. An aerial magnetic map of the range indicates that the basalt along the northeast front of the range extends at least 2 miles east of the alluvium-bedrock boundary and has only a shallow alluvial cover.

At various places in the range the basalt rests on the Happy Creek volcanic series, the undivided Permian and Triassic rocks, the King Lear formation, the Jurassic and the Cretaceous diorites, and the Tertiary tuff unit. Basalt also rests on the Tertiary sedimentary unit in places but the sedimentary unit is actually interbedded with basaltic rocks, so that in some places basalt rests on sediments and in other places the sediments rest on basalt. The basalt unit is overlain by rhyolite in the northeast part of the range. The basalt unit has a variable thickness but locally it is at least 600 feet thick.

The lowermost part of the basalt unit is a distinctive porphyritic rock that is exposed at the north end of the range, in the southwestern part of the range, and on the terrace west of the south end of the range. The distinctive appearance is caused by strongly zoned plagioclase phenocrysts up to 2 inches long, 1 inch wide, and about two-thirds of an inch thick. The phenocrysts commonly make up from 15 to 20 percent of the rock and show crude parallel alignment. The plagioclase phenocrysts are complexly zoned with multiple alterations of calcic and sodic varieties; they are crowded with microcrystalline inclusions. Their composition is thus difficult to determine but it ranges from at least as calcic as An_{60} to at least as sodic as An_{25}. The phenocrysts are set in a matrix of unzoned sodic labradorite (determined by maximum extinction angle), with olivine, augite and probably pigeonite, and black opaque minerals. The rock contains from 40 to 60 percent plagioclase, from 5 to 15 percent olivine, about 30 percent pyroxene, and 3 to 8 percent black opaque minerals and is wholly crystalline and usually dense. Vesicles, where they occur, are commonly partly filled with calcite.

The basalts higher in the section are generally nonporphyritic or contain only scattered small augite phenocrysts in a black dense matrix. Most of them are intermediate between basalt and andesite in composition, and contain calcic andesine as the plagioclase and generally less than 50 percent mafic minerals.

The sedimentary rocks interlayered with the basalt contain fossil leaves and diatoms, but no fossil collections have been made from the unit within the area of this report. A collection of diatoms from about a mile south of the area has been assigned a late middle Miocene to early Pliocene age by K. E. Lohman (written communication, 1958), and fossil leaves from identical-appearing rocks elsewhere in Humboldt County indicate the same age range (Willden, 1962). A Miocene to early Pliocene age seems to be fairly well established for the basalt.

SEDIMENTARY ROCKS

Tertiary sedimentary rocks consisting of shale, water-laid tuff, shaly sandstone, diatomaceous shale, and bedded opaline chert are abundant in the south end of the range, and are exposed in the Bottle Creek quicksilver district. Thin sedimentary units are present at places in the basalt from Bottle Creek south to Cedar Creek, but have not been shown separately on the map.

The sedimentary rocks are interlayered with basalt although at some places, probably owing to irregular pre-basalt topography, they rest on pre-basalt Tertiary rocks. The sedimentary rock attain a maximum thickness of about 400 feet west of the south end of the range. At other localities they are much thinner.

The sedimentary rocks are generally light buff to white, fine grained, and except for some water-laid tuffs, are thin bedded. The diatomaceous shale locally becomes nearly pure diatomite and commonly has been converted to bedded opaline chert.

The sedimentary rocks have been dated, as noted above, as late middle Miocene to early Pliocene.

K. E. Lohman (written communication, 1958) has reported on a collection of diatomite from about one-half mile west of Norton's Ranch as follows:

USGS diatom locality 4409. Norton's Ranch, northern center of Lovelock 1° quadrangle, Nevada. Diatomite from about one-half mile west of Norton's Ranch in the southern Jackson Range. Appears to be youngest lake bed exposed in the range. T. 36 N., R. 31 E. Coll. C. R. Willden, 1956, field no. F56W20.

Twenty-one species and varieties of fresh water diatoms were found in this collection. They are listed below, where relative abundances are indicated by A, abundant; C, common; F, frequent; and R, rare.

Cymbella affinis Kützing	F
c.f. *C. cuspidata* Kützing	F
Fragilaria sp. A*	C
sp. A var. A*	F
sp. A var. B*	F
construens var. *subsalina* Hustedt	A
construens var. *venter* (Ehrenberg) Grunow	A
Gomphonema longiceps var. *subclavata* Grunow	R
Hantzschia amphioxys (Ehrenberg) Grunow	F
Melosira sp. A*	A
cf. sp. A*	C
sp. A var. A*	C
undulata (Ehrenberg) Kützing	R
Navicula bacillum Ehrenberg	F
cf. *N. dicephala* (Ehrenberg) Wm. Smith	F
sp.	F
Opephora martyi Heribaud	R
Pinnularia cf. *P. subpolaris* (Grunow) Cleve	R
Tetracyclus ellipticus (Ehrenberg) Grunow*	F
cf. *T. ellipticus* (Ehrenberg) Grunow*	F
cf. *T.* sp. A*	R

This freshwater diatom assemblage is dominated by pelagic species suggesting that the lake in which they were deposited may have been either fairly deep or that the water was too turbid to allow light to penetrate in sufficient strength to the bottom where a bottom living assemblage could prosper.

The assemblage contains a total of 8 extinct species and varieties of diatoms, indicated in the list by an asterisk (*) following the name. Most of these are new species (indicated by sp. A, etc.) which I will describe in a paper on the Cenozoic nonmarine diatoms from the Great Basin * * *. Seven of the 8 species and 62 percent of the whole assemblage also occur in the middle of a 440 foot measured section in the Esmeralda formation on the East slope of Cedar Mountain, Nye County, Nev., from which J. C. Merriam and others have described a lower Pliocene vertebrate fauna. The same seven extinct species and 57 percent of the whole assemblage also occur in a 150 foot measured section in the upper part of the lower Virgin Valley beds in northern Humboldt County, Nev. J. C. Merriam (1910) described a late middle Miocene vertebrate fauna from these beds. It so happens that the extinct species in question have known geologic ranges of late middle Miocene to early Pliocene and occur in both localities. Each of these two localities, however, contains shorter ranging species confined to the late middle and late Miocene on the one hand and to early Pliocene on the other, but these do not occur in the assemblage from locality 4409 near Norton's Ranch. Therefore the best age assignment that can be made is early Pliocene (most probable) or late middle Miocene (possible). The younger of the two ages is suggested by the fact that the other species in the assemblage, which range from Miocene to Recent are also present in the higher percentage in the early Pliocene Esmeralda formation. As the difference is slight, the safest assignment would be late middle Miocene to early Pliocene.

One additional sample from the Norton's Ranch locality, but stratigraphically lower in the same section might yield some of the very short ranging species characteristic of the lower part of the Esmeralda formation and enable a more definite age assignment to be made.

At other localities in Humboldt County identical-appearing sedimentary rocks, which contain fossils of the same age or range in age, occur intercalated with rhyolitic rocks or between rhyolite and basalt with either basalt or rhyolite below the sediments (pl. 3).

RHYOLITE

The rhyolite is exposed only in the northeast part of the range where it rests on the Happy Creek volcanic series, the undivided Permian and Triassic rocks, the Tertiary basalt, and the Tertiary sedimentary rocks. Dacite flow breccias occur at the base of the rhyolite unit on the east side of Buff Peak, but elsewhere it consists mainly of rhyolite flows. The unit is about 1,500 feet thick.

The dacite flow breccia at the base of the rhyolite contains abundant large fragments (as much as 1½ inches) of chert, hornfels, fine-grained quartzite, and some limestone in a dacite matrix. The matrix consists of quartz, plagioclase, chlorite relicts after biotite, and amphibole. Epidote and calcite occur as secondary minerals in the rock.

The rhyolite flow rocks contain quartz, sanidine, biotite, and plagioclase in a cloudy partially devitrified glassy matrix. Most of the quartz crystals are rounded and some are embayed. The sanidine is also partially rounded and embayed. The plagioclase crystals are skeletal with glassy material inside the crystal outlines. Crystals make up only about 15 to 20 percent of the rock.

The rhyolite is the youngest Tertiary unit in the range. It probably correlates with some part of the thick sequence of rhyolitic to dacitic rocks exposed in the upper part of the Tertiary section at several places in Humboldt County (pl. 3); exact correlation is difficult because at most other places this silicic part of the Tertiary section is composed principally of welded tuffs.

QUATERNARY DEPOSITS

Three units of Quaternary or probable Quaternary age have been shown on the map. These are, from oldest to youngest: gravel deposits, older alluvium, and younger alluvium and lake sediments. Of these the younger alluvium covers by far the greatest area.

GRAVEL

Gravel mounds apparently produced in some earlier geomorphic cycle are at two places in the southern part of the map area. Both of the mounds are composed of angular to subrounded clasts of locally derived material, and well over half the clasts were derived from the Tertiary tuff unit. The clasts exhibit a wide range in size but cobble-size clasts are most abundant.

The angularity of the clasts and the generally poor sorting suggest that the gravel mounds are remnants of alluvial fans that predate the present physiography of the range.

OLDER ALLUVIUM

The older alluvium includes the dissected alluvial fan deposits along most of the east side of the range and parts of the west side, and the alluvial cover in some upland valleys.

The older alluvium is for the most part poorly sorted subangular to subrounded sand to cobbly gravel. The coarser material is found high on the alluvial fans and the finer material low on the fans. The fans have all been dissected, and perennial streams now occupy channels cut in the fans. The downcutting, in most cases, appears to have begun at the upper terrace of Lake Lahontan or a terrace near the upper level (fig. 8), and has extended headward. Scarps other than wave-cut terraces are present in the older alluvium in the southeast part of the range. These scarps mark the extensions of faults from the bedrock areas of the range.

YOUNGER ALLUVIUM AND LAKE SEDIMENTS

Younger alluvium, consisting of the alluvial material in the stream channels entrenched in the alluvial fans, and Lake Lahontan sediments surrounds the bedrock area of the Jackson Mountains. The contact between the younger and older alluvium is generally drawn at the highest recognizable terrace of Lake Lahontan. The younger alluvium and lake-sediments unit includes fine silt on the playas on both sides of the range, lake-shore deposits such as well-sorted pebble bars and spits, stream gravels, and some windblown sand. The younger alluvium is generally much finer grained than the older alluvium, except in the former shore areas of Lake Lahontan, where the younger alluvium includes reworked fan material, and in the bottoms of the present stream channels.

STRUCTURE

GENERAL STATEMENT

The structure of the Jackson Mountains is of considerable significance in deciphering the structural history of the Great Basin, because this range is one of very few areas where folded and faulted rocks of Cretaceous age record late Mesozoic and early Cenozoic structural events. In addition to the late Mesozoic and early Cenozoic orogeny recorded in the rocks of the range, at least one and perhaps two or more pre-late Mesozoic periods of deforma-

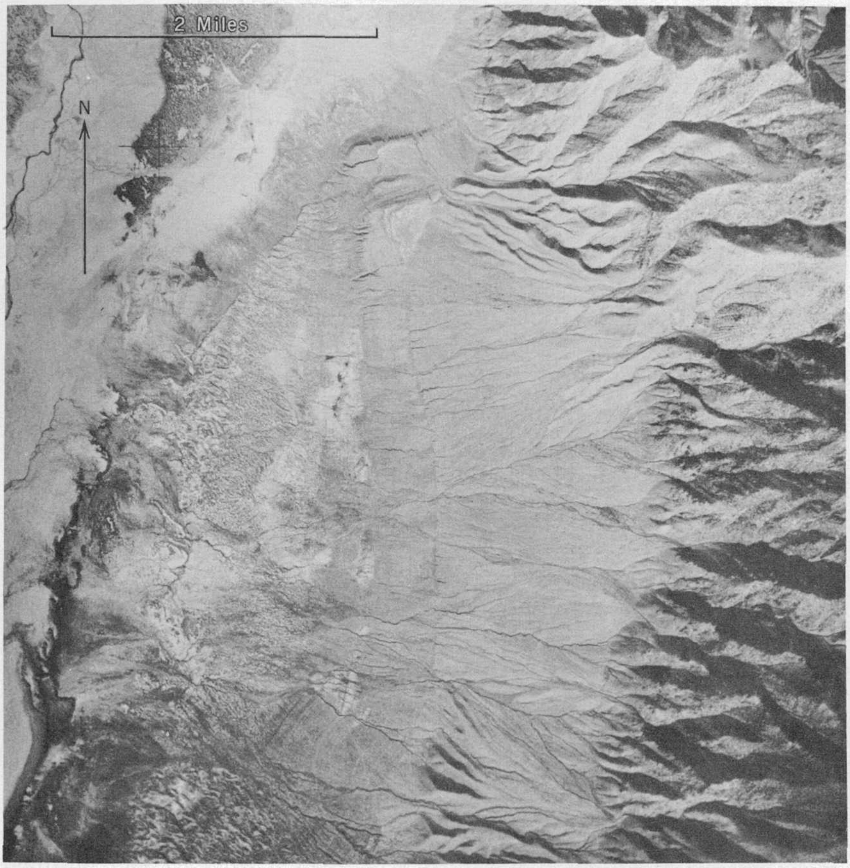

FIGURE 8.—Dissected alluvial fans on the west side of the Jackson Mountains south of McGill Canyon. Lake Lahontan terraces are conspicuous in center of photograph. Army Map Service photograph: Project 109, Area F, number 11191.

tion have affected the range, and it has been subjected to a long period of adjustment to vertical stresses in late Tertiary to Recent time.

At least four periods of intense orogenic activity characterized by the development of tight folds and thrust faults have affected much of north-central Nevada (Roberts and others, 1958, p. 2850–2855). These orogenic periods include the Antler orogeny of Late Devonian to Early Pennsylvanian age, which may well predate the rocks exposed in the Jackson Mountains; a Permian orogeny, the effects of which are rather obscure in the Jackson Mountains; a Jurassic orogeny, which is responsible for part of the deformation and virtually all of the metamorphism of the rocks in the range; and the Late Cretaceous to early Tertiary orogeny, which is responsible for many of the structural features of the range. These repeated periods of deformation have undoubtedly produced a complex structural pattern in the Jackson Mountains, but much of the complexity is lost in the massive and generally featureless Happy Creek volcanic series.

FOLDS

The various periods of deformation in the Jackson Mountains have produced a few large folds that are shown on plate 1. Many folds are too small to be shown. The smaller folds have been recognized in most of the rock units and include drag folds associated with faults, domelike folds produced by intrusive bodies, and small isoclinal folds in the phyllitic units. These isoclinal folds may be related to unrecognized overriding thrusts or may be drag folds on the limbs of larger folds which at most places likewise have not been recognized. The axial planes of these small folds are inclined at many different angles and have a random trend, except those of the isoclinal folds in the unnamed phyllite unit of Triassic age, which generally trend about N. 70° E.[2] and dip from 30° to 70° NW. The larger folds trend north-northeast and the axial planes recognized in the undivided Permian and Triassic unit and the Cretaceous rocks are vertical or nearly so.

FAULTS

Faults undoubtedly formed in most of the periods of deformation but nearly all those shown on the map cut Cretaceous or younger rocks. Faults wholly within the monotonously similar rocks of the Happy Creek volcanic series or the undivided Permian and Triassic rocks are particularly difficult to recognize. Most of the mapped faults are high-angle faults with essentially dip-slip displacement, but one discontinuously exposed thrust fault, the Deer Creek thrust, has been mapped through much of the length of the range. The fault that forms the south limit of the Pansy Lee conglomerate at its exposure on the northeast side of King Lear Peak appears to be a strike-slip fault and may be a tear fault related to the Deer Creek thrust.

Range-front faults are conspicuous only along the west side of the Jackson Mountains in the vicinity of the mouth of Alaska Canyon. The abrupt west front of the northern two-thirds of the range suggests that much of the west front may be controlled by a fault.

PRE-TRIASSIC DEFORMATION

Pre-Triassic deformation in the Jackson Mountains is difficult to establish. The Antler orogeny of Late Devonian to Early Pennsylvanian age may have affected the Happy Creek volcanic rocks.

[2] Incorrectly reported as N. 10° E. in Willden, 1958, p. 2396.

The Permian (pre-Koipato) orogeny, whose effects are particularly noticeable in the East and Tobin Ranges (Roberts and others, 1958, p. 2854–2855), probably had some effect on the older rocks of the Jackson Mountains. Structures produced during a Permian orogeny have not been recognized, but the conglomerates and other clastic sediments in the lower part of the undivided Permian and Triassic unit are evidence of nearby positive areas.

PRE-CRETACEOUS DEFORMATION

The effects of pre-Cretaceous deformation in the Jackson Mountains can be identified with considerable confidence, although only a few structures can be assigned such an age. These effects include the nearly universal regional metamorphism of the pre-King Lear rocks, the tight fold in limestone assigned to the undivided Permian and Triassic unit beneath the King Lear formation at the mouth of Rattlesnake Canyon, and possibly the folds in the Triassic phyllite unit, which are best exposed south of the map area. The intrusion of the diorite stocks probably can be regarded also as related to the deformation.

The stretched-pebble conglomerates in the undivided Permian and Triassic units are regarded as evidence of compressive deformation, which was probably contemporaneous with the metamorphic recrystallization of the other rocks. The stretching, which was accompanied by marked flattening, may have been accomplished by either crystal gliding or fracture dislocation, but the pebbles now show no fractures. The absence of fractures contrasts sharply with the stretched-pebble conglomerates associated with the Deer Creek thrust, in which the fractures along which gliding has taken place are clearly visible. The absence of fractures in the pebbles of the older conglomerates is believed to indicate that the deformation was accomplished under much greater load. The quartz veinlets may be related to the later thrusting or to some other post-metamorphic tectonic event.

The metamorphism exhibited by all the pre-King Lear rocks is recognized in the Triassic rocks, except the Quinn River formation at the south end of the Kings River Range, as far east as the Santa Rosa Range (Compton, 1960). The Tertiary volcanic cover to the west hides the greenschist facies metamorphic rocks to which the Jackson Mountains rocks belong, but probable greenschist facies metamorphic rocks are present in the northern Sierra Nevada (Durrell and Proctor, 1948).

FOLDS

At least one small fold can be dated as definitely pre-Cretaceous and post-Permian. This fold is a nearly isoclinal anticline and its vertical axial plane is in limestone beds mapped as part of the undivided Permian and Triassic unit at the mouth of Rattlesnake Canyon. The King Lear formation rests unconformably on the limestone, indicating that the folding predates the King Lear.

The folds in the Triassic phyllite unit along the east front of the range south of the map area may also be pre-Cretaceous but positive evidence of their age is lacking. Their east-northeast trend and universal overturned character contrast markedly with the vertical north-northeast-trending folds in the rest of the range. The King Lear formation is involved in these nearly vertical folds (section *E–E′*, pl. 1) and provides evidence that at least some of the folds with vertical axial planes are Cretaceous or younger.

The large folds in the range involving only the Permian and Triassic rocks (pl. 1, sections *A–A′* and *C–C′*) are generally tighter folds than those involving the Cretaceous rocks and for this reason might be assigned a pre-Cretaceous age.

FAULTS

Faults of definite pre-Cretaceous age have not been recognized in the range, but there is some indirect evidence that thrust faults of possible pre-Cretaceous age are responsible for the present distribution of some of the units in the range. The change of strike of the metamorphic facies in north-central Nevada lends some support to the supposition that large-scale post-Triassic thrusting is responsible for the distribution of various late Paleozoic and Triassic formations in the East, Tobin, and Sonoma ranges (Roberts and others, 1958, p. 2854–55; Ferguson and others, 1951). Evidence of post-Triassic thrusting of undetermined magnitude but probably with at least several miles displacement is found in the anomalous fold pattern of the Triassic phyllite unit in the southern part of the Jackson Mountains. The folds in the phyllite are common but not large and trend about N. 70° E. Their axial planes dip from 30° to 70° NW and the folds are generally tight to isoclinal. The major fold axes in the northern part of the range trend about N. 30° E. and their axial planes are vertical or nearly so. The phyllite unit is separated from the older rocks by Tertiary volcanic rocks and by a high-angle fault south of the map area, but the phyllite may have been thrust on the older rocks; the thrust contact may be hidden by Tertiary volcanic rocks or later high-angle displacement may have occurred along the surface trace of the thrust. The abrupt eastward swing in the strike of the metamorphic facies is the chief reason for considering the phyllite to be on the upper plate of a thrust.

INTRUSIVE ACTIVITY

The Jurassic diorites in the range are not foliated but they have been metamorphosed to the same low-grade facies as the other pre-Cretaceous rocks in the range. If the metamorphism and compressive deformation were contemporaneous, the diorites must have been intruded and crystallized before compressive deformation. Had the diorites been crystallizing when the deformation took place, it is likely that some preferred orientation would have been imparted to the crystallizing rock.

CRETACEOUS AND POSSIBLY EARLY TERTIARY DEFORMATION

The Cretaceous and possibly early Tertiary deformation of the Jackson Mountains is important to the unraveling of the complex structural history of north-central Nevada. A major orogeny consisting of several pulses or phases through Cretaceous and early Tertiary time has been assumed to have affected all of the Great Basin (Nolan, 1943, p. 173–178), but this orogeny can be definitely dated in very few areas. Most of the effects of compressive deformation visible in the Great Basin might be assigned to the Permian or probable Jurassic orogenic phases if it were not for such areas as the Muddy Mountains in southern Nevada (Longwell, 1949), the Jackson Mountains, and the Eureka mining district (Nolan and others, 1956) where Cretaceous rocks are present to aid in the dating the Cretaceous and Tertiary deformation.

The late Mesozoic and early Tertiary orogenic period in the Great Basin province as a whole was characterized by the development of folds followed by thrust faults (Longwell, 1949, p. 963–964; Nolan, 1935, p. 55–56, 63–64; Morris, 1957, p. 44–45; Hewett, 1956, p. 50). Some of the thrusts, particularly those on the east side of the province, must have moved tens of miles (Longwell, 1949, p. 924; Christiansen, 1952, p. 739; Tschanz, 1959, p. 1753). This sequence of structural events is repeated in the Jackson Mountains.

FOLDS

The King Lear formation has been folded into a tight northeastward-plunging syncline on the south side of King Lear Peak (pl. 1) and into a gentler syncline east of Navajo Peak (pl. 1, section *A–A′*). This folding predates the deposition of the Pansy Lee conglomerate, which has a uniform 25° eastward dip only 3 miles north of the tight fold in the King Lear formation on the south side of King Lear Peak. These two folds in the King Lear are the only folds that can be definitely assigned to a Cretaceous or possibly early Tertiary period of deformation, but their general parallelism with the major folds in the Triassic and older rocks, and the essentially vertical axial planes of the two sets of folds suggest that the major folds in the Triassic and older rocks may also be Cretaceous or possibly early Tertiary age.

FAULTS

One extensive thrust fault and many high-angle faults have been recognized in the range. The thrust fault, which has been named the Deer Creek thrust, belongs to this late Mesozoic and possibly early Tertiary orogenic period, but most of the high-angle faults are difficult to date.

Many of the high-angle faults involve the late Tertiary rocks and thus are late Tertiary or younger, although some late Tertiary or Recent displacement has probably taken place on older faults. Other high-angle faults involve only pre-Tertiary rocks and some of them are probably of late Mesozoic or early Tertiary age.

A northward trending fault in the King Lear formation on the east side of Navajo Peak terminates against intrusive diorite on the south and is cut off on the north by a fault that is in turn cut off by a high-angle fault involving late Tertiary basalt. The two prebasalt faults cut two other faults involving the King Lear formation. The four faults involving only the King Lear or older rocks can all be regarded as of Cretaceous or early Tertiary age. Other faults involve rocks no younger than the King Lear or Pansy Lee formations but their age with respect to the late Tertiary rocks can not be established.

DEER CREEK THRUST

The King Lear formation and the Pansy Lee conglomerate have been overriden by the Happy Creek volcanic series in a thrust sheet that can be identified over a 25-mile segment of the range. This thrust has been named the Deer Creek thrust for excellent exposures on the north side of Deer Creek Peak (fig. 9). The southernmost exposure of the thrust is at Rattlesnake Canyon on the west front of the range near the southern boundary of the map (pl. 1). A small klippe of the Happy Creek volcanic rocks rests on the King Lear formation on Cedar Creek east of Navajo Peak (pl. 1, section *F–F′*). The thrust is also exposed on the southeast flank of King Lear Peak, and it can be traced from the southwest side of DeLong Peak to the north side of Deer Creek Peak, a distance of about 8 miles. On the west and north sides of Deer Creek Peak the thrust overrides both the Pansy Lee conglomerate and the King Lear formation. The relation of the thrust and the King Lear formation is shown in sections *A–A′*, *E–E′*, and *F–F′* on plate 1.

The rocks immediately below the thrust are commonly sheared, and stretched-pebble conglomerates have been produced at some

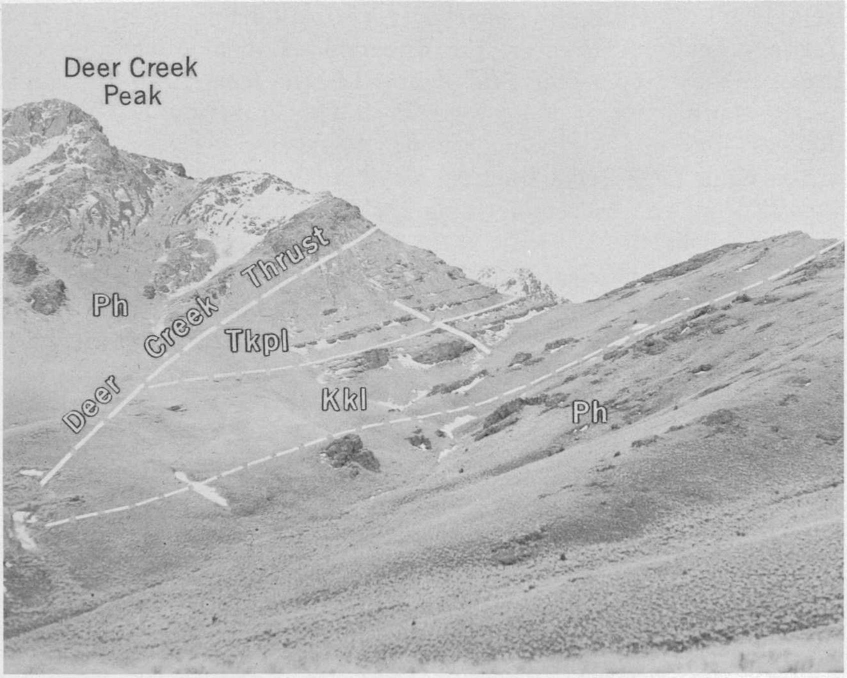

FIGURE 9.—Deer Creek thrust on the north side of Deer Creek Peak. Happy Creek volcanic series (Ph), Pansy Lee conglomerate (TKpl), and King Lear formation (Kkl) are shown.

places. The stretched pebbles produced by the thrust appear quite different from those in the conglomerates of the undivided Permian and Triassic unit. Fractures along which gliding has taken place are still clearly visible in the stretched pebbles due to the thrust.

The volcanic rocks on the upper plate of the thrust are cut by innumerable, more or less randomly oriented slickensided surfaces. Serpentine and calcite are commonly formed on the slickensided surfaces but otherwise the rocks lack evidence of shearing or recrystallization.

The Tertiary volcanic rocks widely exposed in the range were not involved in the thrusting. Thus the thrusting predates the Tertiary volcanic rocks, and postdates the deposition of the Pansy Lee conglomerate.

The dip of the thrust plane provides no information about the direction of displacement because the plane dips east in the northern part of the range, northwest on the southeast flank of King Lear Peak, east under the klippe north of Cedar Creek, and south at Rattlesnake Canyon. These apparently anomalous dips of segments of the thrust plane may be due to folds produced by compressive forces after the thrust plate ceased to move or they may be a result of tilting by essentially vertical displacement on late Tertiary faults. However, the direction of displacement on the thrust is shown by a drag fold observed in the King Lear formation on the south flank of King Lear Peak (pl. 1, section *E–E'*). On the west limb of the syncline south of the thrust, conglomerate beds of the King Lear strike from N. 15° E. to N. 30° E. and dip about 50° SE., but the beds underlying the thrust have been overturned and dip about 45° W. with a N. 15° E. strike. This drag shows that the relative movement of the upper plate was from west to east.

The amount of displacement is not known but is thought to be small because all the rock units involved in the thrusting are part of a compatible sequence.

INTRUSIVE ACTIVITY

The Cretaceous or Tertiary diorites were emplaced after the folding of the King Lear formation and after the formation of at least some of the high-angle faults inovlving the King Lear formation. Their age with respect to the thrust faulting or the deposition of the Pansy Lee conglomerate is unknown. The Pansy Lee contains some dioritic pebbles, but these pebbles could have been derived from the Jurassic diorites.

The time of emplacement of the granodioritic stock is unknown. It has not contributed detritus to the Cretaceous or the Tertiary conglomerates exposed in the range, and has not been involved in any known faults except possibly the range bounding faults.

REGIONAL SIGNIFICANCE OF LATE CRETACEOUS AND EARLY TERTIARY OROGENY

Much of the deformation of the Triassic rocks in north-central Nevada might be better assigned a Late Cretaceous or possibly early Tertiary rather than a Jurassic age as has been done in the past.

The Jurassic age of the northern Nevada orogeny has been based on comparison with the well-dated Jurassic thrusting and folding of the Hawthorne and Tonopah quadrangles (Ferguson and Muller, 1949), and on the fact that the thrust plates involving Triassic rocks have been cut by granodiorite intrusive bodies (Ferguson and others, 1951; Muller and others, 1951). The granodiorite intrusive bodies were believed to be "satellitic to the Sierra batholith," which was believed to be Late Jurassic. The Late Jurassic age of the Sierra batholith is not supported, however, by recent potassium-argon and lead-alpha age determinations. Potassium-argon age determinations of rocks from Yosemite National Park range from 76.9 to 95.3 million years (Curtis and others, 1958, p. 7–9), and lead-alpha ages of rocks from Yosemite National Park and from an area near Bishop, California range from 88 to 117 million years (Larsen and others, 1958, p. 52). These rocks by either method of age determination would be assigned to the Cretaceous according to the Holmes B time-scale (Holmes, 1947). The granodiorite intrusive bodies used to date the orogeny as Jurassic, however, may be considerably younger than those in the Sierra batholith. The nonfoliated granodiorite intrusive bodies in Humboldt County show a range in age by the lead-alpha method from 35±10 to 65±10 million years (H. W. Jaffe, written communication, 1956; T. W. Stern, written communication, 1959).

The folding and the overthrusting which characterized the Late Cretaceous and possibly early Tertiary orogeny in the Jackson Mountains produced thrust faults and tight locally overturned folds in the lower plate rocks similar to those ascribed to the Jurassic orogeny in north-central Nevada. The Jurassic age of an orogeny in northern Nevada has been substantiated by the discovery of the Quinn River thrust at the south end of the Kings River Range (Willden, 1960), but many of the structural features assigned a Jurassic age should be re-examined for evidence of Cretaceous or early Tertiary age.

LATE TERTIARY DEFORMATION

The late Tertiary deformation was principally displacement on high-angle faults but included some apparent folding, as indicated by the deformed thrust plane previously described and the opposing dips in the Tertiary rocks in the Bottle Creek quicksilver district (pl. 1, section *D–D'*). The late Tertiary deformation, although of relatively small magnitude, has probably taken place over a considerable span of time and has resulted in the formation of new faults and in renewed movement on older faults.

FOLDS

The foldlike structures, particularly the one in the Tertiary rocks of the Bottle Creek quicksilver district, may be related to differential displacement on high-angle faults or they may be compressional features unrelated to faults. Such late Tertiary compressional features might be expected with the subsidence and uplift respectively of basin and range blocks bounded by nonvertical faults.

FAULTS

The late Tertiary to Recent faults shown on the map, with the possible exception of the range–front fault in the vicinity of Alaska Canyon, are probably all relatively minor structural features; the displacement on any one fault is probably at most a thousand feet. Range-boundary faults responsible for the principal uplift of the

Jackson Mountains are probably buried under the alluvium some distance to the west and east of the range.

A gravity profile across the south end of the Jackson Mountains by D. R. Mabey (fig. 10) suggests the presence of an eastern range-boundary fault somewhere near or east of Jungo. Desert Valley on the east side of the Jackson Mountains contains a minimum of 6,000 feet of low density fill; the deepest part of the valley is just east of its center. The deepest part of Desert Valley at the north end of the range, however, is near its west side (fig. 11); but no depth calculations have been made in the northern part of the valley. The gravity profile across the north end of the Jackson Mountains—also by D. R. Mabey—indicates that the eastern boundary fault is probably 2 or 3 miles east of the range front. This location is in good agreement with the aerial magnetic map of the northeastern part of the Jackson Mountains (fig. 12); the map indicates that the volcanic rocks extend a considerable distance east of the range front with only a shallow alluvial cover.

The west side of the Jackson Mountains is also controlled by faults, probably two or more in en echelon arrangement. Displacement is greatest at the south end of these faults and gradually decreases northward. One such fault is the range-front fault exposed at the mouth of Alaska Canyon. It can be projected southward to just west of the isolated basalt and sediment outcrop in the southwest part of the map area, where its displacement probably is 2,000 to 3,000 feet (on the basis of projection of gravity stations several miles northward from the Western Pacific Railroad southwest of Sulphur). Another such fault has probably controlled the west front of the range north of Alaska Canyon but the fault is not exposed.

The aerial magnetic map of the northeastern part of the Jackson Mountains (fig. 12) and the field relations in the Bottle Creek quicksilver district (pl. 1, section *D–D′*) provide evidence that the late Tertiary faulting has persisted for a considerable time. There is a pronounced troughlike magnetic low just east of the northward-trending fault that separates the undivided Permian and Triassic rocks from the Tertiary rocks on the east. The small highs and lows along this trough indicate that it is underlain by volcanic rocks, and it seems best explained as a downfaulted block of basalt. If so, this downfaulting must have taken place and the basalt on the relatively upthrown block to the west must have been eroded before extrusion of the rhyolite, which rests on the Permian and Triassic rocks west of the fault and on basalt east of it. This sequence of extrusive volcanism, faulting, erosion, more extrusive volcanism, and more faulting demonstrates the complexities of the late Tertiary history of the area.

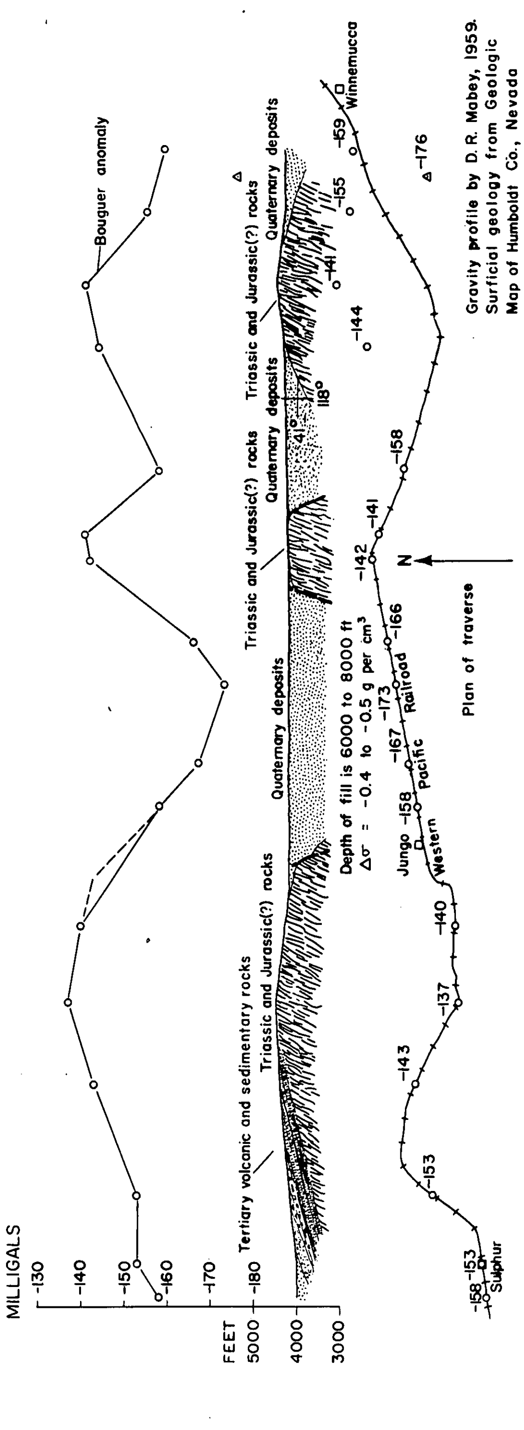

FIGURE 10.—Gravity profile and hypothetical geologic section from Sulphur to Winnemucca across south end of Jackson Mountains.

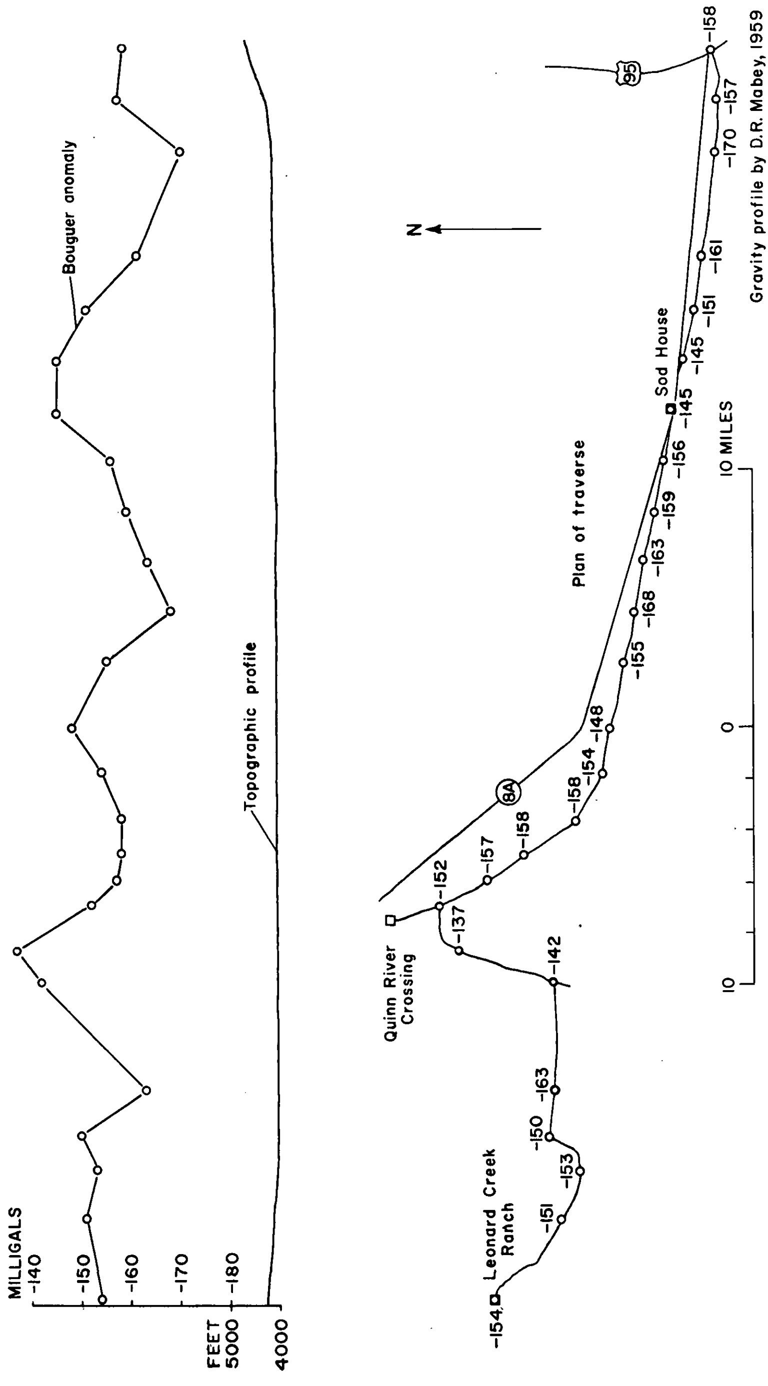

FIGURE 11.—Gravity and topographic profiles from Leonard Creek Ranch to junction of State Highway 8A and U.S. Highway 95 across north end of Jackson Mountains.

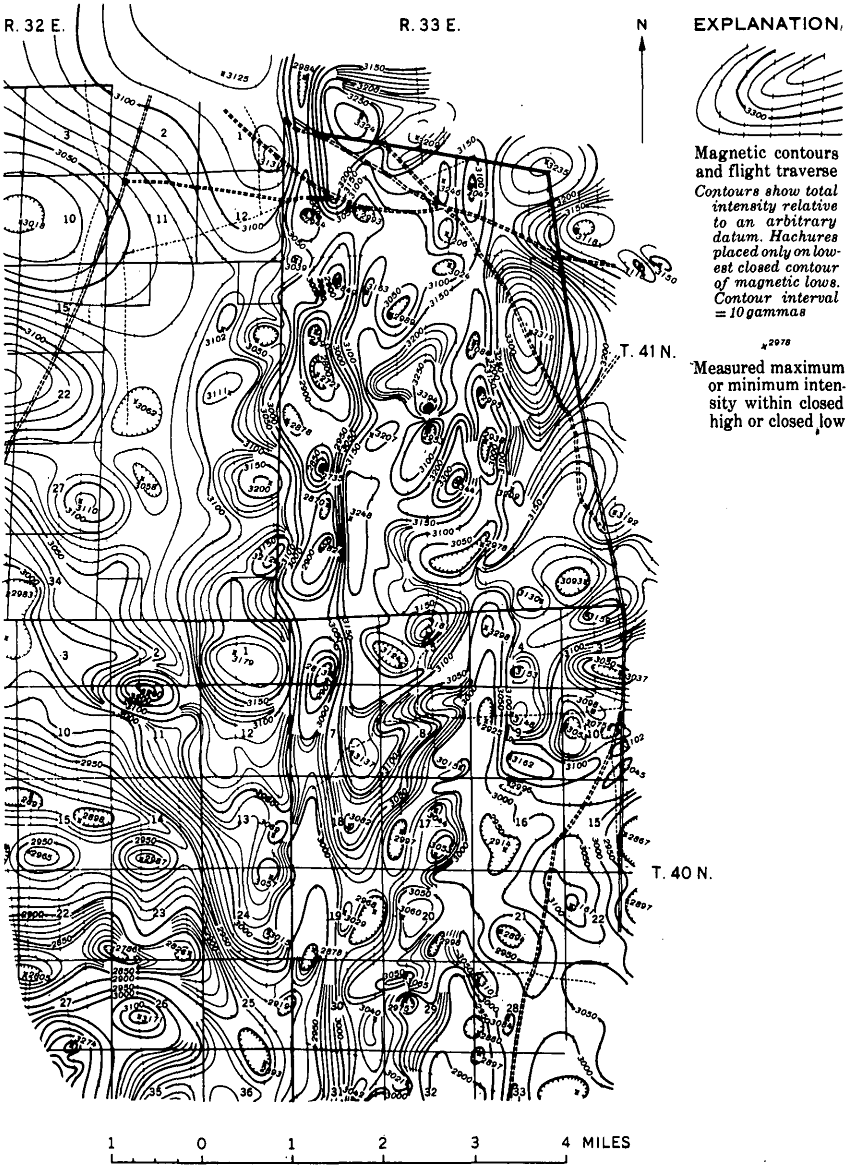

FIGURE 12.—Aerial magnetic map of northeastern part of Jackson Mountains, flown at 500 feet above ground. Map contributed by mining company that granted permission to publish the data.

ORIGIN OF THE JACKSON MOUNTAINS AS A TOPOGRAPHIC FEATURE

It can hardly be doubted that the Jackson Mountains owe most, if not all, of their present relief to uplift on normal faults that in general bound the range. But the origin of these bounding faults and the forces that have caused the uplift is quite another matter.

The problem of the origin of any one range is part of the larger problem of the origin of the Basin and Range structural province. A satisfactory explanation of the late Tertiary structures of the entire province is beyond the scope of this report, but there are certain features of the Jackson Mountains that must be explained by any theory of origin of Basin and Range structure and for this reason deserve mentioning. These features include: (1) the nearly due north trend of the range and its pronounced linearity; (2) the repeated movement on the faults through much of late Tertiary and Quaternary time; (3) the great depth of the basin on the east side and probably also on the west side of the range; (4) the presence of apparent compressional features in the late Tertiary rocks; (5) the large amount of displacement on the bounding faults; and (6) the fact that the range is the site of older mountains or at least positive areas as shown by the unconformities below and above the Cretaceous and early Tertiary rocks.

ORE DEPOSITS

The mines of the Jackson Mountains produced more than $4,000,000 to the end of 1957 (Willden, 1962). Most of this production has come from the Iron King mine, and much smaller amounts have come from the other iron mines and from the quicksilver and sulfur deposits. The few copper mines and prospects have had a very small production.

Nearly all the mines in the range have been studied in some detail by previous workers and reports on this work have been prepared (Ransome, 1909; Vanderburg, 1938; Roberts, 1940; Bailey and Phoenix, 1944; Benson, 1956; and Shawe and others, 1962). Therefore, although the mines were visited as part of this study, detailed mapping was not undertaken.

The various ore deposits were formed in at least two, and perhaps three or more widely separated periods of mineralization. The iron deposits, which were formed before deposition of the King Lear formation, seem to be related to the Jurassic intrusive rocks. At least part of the copper deposits are younger than the King Lear and they may be either related to the Cretaceous diorites, or a product of the late Tertiary period of mineralization. The quicksilver deposits are associated with diabase dikes and with faults that cut the youngest Tertiary rocks and thus are of late Tertiary or younger age. The sulfur deposits are located south of the area of this study and therefore will not be discussed at any length. They are in Tertiary rocks and may be either a product of the same late Tertiary period of mineralization as the quicksilver deposits, or

Quaternary deposits produced during the highest stage of Lake Lahontan (E. H. Bailey, oral communication, 1956).

IRON DEPOSITS

Iron deposits are present as replacement bodies or as veins in the Happy Creek volcanic series on the west side of DeLong Peak, on the west side of the north fork of Jackson Creek, and on the east and north sides of Navajo Peak. The deposits on the west side of DeLong Peak are high-grade magnetite bodies. The other deposits are of somewhat lower grade, and consist of mixed hematite and magnetite ore; hematite is most abundant.

The deposits on the west side of DeLong Peak include the two largest ore bodies in the range: the Iron King ore body and the Red Bird deposit, which may be a faulted continuation of the Iron King deposit. The Iron King deposit is a veinlike replacement body localized along the contact between a diorite intrusive, not shown on plate 1, and the Happy Creek volcanic rocks. Some shearing in the diorite and the volcanic rocks suggests that the contact is a fault rather than an intrusive contact. The mine-run ore has averaged about 65 percent iron. Four samples of ore from the Iron King, Red Bird, and Yellow Boy deposits have been analyzed by the chemical laboratories of a major mining company that prospected the range, and the results are given in the following table.

Chemical analyses of iron ore

[Results in weight percent, except as indicated]

Sample	Fe	SiO_2	S	P	Mn	As	Cu	Ni	Pb	Zn	Ti	F
1	70.5	0.65	0.025	0.006	0.05	0.01	0.01	0.03	0.01	0.01	0.14	-------
2	67.0	3.35	.004	.004	.07	.01	.01	.04	.01	.08	.45	-------
3	61.6	6.60	.008	.006	.07	.01	.01	.06	.02	.15	2.61	-------
4	62.9	6.60	.009	.040	-------	.02	.01	.015	-------	-------	-------	128 ppm

Dash indicates value not reported.

Samples 1 and 2 are grab samples from Red Bird claims; sample 3 is grab sample from Yellow Boy claims, which adjoin Red Bird; and sample 4 is chip sample from face of Iron King deposit. Analyses were kindly supplied by mining company in the area.

Structural control of these deposits other than the contact of the diorite and volcanic rocks has not been noted, but the deposits are cut by several post-ore faults. All the available evidence indicates that the deposits are in the upper plate of the Deer Creek thrust. The thrust must be several hundred to perhaps a thousand feet lower than the deepest workings of the Iron King mine and considerably farther below the Red Bird mine. The fault will thus be of little consequence to the mine operations unless deep underground development is undertaken.

The deposit on the north fork of Jackson Creek was not visited, but, according to Shawe and others (1962), consists of small pod-like replacement bodies of hematite and some magnetite in the Happy Creek volcanic rocks.

The deposits in the vicinity of Navajo Peak consist of veins of hematite with some magnetite in bleached and altered volcanic rocks assigned to the Happy Creek. Several of these deposits have been explored by bulldozer trenches and some drilling has been done at one deposit, but no ore has been shipped. The veins are generally narrow, range from a few inches to about 5 feet, and have a maximum strike length of only a few hundred feet. No structural control of these deposits, other than possibly the joints in the volcanic rocks, has been noted.

Evidence of the pre-Early Cretaceous age of the iron deposits is furnished by abundant hematite and magnetite clasts in the lower conglomerates of the King Lear formation on the east side of Navajo Peak (fig. 13), and a few scattered magnetite clasts in the King Lear conglomerates below the Iron King mine road about 4 miles by road southwest of the mine. The general scarcity of iron detritus in the vicinity of the largest ore bodies, and its abundance near the much smaller deposits near Navajo Peak are explained by the Deer Creek thrust, which has placed the large ore bodies in proximity to the King Lear formation.

ORIGIN

The volcanic rocks in the vicinity of the hematite veins near Navajo Peak are generally bleached and some of them are cut by closely spaced parallel joints on the walls of which specular hematite has formed. The bleached rocks consist almost wholly of albite (An content of 4 to 6 percent as indicated by X-ray diffraction patterns) and a small amount of quartz. The rocks have been subjected to some sort of alkali metasomatism but its nature and extent are unknown because the bleached rocks were not mapped separately and few specimens are available for study.

As a part of the alteration process, the iron contained in widely distributed minerals has been leached and is concentrated along the joints that cut the rocks. This evidence immediately suggests the possibility that the iron deposits, particularly the hematite veins, have had their ultimate source in the Happy Creek volcanic series. The diorite intrusive bodies provided an energy source and possibly solutions to effect the transfer of iron from the volcanic rocks to the joints and thence to the veins and replacement bodies.

The mechanism would be similar to that proposed by Mackin (1947, p. 43–47) for the origin of the iron deposits at Iron Springs,

FIGURE 13.—Specimen of conglomerate from the King Lear formation containing abundant hematite (h) and magnetite (m) clasts.

Utah. At Navajo Peak, however, instead of the iron having been derived from the intrusive rocks during a late stage of autometamorphism, it was derived from the country rocks during their alteration to extremely sodium-rich rocks; the alteration was probably triggered by the intrusion of the diorites.

To test the possibility that the iron of the iron deposits may have been derived from the Happy Creek volcanic series, 11 samples of unbleached rocks of the Happy Creek selected at random from my collection of over 50 samples from the formation were analyzed for their iron content by X-ray spectrographic techniques. The 11 samples were compared with 2 chemically analyzed samples of igneous rock from elsewhere in Humboldt County which contained 7.9 and 3.0 percent total iron. The indicated iron content of these 11 samples as determined by comparison with the high-iron standard was found to be from 0.2 to 1.5 percent higher than that determined by comparison with the low-iron standard (the higher the indicated iron content of the sample, the greater the discrepancy). Therefore, the high-iron standard was used for comparison purposes with samples having an indicated iron content near or greater than 7 percent and the low-iron standard was used for samples having an indicated iron content near 3 percent or lower. For indicated iron contents between 3 and 7 percent, the average value obtained by comparison with both standards was used. The indicated iron content of the 11 samples of unbleached volcanic rock is given in the following table along with the indicated iron content of 2 samples of bleached volcanic rocks and 1 sample of bleached rock from between 2 hematite-lined joints.

Spectrographic analyses of iron content of Happy Creek volcanic series

Sample	Rock type	Location	Iron content (percent)
56W27b	Unbleached rock.	Just south of Gilbert and Stroud mine	9. 0
56W28b	do	3 miles southeast of Red Butte mine	7. 4
56W33	do	do	3. 1
56W53a	do	2 miles southwest of mouth of Rattlesnake Canyon.	8. 8
56W53d	do	do	7. 6
56W72	do	1 mile west of contact with Permian and Triassic unit along Bottle Creek.	5. 6
57W23b	do	1 mile east of mouth of Jackson Creek	3. 9
57W36	do	North end of ridge west of Happy Creek	4. 6
57W37	do	0.7 mile southwest of sample 57W36	4. 5
57W38	do	East side of Deer Creek Peak	1. 8
57W39	do	Deer Creek Peak	2. 2
56W60	Bleached rock from between two hematite-lined joints.	East side of Navaho Peak	1. 3
56W62a	Bleached rock	do	. 4
56W62b	do	do	. 4

The 11 samples of unbleached volcanic rock have an average iron content of 5.3 percent. The two samples of bleached rock contain 0.4 percent iron and the intrajoint material contains 1.3 percent iron. These analyses show a marked decrease in the iron content from the average value for the unbleached rocks to the bleached rocks; however, the few samples of bleached rock available can hardly be regarded as representative of all the bleached rocks around the ore deposits. Nevertheless, the data permit the assumption that the iron of the iron deposits has indeed been derived from the volcanic rocks.

The hypothesis can be further tested by calculating the amount of unbleached volcanic rock that would have to be altered to yield the known ore deposits. Such a calculation shows that a cube of volcanic rock about 650 feet on a side would yield sufficient iron for the ore body at the Iron King mine, which is the largest known deposit in the range. Much larger volumes of altered rock can be postulated from the surface extent of bleached rock exposed on the east side of Navajo Peak.

COPPER DEPOSITS

The copper deposits are all small and have had no important production. The discovery at Red Butte in 1906 caused a brief flurry of prospecting activity but did not result in any important discoveries. None of the mines were active in 1937 when Vanderburg (1938) visited the area and there has been very little activity since then.

The deposits at Red Butte are in the Happy Creek volcanic rocks and in a diorite intrusive body. According to Ransome (1909, p. 27–30) the deposits consist of oxidized ore (cuprite, covellite, native copper, and chrysocolla, associated with hematite, limonite, and a little barite) irregularly distributed through aplite dikes. I visited the deposits but found only a faint copper stain as evidence of the copper mineralization. The aplite dikes consist of 95 percent or more sodic oligoclase with some nearly colorless amphibole.

Several small prospects are located in the diorite intrusive body east of Red Butte. One of these prospects is developed by an inclined shaft and, judging by the size of the waste dump, has considerable underground workings, but I found no record of production from it.

A prospect on the east side of Navajo Peak is located in mudstones of the King Lear formation cut by a quartz vein. The prospect is developed by an adit and a shallow shaft down to the adit level from the hillside above and about 500 feet northwest of the adit portal. A small pile of quartz on the dump at the shaft contains several percent copper as azurite and chalcocite. This was the only prospect visited that showed any evidence of copper mineralization in sufficient amounts to be profitably mined.

The Gilbert and Stroud mine in the Happy Creek volcanic rocks in the south-central part of the area, although it contains some copper, is reported by local residents to have been operated as a gold mine.

The prospect on a copper-bearing quartz vein in the King Lear formation on the east side of Navajo Peak is evidence that at least part of the copper deposits are post-Early Cretaceous in age. The vein may be related to the Cretaceous diorite and if so would indicate that the copper deposits, which are younger than the iron deposits, are older than the quicksilver deposits. Some support for this idea is the fact that quartz veins are altogether lacking near the quicksilver deposits; however, quartz veins are nowhere abundant in the range and their absence near the quicksilver deposits may be of little significance.

QUICKSILVER DEPOSITS

The quicksilver deposits in the Bottle Creek district, which had only been known a few years when Roberts and Granger (Roberts, 1940) mapped them in 1939, became important producers during the Second World War. By the end of 1943 they had produced 4,544 flasks of quicksilver (Bailey and Phoenix, 1944, p. 80). Production declined after the war, and ceased altogether in 1947. The mines remained idle until late 1955, when the extraordinarily high price of mercury stimulated activity in most of the known quicksilver districts in the State. A mill was constructed for the purpose of upgrading low-grade material, and open-pit mining operations were begun at several of the old mines. In 1957 the mill was treating about 60 tons per day of material containing 2 to 5 pounds of quicksilver per ton and upgrading it by gravity concentration to about 20 percent mercury. The concentrates were fired in a *D* retort at Winnemucca.

The deposits occur for the most part as disseminated cinnabar in the diabase dikes, but there are some cinnabar-bearing fault zones in the rhyolite and pre-Tertiary rocks. Most of the early production from the district came from deposits in two of the diabase dikes. The recent production has been from the deeply weathered near-surface parts of the diabase dikes.

The quicksilver deposits seem to be of late Tertiary or younger age because some deposits are in faults that cut the rhyolite, the youngest Tertiary rock in the area.

GEOLOGIC HISTORY

In Permian time or earlier a thick section of andesitic to basaltic volcanic rocks accumulated in what is now the Jackson Mountains. Pillow lavas indicating subaqueous origin have been observed only in the upper part of the section. The flow breccias and tuffs are texturally much like the late Tertiary terrestrial volcanic rocks of northern Nevada. Perhaps a large proportion of these Permian or older volcanic rocks were of terrestrial origin.

The fusulinids and corals in the limestone in the lower part of the overlying Permian and Triassic unit show that marine deposition took place in the Permian; these conditions persisted throughout the Triassic and possibly into the Jurassic. The conglomerates in the lower part of the Permian and Triassic unit indicate the presence of upland areas somewhere in the vicinity and may reflect the Permian orogeny recognized in much of north-central Nevada.

The Permian and Triassic formations were intruded by diorite stocks in probably late Jurassic time, following which the rocks were subjected to low-grade regional metamorphism, as a part of which stretched-pebble conglomerates were produced and some folds developed. Following this period of metamorphism the area was uplifted and so extensively eroded that the Permian and Triassic sedimentary rocks were completely removed throughout much of the range before Early Cretaceous time. The iron deposits in the range were formed sometime during this interval and are related either to the diorite intrusive bodies or to the somewhat later regional metamorphism.

When the King Lear formation was deposited in Early Cretaceous time, considerable relief existed in the area and most of the high areas were underlain by the Happy Creek volcanic rocks or diorite. The rocks were again folded following the deposition of the King Lear formation. Diorite stocks may have intruded the King Lear shortly after its deposition or they may be part of the Late Cretaceous or early Tertiary period of igneous activity in which the granodiorite was emplaced. The copper deposits may have been formed following the intrusion of the diorite, or they may be of Tertiary age. Uplift and extensive erosion followed deposition of the King Lear, so that when the Pansy Lee conglomerate was deposited much of the King Lear formation had been removed and the relief in the area was low.

Before the end of the deposition of the Pansy Lee the local relief had disappeared and all the material contributed to it was brought in from considerable distance.

The Deer Creek thrust fault developed after the deposition of the Pansy Lee conglomerate. The age of the thrust with respect to the granodiorite intrusive is unknown, the granodiorite probably post-dates the thrust. The formation of the thrust can be regarded as the culminating phases of the Late Cretaceous and possibly early Tertiary orogeny and the granodiorite is probably a post-orogenic intrusive.

Sometime prior to middle Miocene time the rocks were intruded by dacite porphyry and microdacite stocks and dikes, following which a thick section of dacitic to rhyolitic flows, flow breccias, and tuffs accumulated. A thick section of tuffs of rhyolite to quartz latite composition is probably younger than the dacitic flows. These rocks were partly eroded to produce the Tertiary conglomerate.

In middle Miocene to early Pliocene time basalt with interlayered fine-grained clastic sedimentary rocks accumulated all around what is now the Jackson Mountains. The complete absence of basalt in the upland areas of the range suggests that the range was a positive area when the basalt was extruded, but late Tertiary erosion could also explain its absence.

The range had begun to take shape by displacement on high-angle faults at least as early as the period between the extrusion of the basalt and the younger rhyolite. After the extrusion of the rhyolite, continued movement of the faults took place, diabase dikes were intruded, and quicksilver was deposited in the diabase dikes and some fault zones.

Gravel mounds in the southern part of the range accumulated, probably as alluvial fans, in early Quaternary time. Continued displacement on the faults obliterated the physiographic features that controlled the formation of these old fans. This displacement was followed by the deposition of the present range-front fans, and later the water of Lake Lahontan occupied the basins on both sides of the range, cut terraces in the fans, and otherwise reworked the fan material. Fine-grained sediments accumulated in Lake Lahontan, and following or accompanying its desiccation the alluvial fans were dissected and the stream channels were filled with younger alluvium.

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INDEX

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