Apartment 3
545 Madison
Eugene, Oregon
December 2, 1959

Mr. Robert R. Coats
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California

Dear Mr. Coats:

I am in the process of completing a Master's degree in Geology at the University of Oregon. The area chosen for the thesis topic is in the Elk Mountains which are located adjacent to the Nevada-Idaho state line, about 20 miles east of Jarbidge, Nevada. I have been mapping in this area for part of the last two summers. Dr. Shotwell, vertebrate paleontologist at the University of Oregon, suggested that I write Harold Malde for information concerning the welded tuffs which occur in the northern Nevada-southern Idaho area. Accompanying my communication with Dr. Malde was the brief sketch of the Tertiary rocks in the thesis area which I am enclosing for your information.

In his replying letter (which you have a copy of), Malde suggested that I write you for information about the Tertiary sequence in the Jarbidge and Mountain City quadrangles. There appears to be considerable question about the age and correlation of the vitric tuffs and welded tuffs indicated in the Elk Mountain section. I agree with Malde that correlation of the vitric tuffs with the entire Humboldt formation is not sound. Apparently the Humboldt formation as described by Sharp (Jour. Geol., v. 47, p. 133-160) is divisible into many units of varying ages. It would have been better to correlate on the basis of the vitric tuff unit described by Van Houten (Bull. Amer. Assoc, Petrol. Geol., v. 70, p. 552-558). Van Houten assigns a late Miocene to medial Pliocene age to the vitric tuff unit and believes that this unit is the same as those rocks in the middle part of the Humboldt formation. He also intimates that the limestone in the lower part of the Humboldt is probably of Oligocene or early Miocene age. Lovejoy assigns a late Miocene age to the vitric tuffs and welded tuffs exposed in the Lone Mountain area, about 22 miles north of Elko, Nevada. According to Lovejoy the vitric tuffs exposed at Lone Mountain are correlative with the vitric tuff unit of Van Houten. Malde indicates that similar rocks in the Goose Creek Mountains, southern Idaho, are dated early to medial Pliocene. I did not find fossils in the vitric tuffs of the Elk Mountains; therefore, I am forced into correlating these rocks on the basis of lithology.

I believe these rocks are of the age indicated by Lovejoy. A Barstovian age for these rocks is further confirmed by the Clarendonian mammals in the Poison Creek formation as indicated by Malde.

The welded tuffs above the vitric tuffs are distinctive and should be of use in lithologic correlation. Have you noted a similar sequence of Tertiary rocks in the Jarbidge and Mountain City quadrangles? The younger rhyolite described by Schrader appears to be dominantly welded tuffs, but as these rocks thicken towards the northwest, or towards the Snake River plains, they may include silicic flows. I am particularly interested in the medial Miocene age applied by Stirton to the tuffs beneath the older rhyolite of Schrader. Any information you may be able to furnish me will not be quoted or paraphrased in published material, but shall be used only for this thesis which I am planning to complete by February 1, 1960.

The pre-Tertiary sedimentary rocks of the Elk Mountains may also be of interest to you. These rocks include Upper Cambrian limestones equivalant to the Windfall formation, and Ordovician limestones and quartzites which may be correlative to the Pogonip group and the Eureka quartzite. Trilobites from the Cambrian limestones are dated as Trempealeaun by A. R. Palmer, U. S. Geological Survey. Thrust faults and rocks of the western, eugeosynclinal assemblage (Roberts, Ferguson, Holtz, and Gilluly) were not observed.

Yours truly,

Nelson B Higgs

Nelson B. Higgs

Rock Type	Age	Description
Welded tuff (Younger Rhyolite of Schrader)	Early to medial Pliocene (?)	Two to seven units of welded tuff. A welded tuff unit is usually characterized as follows. Top of unit: Aphanitic, glassy welded tuff with tyachytic structure. Glass shards present. Middle of unit: Porcelaneous, porphyritic welded tuff with pronounced trachytic structure. Phenocrysts are sodic-andesine and quartz. Groundmass is dominantly fluidal glass and tridymite. Discrete glass shards not observed. Gradational into highly vesicular, aphanitic, glassy welded tuff at base. Bottom of unit: Variable. Rhyolite vitrophyre, spherulitic obsidian, or perlite. Rhyolite vitrophyre is predominant and has phenocrysts of aegerine-augite, quartz, and andesine. Tridymite and fluidal glass in groundmass.
Conformable		
Vitritic tuff (Equivalant to Humboldt formation)	Late Miocene to early Pliocene	Stratified vitric tuff with intercalated yellow to green stratified sandstone and massive buff siltstone.
Unconformity		
Rhyolite (Old Rhyolite of Schrader)	Miocene	Porphyritic rhyolite with hyalopilitic groundmass. Phenocrysts are sanidine, quartz, and calcic-oligoclase.
Unconformity		
Pre-Tertiary		

November 20, 1959

Mr. Nelson B. Higgs
545 Madison, Apartment 3
Eugene, Oregon

Dear Mr. Higgs:

I appreciate your letter describing the rocks in the Elk Mountains, Nevada, and am glad to have this information. Where I have worked with Howard A. Powers between Twin Falls, and Mountain Home, Idaho, the oldest rock unit is silicic latite occurring mainly as welded tuff, but including some bedded vitric tuff and lava flows, correlative with the younger rhyolite of Schrader. Thus, even though our reconnaissance includes observations of older rocks at margins of the Snake River Plain, the only formation we have studied in detail that can be correlated with the Elk Mountains is the silicic latite. In a report now in preparation, this rock unit is included in a regional formation named the Shoshone volcanics.

The Shoshone volcanics of the western Snake River Plain seem to resemble mineralogically the welded tuff in the Elk Mountains except that grains of quartz are rare and these probably occur as xenocrysts rather than as phenocrysts. These volcanics are usually porphyritic with phenocrysts of andesine, clinopyroxene, hypersthene, zircon, and magnetite, but with no sanidine, hornblende, or biotite. Similar mineralogy for tuffs at the top of the volcanic sequence in the Jarbidge and Mountain City quadrangles, Nevada, has been found by Robert R. Coats, U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California. The volcanic sequence at Jarbidge is closely parallel to that in the Elk Mountains, but includes some older Tertiary volcanics. Rather than paraphrase what Coats has reported in correspondence, I suggest that you obtain his latest views by writing direct.

Another area where rocks probably related to those in the Elk Mountains have been studied is Carlin, Nevada, an area described by J. P. M. Regnier in a Columbia University Ph. D. thesis dated 1958.

Rock Type	Age	Description
Welded Tuff (Younger rhyolite of Schrader)	Early to medial Pliocene (?)	Two to seven units of welded tuff. A welded tuff unit is usually characterized as follows: Top of unit: Aphanitic, glassy welded tuff with trachytic structure. Glass shards present. Middle of unit: Porcelaneous, porphyritic welded tuff with pronounced trachytic structure. Phenocrysts are sodic-andesine and quartz. Groundmass is dominantly fluidal glass and tridymite. Discrete glass shards not observed. Gradational into highly vesicular, aphanitic, glassy welded tuff at base. Bottom of unit: Variable. Rhyolite vitrophyre, spherulitic obsidian, or perlite. Rhyolite vitrophyre is predominant and has phenocrysts of aegerine-augite, quartz, and andesine. Tridymite and fluidal glass in groundmass.
Conformable		
Vitric tuff (Equivalant to Humboldt formation)	Late Miocene to early Pliocene	Stratified vitric tuff with intercalated yellow to green stratified sandstone and massive buff siltstone.
Unconformity		
Rhyolite (Old Rhyolite of Schrader)	Miocene	Porphyritic rhyolite with hyalopilitic groundmass. Phenocrysts are sanidine, quartz, and calcic-oligoclase.
Unconformity		
Pre-Tertiary		

545 Madison, Apartment 3
Eugene, Oregon
November 16, 1959

Harold E. Malde
U. S. Geological Survey
Denver Federal Center
Denver, Colorado

Dear Dr. Malde:

I am in the process of completing a Master's degree in Geology at the University of Oregon. The area chosen for the thesis topic is in the Elk Mountains which are located adjacent to the Nevada-Idaho state line, about twenty miles west of Contact, Nevada. Dr. Shotwell has informed me that you are mapping the Tertiary formations of southern Idaho, and thus may be of help to me in distinguishing and correlating the welded tuffs which occur in the northern Nevada-southern Idaho area. For your information I have included a brief sketch of the Tertiary rock types in my thesis area. The welded tuffs shown on the sketch were originally described as younger rhyolites by Schrader (1912) in his reconnassiance of the Jarbidge, Contact, and Elk Mountain mining districts.

Have you noted similar rocks in southern Idaho, and if so, do they have a like sequence and age? I am asking you for this information because the nearest location with similar rocks is that described by Mapel and Hail (1956) in the Goose Creek area which is approximately eighty miles from the thesis area. Because of the distance between these two areas, I would like to be able to quote some additional information. Any information you may be able to furnish me will not be quoted or paraphrased in published material, but shall be used only for this thesis which I am planning to complete by February 1, 1960.

Yours truly,

Nelson B. Higgs

Nelson B. Higgs

You have given rather specific age assignments to the rock units in the Elk Mountains, and I would very much like to have a summary of the evidence for the dates. Assigning the vitric tuff beneath the welded tuff to the late Miocene and early Pliocene is probably sound, but I have doubts about correlating this unit with the Humbolt formation. Fossils for dating the Humbolt formation are not very abundant, but Dwight W. Taylor of the U. S. Geological Survey regards some mollusks collected from limestone low in the Humbolt near Twin Bridges on Huntington Creek as probably Oligocene, but possibly of late Eocene or early Miocene age. On the other hand, plant fossils from the uppermost part of a tuff at Copper Basin, Nevada (beneath the old rhyolite of Schrader) are dated by D. I. Axelrod (Geol. Soc. Am. Bull., v. 68, p. 28) as late Barstovian or early Clarendonian, and, according to Coats, mammals from this tuff in the Mountain City quadrangle are dated by R. A. Stirton as middle Miocene. Fossils from higher in the volcanic sequence are hard to find. Plant fossils from vitric tuff at Jarbidge (probably equivalent to the vitric tuff in the Elk Mountains) are dated as upper Miocene by R. W. Brown, but as middle Pliocene by Axelrod. Diatoms collected in the Goose Creek Mountains from the lowest exposed beds of tuff (probably equivalent to the welded tuff in the Elk Mountains) are dated by K. E. Lohman as early Pliocene, whereas mollusks and mammals from somewhat higher in this tuff are dated by D. W. Taylor and G. E. Lewis as middle Pliocene. The Shoshone volcanics at Jump Creek and Reynolds Creek, Idaho, are overlain by the Poison Creek formation that contains Clarendonian mammals. Any fossils from the Elk Mountains would be a valuable supplement to this meager record.

I would appreciate being kept advised of the progress of your work in the Elk Mountains.

Sincerely yours,

Harold E. Malde, Geologist
Engineering Geology Branch

opy to: J. A. Shotwell
R. R. Coats (w/letter from Higgs)
EGB, Denver
DRF
EGB, Wash.
Chron.
Powers
Malde

Branch of Mineral Deposits

December 3, 1959

Mr. Nelson B. Higgs
Apartment #3
545 Madison
Eugene, Oregon

Dear Mr. Higgs:

Thank you very much for the information in your letter of December 2. I am interested in your work in the Elk Mountains, and would like to see a copy of your thesis when it is completed.

The age of the "vitric tuff unit" is, as you say, probably Late Miocene to early Pliocene. A very small flora (two species) was identified by R. W. Brown as Upper Miocene. Kenneth Lohmann identified the diatoms as "early Pliocene or possibly late Miocene, with a preference for early Pliocene". These beds I am calling the Jenny Creek tuff, after exposures near the junction of Jenny and Jack Creeks, in the Jarbidge quadrangle.

The welded tuff unit (Shoshone volcanics of Malde and Powers) I am calling the Cougar Point volcanics. I have seen no aegirine-augite in it. Axelrod (personal communication, July, 1959) says that the Cougar Point tuff is underlain conformably by the Trapper Creek (late Miocene), ~~and~~ in the Goose Creek area, and overlain by Lower Pliocene Humboldt south of Contact. I cannot put the Cougar Point very high in the Pliocene, because it is overlain unconformably by the Banbury formation in the Jarbidge quadrangle.

Both Axelrod (personal comm.) and Stirton, now call equivalent(?) beds under the Jarbidge rhyolite middle Miocene. This would suggest that the Jarbidge is late middle or early upper Miocene. The beds that furnish the leaves to Axelrod and those from which the vertebrates come that Stirton identified are separated by some distance, and are not quite identical lithologically, but both are unconformably beneath the Jarbidge.

It looks as if the "Humboldt formation" of King represents a facies, lacustrine and fluviatile, elsewhere represented in part by tuffs and in part by welded tuffs. It has been used for rocks of such a wide range of ages that correlating with the "Humboldt" does not give the reader much information.

Sincerely yours,

Robert R. Coats
Geologist

Directors' reading file

Coats

RRC:rdh

545 Madison
Eugene, Oregon
May 23, 1960

Mr. Robert R. Coats
Minerals Deposits Branch
U. S. Geological Survey
345 Middlefield Road
Menlo Park, California

Dear Mr. Coats:

Thank you for the information on the Tertiary rocks of the Jarbidge quadrangle. The information furnished by you aided greatly in dating and correlating the Tertiary rocks of the Elk Mountains. I apologize for not answering you letter of December 3 sooner, but have delayed in writing you until completing my thesis.

In your letter you asked to see a copy of the completed thesis. I am sorry I cannot forward you a copy as only four copies were made. Enclosed is an extra copy of Plate 1 of the thesis which may be informative.

My thesis describes the rocks of the southeastern part of the Jarbidge 1 quadrangle (Elk Mountains). Adjacent theses areas were also mapped by Donald E. Mathias and H. Clay Fifer. The location of their theses areas is indicated upon Plate 1. The theses will be available for interlibrary loan by the fall of 1960.

The welded tuffs mapped are quartz latites on the basis of phenocryst percentages. These rocks do not contain aegerine-augite. The mafic minerals are hypersthene and augite (pigeonite ?).

Sincerely yours,

Nelson B. Higgs

Nelson B. Higgs

Branch of Mineral Deposits

June 6, 1960

Mr. Nelson B. Higgs
545 Madison
Eugene, Oregon

Dear Mr. Higgs:

Thank you very much for your kindness in sending me the copy of the map of your thesis area (now called the Elk Mountain quadrangle).

I shall look forward to reading your thesis when it can be borrowed.

I note that you show no fossil localities, although you mention fossils in your letter to Malde. Were these in one of the other thesis areas? It would be desirable to have these indicated on the maps, if possible. The post-Jarbidge and pre-Shoshone tuffs are apparently more extensive in your area than in the Jarbidge quadrangle. Do you know whether there is a prospect of other University of Oregon theses being done in this general area?

Have you any plans for publication?

Sincerely yours,

Robert R. Coats
Geologist

Director's reading file

Coats ✓

RRC:sws

Higgs, N. B. Geology of the southeastern part of the Jarbidge 1 quadrangle. Univ. Ore. M.S. Thesis 1968

1920 0011

ABSTRACT

About 54 square miles in the southeast part of the Jarbidge 1 quadrangle, Elko County, Nevada, was mapped geologically by the writer during the summers of 1958 and 1959.

The oldest rocks exposed in the area are Upper Cambrian limestones correlative with the Windfall formation of Trempealeauan age. The limestones, which are about 1300 feet thick, are light-gray to black, laminated to thin-bedded, and contain nodules and layers of chert in the lower part. The limestones accumulated under quiet-water conditions in the miogeosynclinal environment of sedimentation.

Intruded into the Cambrian limestones are granitic rocks of probable Cretaceous age. The intrusion is a stock which consists predominantly of granodiorite, but also includes aplite dikes and porphyritic quartz monzonite. During the emplacement of the intrusion, the limestones were bowed into a dome, and now these stratified rocks dip away from the intrusion in a quaquaversal manner.

Unconformably overlying the Paleozoic and Mesozoic rocks are rhyolite flows of Miocene age. The rhyolite is, in turn, unconformably overlain by stratified vitric volcanic ash and welded tuffs of Miocene and/or Pliocene (?) age. The stratified vitric volcanic ash contains interbeds of stratified tuffaceous sandstone and massive tuffaceous mudstone. Within the area, the stratified vitric volcanic ash and the welded tuffs are conformable, and in places the welded tuffs are intercalated within the upper parts of this deposit. Fragmental dikes that are genetically related to the welded tuffs were observed.

Rocks of Miocene and Miocene and/or Pliocene (?) age are displaced by normal faults which trend towards the northeast. The range front normal fault, which separates Cambrian limestones from late Tertiary rocks, is the largest fault in the area. Movement along this fault probably started during the emplacement of the Cretaceous(?) intrusion and has recurred through late Tertiary time.

The possible economic metalliferous deposits of the area are confined to the contact metamorphic zone bordering the granitic intrusion. Tungsten and molybdenum mineralization in yet undetermined quantities exists here. However, at present these metals are not being mined. Igneous rocks and stream gravels in the area can be utilized for road rock.

during the Antler orogeny of latest Devonian to early Pennsylvanian age. These authors indicate that thrusted rocks of the western assemblage are present in the Centennial and Independence Ranges, approximately 60 to 80 miles to the west and southwest of the Jarbidge 1 quadrangle. Shales of Ordovician Vinini formation (western assemblage) crop out north of Deeth, Nevada, and are described by Granger, Bell, Simmons, and Lee (1957, p. 9). Petrological and faunal characteristics indicate that the limestones within the thesis area are miogeosynclinal and represent deposits of the eastern assemblage.

Paleozoic rocks younger than Cambrian have been reported in areas to the south, north, and east of the mapped area. These rocks are predominantly carbonates and probably represent either the eastern assemblage of Roberts et al., or the cyclic clastic sediments described by Dott (1955 and 1958). Mathias (1959, p. 40) reports rocks equivalent to the Eureka quartzite in the area to the north of the thesis area. Schrader (1912, p. 105) measured a 1600-foot sequence of Carboniferous shales, limestones, and quartzites in the Contact quadrangle adjacent to the Jarbidge 1 quadrangle on the east. In the Cassia Mountain region, Twin Falls and Cassia counties, Idaho, Youngquist and Haegele (1956, p. 8-12) describe 2883 feet of Permian and 1121 feet of Ordovician marine sediments consisting predominantly of carbonate rocks, but including some quartzites. The Ordovician rocks were tentatively considered by these authors to be an extension of the Pogonip limestone, and they suggest that the total marine sedimentary rock section in this region may amount to as much as 8000 to 10,000 feet. The Cassia Mountains are about 40 miles northeast of the thesis area. Clark (1957, p. 2203-2204) reports Permian chert and limestones in contact with Lower Triassic rocks at O'Neil Pass (along the O'Neil ranch road), about four miles southeast of the thesis area. The thickness or extent of the Permian rocks was not indicated. Pickard (1955, p. 1042), and Pickard and Wise (1956, p. 1310) indicate that Gulf Oil Corporation stopped drilling in Mississippian or Devonian rocks in wells east of Wilkins, Nevada; north of Wells, Nevada; and near Mary's River ranch, north of Deeth, Nevada. The age or type of rocks in which these wells were started was not indicated. The shallowest of these wells in the north Deeth Basin was 5465 feet.

The presence of Paleozoic rocks younger that Cambrian in adjacent areas indicates the possibility that they were present at one time in the mapped area but are now missing because of erosion. The removal of these rocks is attributed to uplift caused by the Antler orogeny of latest Devonian to early Pennsylvanian age (Roberts, et al., p. 2850) and/or by uplift of the Cretaceous(?) granitic stock in the thesis area. Deformation of the Cambrian rocks in the mapped area is related to the granitic stock; therefore, the later period of uplift and erosion is believed to be the more significant.

Cambrian limestones:

Distribution and thickness: Upper Cambrian limestones equivalent to the Windfall formation are exposed on Mahogany Elephant Butte and on the northern flank of White Elephant Butte where these rocks are in contact with the granitic intrusive. Small outcrops of the Cambrian limestones are also present on the south flank of White Elephant Butte near the intrusive contact. Equivalent rocks were also mapped by Fifer (1960, Pl. 1) and Mathias (1959, Pl. 1) on Red Elephant Butte, Pearson Mountain, and Quartzite Butte.

About 1300 feet of the limestones are exposed on the southwest flank of Mahogany Elephant Butte. A thicker section of the limestones may be present on the northern side of this mountain; however, measurements were not taken at this site.

Stratigraphic relations: The lower parts of the Cambrian limestones are cut by granitic intrusive rocks of probable Cretaceous age. The limestones have been bowed into a dome and dip away from the intrusion in a quaquaversal manner. The exposed rocks are successively younger away from the intrusion. According to Mathias (1959), the Trempealeauan Windfall limestones are in unconformable contact with rocks of the Ordovician Eureka quartzite on Quartzite Butte. Quartzite Butte is about three miles north of the nearest intrusive contact on White Elephant Butte.

Petrology and petrography: The limestones exposed on the southwestern and eastern flanks of Mahogany Elephant Butte are divisible into three types: (1) laminated to thin-bedded, light-gray to black limestone with layers and nodules of chert, (2) laminated to thin-bedded, light-gray to black limestone without chert, and (3) laminated to thinly laminated, dark-gray to black limestone which weathers dark yellowish-brown to light-gray and contains pink and yellowish-brown, papery limestone interbeds. The chert-bearing limestone is exposed chiefly near the bottom of the southwest slope of Mahogany Elephant Butte and on the southeast side of this mountain. The limestone with pink and yellowish-brown interbeds crops out on and near the summit of Mahogany Elephant Butte (Pl. 3, fig. 2). The light-gray to black limestone which does not contain chert is exposed between the other limestone types on the southwest flank of Mahogany Elephant Butte. This limestone is also exposed on the northeastern flank of this mountain.

A section of the limestones was measured on the southwest slope of Mahogany Elephant Butte from the summit to the draw between it and White Elephant Butte. Some of the limestones have been recrystallized and altered during the emplacement of the intrusion. A description of these limestones is given in the section on metamorphism of the limestones. The measured section, which is based on the characteristics of the unaltered limestones, is presented below. The contacts between units are gradational.

Section of limestones, southwest flank of Mahogany Elephant Butte.

Unit No.	Description	Feet
3	Limestone, dark-gray to black, weathering light-gray to dark yellowish-brown, laminated to thinly laminated, platy to flaggy; contains pink and yellowish-brown, papery, thinly laminated limestone interbeds that are randomly distributed.	25-50

through some of the nodules and (2) the layered chert contains areas of unreplaced calcite.

Insoluble residues were obtained from three samples of unit two, and one residue each from units one and three. The percentages of insoluble residue obtained are: unit one, 29 percent; unit two, 11, 36, and 23 percent; and unit three, 44 percent. The residues contain microcrystalline quartz, muscovite and/or illite, pyrite, and black organic matter. Quantitative analyses were not made; however, the microcrystalline quartz and black organic matter predominate.

The microcrystalline quartz is present as aggregates of weakly polarizing, interlocking quartz grains. Individual interlocking quartz particles are anhedral with denticulate margins and contain inclusions of black and isotropic organic matter. The inference from these features is that the microcrystalline quartz is not detrital. It is believed to be formed by diagenetic changes prior to complete lithification. A diagenetic origin for quartz is further indicated by the presence of the black organic material as inclusions within the quartz.

The pyrite contained in these units is considered to be of sedimentary origin. It consists of aggregates of microcrystalline euhedral pyrite and is distributed throughout a bed. Pyrite formed by emanations from the intrusion is not in aggregates, is not dispersed throughout a bed, and has contact metamorphic minerals associated with it.

The difference between small grains of illite and muscovite is not easily determined with the petrographic microscope. According to Pettijohn

(1957, p. 667-668), montmorillinite and, to a lesser extent, kaolinite are converted to authigenic clay mica which is known as illite. The alteration is achieved by reaction by potassium-bearing sea water with clay minerals. Potassium is preferentially fixed in the lattice of hydromica. Because of this genesis of illite, it is thought that illite is the clay mineral present.

Thin sections and etch sections of the limestones were examined utilizing the parameters postulated by Bramkamp and Powers (1959, p. 1305-1317) in their carbonate rock classification. This classification, which is presented on Table 2, is derived from a consideration of the parameters; particle size, type of clastic fragment, and recrystallization. Under particle size are included clay- and silt-size calcilutite grains, sand-size calcarenite grains, and greater that sand-size calcirudite grains. Clastic fragments include five types: (1) fragments of older carbonate rocks, (2) fossils, (3) oolites and pisolites, (4) pellets, and (5) terrigenous elements such as clay and quartz. The clastic fragments may range in size from calcilutite to calcirudite. Based upon the original particle size carbonate rocks can be divided into the four main groups depicted upon the carbonate rock classification table (column two of Table 2): fine-grained limestone, calcarenitic limestone, calcarenite, and coarse carbonate clastic. The percentages and size of the constituent particles within each limestone group are indicated within column three of the table. The main limestone groups may be further divided into various carbonate facies dependent upon the limestone group and the percentage and type of impurities (column four of Table 2).

Calcarenite and coarse carbonate clastic rocks are current-washed deposits, because currents were strong enough to transport sand-size and larger clastic fragments and to winnow away fine-grained matrix. Conversely, fine-grained and calcarenitic limestones indicate quiet-water conditions because currents were not strong enough to winnow away the fine-grained constituents.

The original carbonate sedimentary texture may be altered by two processes: (1) recrystallization alone without change in composition, or (2) recrystallization by dolomitization. Dependent upon the intensity of recrystallization and/or dolomitization, the original sedimentary texture may be divided into four types: (1) unaltered sedimentary texture, (2) moderately altered sedimentary texture, (3) strongly altered sedimentary texture, and (4) obliterated sedimentary texture. Dolomitization, as considered by these authors, indicates replacement of calcite by dolomite, rather than primary precipitation of dolomite.

Staining of specimens with copper nitrate solution and tests with dilute hydrochloric acid indicate that dolomite is present in amounts less than ten percent. Therefore, only the textures shown by columns four, five, and seven of the classification table are applicable to the limestones under consideration.

Limestones with a strongly altered texture are usually granoblastic, whereas limestones with a moderately altered texture have been recrystallized to a poorly developed or patchy mosaic. According to Bramkamp and Powers, the limited degree of recrystallization of rocks with a moderately altered texture does not interfere with the recognition of the original texture.

The recrystallized textures outlined by these authors are applicable to the limestones within the thesis area, as a large part of these rocks have been altered and recrystallized during the emplacement of the granitic stock. The limestones of the measured section, particularly those of unit one, have both strongly and moderately altered textures. Samples from units two and three on the north side of Mahogany Elephant Butte (farther away from the intrusion) were moderately altered or unaltered and are of use in classification. Examination of all the sections with moderately altered or unaltered textures indicates that the limestones within units two and three are either impure fine-grained limestone, or impure calcarenitic limestone. A photomicrograph of a sample from unit two, which is representative of the impure fine-grained limestone, is shown on Plate 4, figure 1.

The parts of unit one which contain flat pebble conglomerate may be a calcarenite, but a precise designation could not be made because of metamorphic recrystallization. The dominant carbonate type within this unit is believed to be impure fine-grained limestone. Examination of less altered areas within thin sections from this unit shows fine-grained impurities which should have been winnowed away if the limestone were a current-washed deposit. Because of the limited variation in texture and the small size of the particles in the fine-grained limestones, it was extremely difficult to determine whether they resulted from abrasion and transportation or direct chemical or biochemical precipitation. Formation of the limestones by chemical or biochemical precipitation is believed to be the origin of these strata.

Impure fine-grained and impure calcarenitic limestone indicates quiet-water deposition. However, the depth of water cannot be estimated. Bramkamp and Powers state that quiet-water deposits can accumulate in sheltered areas near shore or depths farther basinward. The writer believes that the limestones mapped accumulated in shallow water (less than 600 feet in depth). Bases for this contention are:

1. The presence of flat pebble conglomerates in unit one. Krumbein and Sloss (1955, p. 127) in discussing the intraformational conglomerates found in limestones state:

> It is believed that thin layers of lime mud, lithified by cementation or exposure above tide level, may be broken and slightly shifted during storms, to produce a layer of angular fragments incorporated in muds which accumulated on the surface later.

2. Mathias (1959, p. 33-35) observed ripple marks in limestone equivalent to unit three, but stratigraphically higher in the Windfall formation. Based upon this observation, he also concluded that the limestones were deposited in shallow water.

3. The trilobites present are of mixed stock; a conaspid stock derived from the cratonal environment and an olenid stock from the eugeosynclinal environment. Intermixture of these two faunas is an indication of a miogeosynclinal environment according to Lochman-Balk and Wilson (1958, p. 334). These authors indicate that shallow water and low pressures are common in the miogeosynclinal environment.

4. An isopachous map prepared by Palmer (1956, p. 668) shows a northeast to southwest depositional trough for Middle and Upper Cambrian rocks in eastern Nevada and western Utah. The axis of the trough passes

through the central part of the state line between Nevada and Utah. According to the isopachous map, the Middle and Upper Cambrian formations thin towards the northwest, that is towards the Elk Mountains. Presumably shallow water deposition is more probable on the margins of a depositional basin.

5. The mapped limestones have been correlated with the Windfall formation. The Dunderburg formation which underlies the Windfall formation in the Eureka area is considered to be detrital by Palmer (1956). The fauna zone of the Dunderburg is missing from the type Upper Cambrian section in Wisconsin (Lochman-Balk and Wilson, p. 333). These authors believe there was a cratonal uplift during Dunderburg time, and clastics were derived from the craton. Shallowing of the seas during deposition of the underlying formation at least implies transgressive seas during deposition of the Windfall formation.

In summary, the limestones exposed in the mapped area accumulated under quiet-water conditions. The limestones may be shallow-water deposits formed on lime-mud banks as chemical or biochemical precipitates.

Age and correlation: The limestones of the Elk Mountains have been assigned a late Cambrian, Trempealeauan, age by Palmer (U. S. Geological Survey, written communication, 1958) on the basis of trilobites considered diagnostic of the Saukia faunizone in Nevada. Palmer tentatively correlated these limestones with the Windfall formation. According to Palmer (op cit., written communication), the nearest Cambrian outcrop with Windfall equivalent beds is in the Cherry Creek area, southern Elko County, approximately 100 miles to the south of the Elk Mountains.

The trilobites identified by Palmer were collected by Mathias (1959) from fossil zones on Pearson Mountain (northern part of Plate 1), Quartzite Butte (about one mile north of Pearson Mountain), and the ridge between the Middle and South Forks of Lime Creek (northwest part of Plate 1). Palmer's report on the trilobites identified is given below. The localities where Mathias collected these specimens are also indicated below within parentheses.

EN-1 Olenid cf. Plicatolina, but with large pygidium. (Pearson Mountain)

EN-2 Saukid - indicating this collection to be Trempealeau in age. (Pearson Mountain)

818-03MS, A-C - All specimens seem to be of an indeterminate olenid, perhaps the same as that of EN-1, with a large pygidium. (Pearson Mountain)

CuM-1 - thorax of a Eurekia?? - perhaps Trempealeau age. (ridge between Middle and South Forks of Lime Creek)

K-3 - pygidium of a Eureka or closely related trilobite - Trempealeau age. (Quartzite Butte)

The trilobites collected on Pearson Mountain are from a fossil zone within the yellowish-brown, platy limestones cropping out halfway up the south slope of the mountain (between the 7200 and 7400 foot contours). Indeterminate trilobites were also collected by the author from the limestones of unit two on the northeast side of Mahogany Elephant Butte. As shown by cross-section C-C', Plate 1, the limestones of Mahogany Elephant and White Elephant buttes dip away from the intrusion and are successively younger towards the fossil zone on Pearson Mountain; therefore, by stratigraphic position these limestones are older than the rocks from which fossils of Trempealeauan age were collected. However, the limestones exposed on the north side of Mahogany Elephant Butte also crop out on the lower part of Pearson Mountain because the canyon walls of Lime Creek rise above this stream at an average angle of about 27 degrees, or at an angle greater that the 10°-20° dip of the limestones exposed on these mountains. The limestones of Mahogany Elephant Butte are therefore considered to be of late Cambrian age and as portions of these limestones also crop out on the lower part of Pearson Mountain these rocks are included within the Windfall formation.

The trilobites identified by Palmer include Eurekia, which has also been described from the type Upper Cambrian section in Wisconsin. Associated with Eurekia are trilobites of the olenid stock (cf. Plicatolina). Lochman-Balk and Wilson (1958, p. 334) believe that Eurekia belonging to the conaspid stock has cratonal affinities; whereas trilobites of the olenid stock are representative of a eugeosynclinal environment. Intermixture of these two faunas reflects an environment that is transitional between the eugeosynclinal and cratonic positions. This transitional intermediate environment, according to these authors, is characteristic of the miogeosyncline. On the basis of the contained fauna, the limestones indigenous to the Elk Mountains are therefore assigned to the miogeosynclinal environment of sedimentation.

Metamorphism of limestones: An aureole of contact metamorphic rocks has been formed by the intrusion of Cretaceous(?) granitic rocks into the Cambrian limestones. Included within the term "contact metamorphic" are contact metasomatic, pyrometamorphic, and contact pneumatolytic deposits.

birefringence of the scapolite indicates a composition that is intermediate between the marialite and meionite end members.

An unusual and interesting metamorphic feature is the occurrence of axinite within the limestones exposed on the southeast side of Mahogany Elephant Butte. The nearest intrusive contact is over 2000 feet from the axinite deposit. The axinite crystals are black and have the acute-edged crystal form which is characteristic of this mineral. The crystals, which are randomly oriented near or at the bedding planes of the limestones, are of uniform size with a maximum dimension of 4 mm. Axinite is regarded as a pneumatolytic mineral by Tyrell (1926, p. 324).

The strongly and moderately altered textures used by Bramkamp and Powers (Table 2) can be applied to the recrystallized limestones near the intrusion. The limestones along a southwest to northeast traverse from the intrusive contact on White Elephant Butte to the top of Mahogany Elephant Butte, a distance of about one mile, have strongly altered, moderately altered, and unaltered textures. Strongly recrystallized limestone occurs along the contact with the granitic rocks on White Elephant Butte. Quartz, tremolite, epidote, and some garnet are dispersed throughout the coarsely crystalline limestone. In some samples the calcite grains are arranged in an equigranular granoblastic mosaic, whereas in others the calcite grains have irregular margins and tend to form interlocking complexly sutured aggregates.

On the lower part of the southwest side of Mahogany Elephant Butte, metamorphism has decreased until strongly recrystallized limestones

Mesozoic Rocks

General statement: Mesozoic rocks within the area consist of a Cretaceous(?) granodiorite stock with associated aplite dikes and porphyritic quartz monzonite.

Marine Lower Triassic rocks crop out along the O'Neil ranch road approximately four miles southeast of the mapped area. These rocks have been described by Clark (1957, p. 2203-2204) and include "...(1) a lower shaly and conglomerate interval, (2) a middle shaly part which is structurally complex, and (3) an upper limestone part..." The lower interval is in contact with Permian limestone and chert. According to Clark, the Triassic section is about 1000 feet thick and contains Neoprioniodus bransomi Müller and Gondollela spp. (conodonts found in the Meekoceras zone). The proximity of the Lower Triassic rocks to the area indicates that these rocks were present at one time at what is now the site of the Elk Mountains. These rocks may underlie the Tertiary rhyolitic extrusives.

Cretaceous(?) granitic rocks:

Distribution and intrusive relations: The Cambrian limestones have been intruded by a granitic magma which formed the granodiorite stock that is partially exposed on the southern flanks of White Elephant and Red Elephant buttes. The exposed part of the stock is ovate with a maximum east-west dimension of about 3.5 miles. Fifer (1960) describes the part of the stock cropping out on, and south of Red Elephant Butte.

The part of the stock exposed on White Elephant Butte (Pl. 6, fig. 2) has a map distribution of about 1.5 square miles and is depicted on Plate 1.

The contact of the granitic rocks with the limestone, where observed, is sharp; there is little evidence of metasomatic granitization. The contacts of the intrusive are irregular and small apophyses project outward from the stock in many places. Figure 1, Plate 6 illustrates a small sill and dike intruding limestone at the contact. The intrusion is believed to be steep-walled, as the dip of the contact between the limestones and granodiorite ranges from 40 to 60 degrees.

Petrology and petrography: The intrusion is predominantly a granodiorite, but it becomes more acidic in parts of the outer margins, where it has the composition of quartz monzonite because of the increase in the amount of orthoclase in the form of phenocrysts. The porphyritic quartz monzonite is considered to be a facies of the intrusion. This rock is not present throughout the intrusive margins, but is located only at the southern border of the intrusion near the Robinette prospect. Similar porphyritic rocks were observed by the writer at the western margin of the intrusion near the West Fork of O'Neil Creek, in the area described by Fifer.

The intrusion also has aplitic dikes and xenoliths associated with it. The mineralogic compositions of samples from the rock types present in the intrusion, including the xenoliths and dikes, are presented in Table 3. Modal analyses using the integrating stage were performed on all rock types indicated on the table except the porphyritic quartz monzonite.

In outcrop, the biotite-hornblende granodiorite is equigranular with hypidiomorphic minerals. The felsic minerals consist of cream to light-gray plagioclase, cream to pink orthoclase, and clear and white quartz. Mafic minerals consisting of black to brown biotite and black hornblende are scattered throughout the granodiorite. A representative exposure of the granodiorite is shown by Plate 7, figure 1.

Essential minerals of the granodiorite are orthoclase, plagioclase, quartz, biotite, and hornblende. Plagioclase is usually subhedral, and it is zoned. Some grains have a myrmekitic texture. Orthoclase is perthitic, and many of the grains are poikilitic with inclusions of biotite and hornblende. A few grains of the orthoclase are granophyric. Quartz is usually strained, and in a few places it is granulated. Biotite is brown and tabular and has been altered to chlorite, magnetite, and epidote. Hornblende is green and prismatic and has been partly altered to green biotite, magnetite, and chlorite (pennine). Euhedral sphene is present in amounts up to two percent. Feldspar has been altered to sericite and epidote. Euhedral apatite is included within quartz.

Dark xenoliths, most of which are only a few inches long, are common in the granodiorite and are most abundant within the first few yards from the contact between the limestone and granodiorite. The xenoliths are usually small ovate bodies (Pl. 10, fig. 2), but some are irregular and large, and measure as much as two and a half feet across the maximum dimension. The xenoliths are darker than the surrounding granodiorite because of the increase of biotite and hornblende as indicated in Table 3.

The xenoliths near the intrusive contact have a porphyritic texture with hornblende and plagioclase as phenocrysts. Xenoliths within the intrusion are usually equigranular. Hornblende is earlier than plagioclase, orthoclase, and quartz. Plagioclase is zoned. Orthoclase is poikilitic and includes plagioclase (not zoned), hornblende, and biotite. Hornblende is embayed by quartz. Biotite is abundant, and some of the grains have a subparallel arrangement. Sphene, zircon, and apatite are accessory minerals. Alteration minerals present in the xenoliths are chlorite, epidote, and sericite.

The writer was unable to determine whether the xenoliths are cognate or accidental. The xenoliths contain zoned plagioclase (Pl. 8, fig. 2) and according to Bowen (1947, p. 82-83), the presence of zoned plagioclase in a rock is evidence of an igneous origin. The xenoliths have been tentatively classified as hornblende-biotite quartz diorite and hornblende-biotite diorite on Table 3.

The quartz monzonite is porphyritic with phenocrysts of orthoclase (Pl. 7, fig. 2). The contact of the quartz monzonite with granodiorite is gradational. There is a decrease in the size and number of phenocrysts from the intrusive contact until the rock is no longer porphyritic, but has the equigranular texture of the granodiorite. Near the intrusive contact the phenocrysts are more than two inches in length. The white to flesh-red orthoclase phenocrysts are predominantly euhedral. Some of them are twinned according to the Carlsbad law. Xenoliths resembling those described in the granodiorite are present in parts of the quartz monzonite.

The groundmass of the quartz monzonite is similar to the granodiorite in composition and texture. Its minerals are hornblende, biotite, plagioclase, orthoclase, and quartz. Plagioclase is subhedral and zoned, and a few grains are myrmekitic. Altered hornblende is present as inclusions within some of the plagioclase grains. Hornblende and biotite are altered to epidote and chlorite.

The orthoclase phenocrysts are highly perthitic. Some of the orthoclase grains are granophyric. The orthoclase phenocrysts are late in the crystallization of the quartz monzonite. They contain inclusions of plagioclase, biotite, and hornblende (Pl. 9, fig. 1).

Aplite dikes are present within the stock (Pl. 10, fig. 1) and are associated with the granodiorite and the porphyritic quartz monzonite. They are particularly abundant near the outer margin of the intrusion. The dikes, which are white, light-gray, and pink, usually range from less than an inch to a few inches in width. However, some are wider than five feet.

The dike rocks have a fine-grained, allotriomorphic-granular texture and the composition of leuco-granite (Table 3). They are aplites. Quartz and perthitic orthoclase are present in nearly equal amounts. Plagioclase is essential, but subordinate to quartz and orthoclase. Biotite and muscovite each are present in amounts less than one percent. Plagioclase in the aplite is either calcic oligoclase or sodic andesine. Unlike the plagioclase in the granodiorite and quartz monzonite, this plagioclase is not zoned. Plagioclase is early, as it is embayed by orthoclase.

An examination of the contact between an aplite dike and the granodiorite in thin section shows that the contact between these rocks is sharp (Pl. 8, fig. 1). Examination of this thin section also showed that the dike did not alter the adjacent granodiorite, thus suggesting that the dike was probably formed at a lower temperature. The lateral gradation of some of the aplite dikes into the quartz monzonite and the granodiorite indicates a late magmatic origin for these rocks.

Age of intrusive: A definite age cannot be assigned to the granitic rocks exposed in the Elk Mountains. The granitic rocks intrude Cambrian rocks and are unconformably overlain in places by Miocene rhyolite. Schrader (1912, p. 34, 108, and 153), in describing the granitic intrusions of the Jarbidge, Contact, and Elk Mountains mining districts, believes the emplacement of these intrusives was synchronal and probably occurred during the Cretaceous. His assignment of a Cretaceous(?) age to these rocks was based upon a similar age applied by Emmons (1910, p. 29) to other intrusives in eastern Nevada.

According to Ferguson (1929, p. 118) and Kerr (1946, p. 21-22), numerous granitic masses were intruded in eastern Nevada and western Utah during a time not earlier than Eocene. In discussing the granitic intrusive rocks of Elko County, Granger, Bell, Simmons, and Lee (1957, p. 16) believe that the major period of intrusion was during the Cretaceous. They state:

> After the Mesozoic sedimentary rocks were deposited and folded, large bodies of granitic rocks of different varieties, largely granodiorite and quartz monzonite, were emplaced.

> The largest of these, the Ruby Range batholith underlies almost the entire length of the Ruby and East Humboldt Ranges and is exposed in an area more than 50 miles long and about 12 miles wide. Smaller masses, probably in large part the apical portions of larger bodies not exposed by erosion, crop out in different parts of the county; metalliferous deposits are closely associated with these. Nolan (1933) considers the quartz monzonite stocks of the Mountain City region to be satellitic to the Idaho batholith to the north. The exact ages of the intrusive masses have not been determined; they are younger than most, if not all, of the folding and thrusting that followed the deposition of the Mesozoic sediments. To the south, in Eureka County, this orogeny involved nonmarine sedimentary rocks of Early Cretaceous age. It seems, therefore, that the major period of granitic intrusion was within the Cretaceous and intermediate in time between the upper Jurassic intrusives of the Sierra Nevada batholith and the lower Tertiary stocks of western Utah.

There is evidence that some of the intrusive rocks of Elko County may be younger than Cretaceous. Lovejoy (1959, p. 553), on the basis of potassium-argon analyses, assigns a Miocene age to the granitic rocks exposed at Lone Mountain, Nevada, which is located about 22 miles northwest of Elko, Nevada, and about 70 miles southwest of the mapped area.

Without more definite evidence, such as provided by potassium-argon analyses, the writer does not feel justified in assigning a Miocene age to the intrusive rocks of the Elk Mountains. The Cretaceous(?) age assigned by Schrader to these rocks is the closest approximation that can be made with the existing information. As pointed out by Granger, _et al._, the granitic intrusives of eastern Nevada are generally considered to be of Cretaceous age.

Cenozoic Rocks

General statement: Cenozoic rocks are exposed in approximately three-fourths of the mapped area. These rocks consist predominantly of Tertiary volcanics but also include Quaternary alluvium which mantles earlier rocks as unconsolidated stream deposits, local detritus, and alluvial fan material. In order of stratigraphic sequence, Tertiary volcanic rocks include Miocene porphyritic rhyolite, Miocene and/or Pliocene (?) vitric volcanic ash with intercalated tuffaceous sandstones and massive tuffaceous mudstones, and Miocene and/or Pliocene (?) welded tuffs with associated vitric tuff. Fragmental dikes which are genetically related to the welded tuffs intrude volcanic ash and stratigraphically lower welded tuff north of Canyon Creek (southwest sector of Pl. 1).

Throughout the area the welded tuffs and stratified vitric volcanic ash are conformable (Pl. 11, fig. 2). The welded tuffs usually overlie the stratified volcanic ash, but locally the welded tuffs are interbedded within the upper portions of this deposit. Approximately one-half mile east of the thesis area on the ridge east of the Twin Meadows ranch an angular unconformity, resulting from local faulting, is present between the vitric volcanic ash below, and the succeeding welded tuffs (Pl. 11, fig. 1). At this site, the stratified volcanic ash dips S. 16° E. under nearly horizontal welded tuff. All exposures show evidence of an unconformity between the porphyritic rhyolite and the overlying volcanic ash and welded tuffs. The later rocks are present in erosional or structural valleys within the porphyritic rhyolite. The base of the rhyolite was not exposed within the mapped area. About one mile west of White Elephant Butte (off the mapped area), it rests on granitic rocks of the Cretaceous(?) intrusion and on Cambrian limestones. On the scarp east of Red Point, about three miles northwest of White Elephant Butte, this rock is separated from Cambrian limestones by locally derived lenses of granitic conglomerate and breccias of limestone and quartzite.

Miocene rhyolite: Schrader (1912, p. 36) describes 6000 feet of porphyritic rhyolite characterized by phenocrysts of quartz, potassic feldspar, and plagioclase in the adjacent Jarbidge Mountains. The porphyritic rhyolite exposed within the thesis area is similar lithologically to the rhyolite described by Schrader and represents an extension of it.

Distribution and thickness: As indicated by Plate 1, outcrops of the porphyritic rhyolite within the area are discontinuous. It has been exposed by uplift along faults and by removal of the overlying welded tuff and vitric volcanic ash through erosion. The best exposures and the greatest thickness of this rock are in the southeast part of the area, where at least 700 feet of this rock crops out on the northwest flank of Bear Mountain. In the remainder of the thesis area, less than 300 feet of this rock is exposed. The base of the rhyolite is not exposed within the mapped area. On the scarp east of Red Point (off mapped area), 600 to 800 feet of the rhyolite is in irregular contact with underlying conglomerates and breccias and with overlying welded tuff. Apparently the rhyolite in parts of the Jarbidge 1 quadrangle is not so thick as in the Jarbidge Mountains.

Petrology and petrography: The porphyritic rhyolite occurs as massive flows which are in irregular contact with each other. Although the rhyolite flows are in irregular contact, the rocks are nearly horizontal. Five flows were observed on the northwest flank of Bear Mountain.

As seen in their present weathered state, the rocks within a flow have a variety of colors: light olive gray, brownish-gray, and dark reddish-brown. On a fresh surface the rocks are pinkish-gray, light-gray, brownish-gray, pale purple red, and grayish-red. The various colors displayed are a function of the degree of oxidation of the rock rather than any differences in mineralogic composition.

The rhyolite is easily weathered and eroded and does not form prominent ledges or rims. The rock is broken by numerous fracture planes and, where highly eroded, forms rugged topography with numerous pinnacles and small caves (Pl. 12, fig. 1). Talus is commonly composed of irregular granule-sized fragments with pitted surfaces resulting from the breaking and weathering away of phenocrysts.

In hand specimen, the rock normally consists of phenocrysts of quartz, feldspar, and plagioclase which measure as much as 9 mm in maximum diameter. The phenocrysts are surrounded by a dense aphanitic groundmass with porcelaneous luster. The quartz phenocrysts are distinctive and by far the most abundant. They occur mostly in rounded or globular, clear to white grains with a vitreous or glassy luster. Where the rock is highly weathered, the quartz is tinted with various shades ranging from dark reddish-brown to pale purple. Exposures of the porphyritic rhyolite are shown by the figures on Plate 12.

According to Schrader (p. 48), the rhyolite in the Jarbidge Mountains contains tabular, gold-bearing quartz fissure veins and lodes. Metallization was not observed within the rhyolites exposed in the mapped area.

Under the microscope, the rock is porphyritic and consists of phenocrysts of oligoclase, sanidine, and quartz set in a cryptocrystalline to microcrystalline groundmass (Pl. 15, fig. 2). Random grains of highly altered biotite also occur as phenocrysts. Hornblende was not noted. The phenocrysts comprise about 30 percent of a sample. Of the phenocrysts quartz is the most abundant, sanidine is less abundant, and plagioclase is least abundant.

Where microcrystalline, the groundmass is hyalopilitic and contains glass with unoriented microlites of feldspar. Much of the glass is devitrified, and some is altered to epidote or stained with iron oxides. Devitrified areas occur along cracks or are located adjacent to the phenocrysts. In places the devitrified areas have spherulites of feldspar.

Feldspar phenocrysts, although somewhat corroded and embayed, generally show a subhedral crystalline outline, whereas the quartz phenocrysts are in general rounded or globular and penetrated by embayments of the groundmass. Some of the quartz grains contain sinuous inclusions of glass. Much of the quartz is strained. Plagioclase is unzoned calcic oligoclase, and in places the grains have a myrmekitic texture. Sanidine is clear and some grains are twinned. In some slides the sanadine has resorption borders of plagioclase. A few sanidine grains contain biotite inclusions near the borders. Minute rods of apatite occur in the groundmass. Zircon is present as inclusions in the sanidine. Alteration products include clay minerals, sericite, epidote, chlorite, and iron oxides.

Miocene and/or Pliocene (?) vitric volcanic ash: The vitric volcanic ash is correlative in part with the "vitric tuff unit" described by Van Houten (1956, p. 2814-2819). He describes a "vitric tuff unit" of late Miocene to medial Pliocene age that is extensively exposed in northeastern Nevada. His "vitric tuff unit" includes vitric tuff, reworked ash, interbedded sediments, and welded tuffs derived from local sources. He states (p. 2815) that the "vitric tuff unit" is part of the middle member of the Humboldt formation as outlined by Sharp (1939).

Distribution and thickness: For mapping purposes, to clearly illustrate the distribution of the welded tuffs and vitric volcanic ash, these deposits have been separated at the base of the stratigraphically lowest persistent unit of welded tuff. The volcanic ash beds which are intercalated with the welded tuff are not indicated on Plate 1, because they are only locally exposed and were not mapped in detail. The tuffaceous deposits thicken and thin laterally and in many places are absent. Less than 300 feet of this deposit is exposed. On the ridge east of the Twin Meadows ranch (about one-half mile east of the thesis area) at least 288 feet of this tuffaceous deposit is present between the underlying rhyolite and overlying welded tuff. Measurements taken on Buckhorn Ridge indicate that at least 284 feet of this deposit are present between the rhyolite and capping welded tuff. Northward from the Buckhorn Ridge exposure, the vitric volcanic ash decreases in thickness and pinches out between rhyolite and welded tuff. On the north canyon wall of Canyon Creek, about one-half mile east of O'Neil Creek, a 29-foot ledge of welded tuff is interbedded between 97 and 54 feet of stratified vitric volcanic ash. The upper 54 feet of vitric volcanic ash is in turn capped by another 38-foot ledge of welded tuff. The spherulitic, black, glassy, welded tuff at the base of the 29-foot ledge of welded tuff is in sharp contact with the underlying vitric volcanic ash. About three-quarters of a mile northwest of this exposure, in O'Neil Creek Canyon, the vitric volcanic ash pinches out and welded tuffs rest on rhyolite. Apparently the upper part of the volcanic ash deposit interfingers with the welded tuffs. The vitric volcanic ash may grade laterally into welded tuffs. However, this relationship was not observed because of talus covered slopes.

Petrology and petrography: Outcrops of tuffaceous deposits within the area consist predominantly of stratified, vitric, light-gray volcanic ash with sand- to silt-size particles of volcanic glass; however, these deposits also contain intercalated beds of massive, grayish-orange to light-brown, tuffaceous mudstone and yellowish-green to greenish-yellow, tuffaceous sandstone with particles of obsidian and pumice. The tuffaceous deposits are unconsolidated and do not form prominent outcrops amenable to detailed stratigraphic examination. The best outcrop of this material is on the southern part of Buckhorn Ridge. The section measured at this site is presented below.

Section measured on southern part of Buckhorn Ridge.

Unit No.	Description	Thickness
9	Mostly covered; in part white, friable, vitric volcanic ash; contact with overlying welded tuff is covered.	92 feet
8	Vitric volcanic ash, white to light-gray, laminated; contact with underlying sandstone is irregular.	12 feet
7	Sandstone, yellowish-green to greenish-yellow, tuffaceous, contains subrounded particles of grayish-orange to light-brown massive mudstones.	up to 1.5 feet
6	Vitric volcanic ash, very light-gray to greenish-gray, thinly laminated; in irregular contact with overlying sandstone.	up to 1 foot
5	Sandstone, yellow green to light-green, tuffaceous, very thin-bedded to thin-bedded. Upper 3.5 inches coarser with obsidian and pumice particles ranging in size from coarse sand to pebble, contains subrounded particles of massive mudstone from unit three; cross-laminated locally.	1.5 feet
4	Vitric volcanic ash with intercalated sandstone: Volcanic ash, white to light-gray, thinly laminated, with light-brown to grayish-orange, subrounded particles of massive mudstone from unit three. Sandstone, yellow green, tuffaceous, laminated, contains obsidian, pumice, quartz, and feldspar grains, varies laterally and vertically into volcanic ash or sandstone facies; unevenly bedded.	3.5 feet
3	Mudstone, grayish-orange to light-brown, massive, tuffaceous; sharp irregular contact with overlying and underlying beds; indistinct bedding near contact with unit two. Predominantly mudstone, but includes siltstone.	18.5 feet
2	Vitric volcanic ash, white to light-gray, laminated, thin-bedded and very thin-bedded; contains penecontemporaneous slump and deformation structures within a stratum; cross-bedded locally.	95 feet

Unit No.	Description	Thickness
1	Mostly covered; in part light-gray vitric volcanic ash and grayish-orange to light-brown mudstone; in irregular contact with underlying porphyritic rhyolite.	58 feet
	Total measured thickness	284 feet

An exposure of the massive mudstone of unit three is shown by Plate 13, figure 1. Plate 13 also contains a photograph (figure 2) of the stratified vitric volcanic ash of unit two.

Samples of the sandstone and vitric volcanic ash were examined with the binocular and petrographic microscopes. The vitric volcanic ash consists predominantly of rod-shaped or tabular, angular fragments of glass with an index of refraction slightly higher than 1.505. The glass particles within the sample examined are of uniform size measuring about 0.5 mm across the maximum diameter. Vesicles in the form of curved tubes and spheres were noted in the shards. Some of the glass particles are weakly polarizing along the edges of the fragment. Some sharp-edged fragments of sanidine, plagioclase, and quartz were also observed in the vitric volcanic ash. Mafic minerals were not noted.

The tuffaceous sandstones contain lithic fragments of obsidian and pumice; crystals of sanidine, plagioclase, and quartz; and a fine-grained matrix of glass shards and clay. The crystal and lithic fragments are fine to coarse sand-size. The crystals of quartz, sanidine, and plagioclase range from subangular to rounded, whereas the lithic fragments are angular and subangular. Estimated percentages of the constituents observed in a slide of the sandstone are: 35 percent glass and clay matrix, 20 percent lithic fragments, 20 percent sanidine, 15 percent plagioclase, and 10 percent quartz.

The white to light-gray vitric volcanic ash exposed on Buckhorn Ridge must have been deposited in water because (1) it is laminated and (2) it contains intraformational conglomerates with rounded fragments of massive mudstones that are as much as six inches in diameter. The tuffaceous sandstones are also considered to have been deposited in water because (1) they contain conglomerates of massive mudstone, (2) they contain fine-grained clay and glass matrix which indicates that they are reworked, and (3) they are laminated.

Unit two is of uniform character, and it does not change in thickness laterally within the limits of the Buckhorn Ridge exposure. Therefore, the author believes it may have been deposited in a lacustrine environment. The interlensing of sandstone and vitric volcanic ash in the upper part of the section suggests a fluviatile environment.

Miocene and/or Pliocene (?) welded tuffs and fragmental dikes: The welded tuffs in the area were mapped as Pliocene(?) rhyolite by Schrader (1912, Pl. 1). As these rocks form prominent rims and rest unconformably on older, Miocene(?), porphyritic rhyolite in the Jarbidge Mountains, Schrader calls them the younger or rim rock rhyolites. Within the mapped area the rock is not a crystalline rhyolite. It is composed largely of fragmental glass and the texture of the rock is similar to welded rhyolitic tuffs described by Mansfield and Ross (1935) and Mansfield (1952) in the Ammon and Paradise Valley quadrangles, southeastern Idaho.

Associated with the welded tuffs are interbeds (less than 20 feet thick) of yellowish-brown vitric tuff which contains crystals of sanidine, andesine, augite, hypersthene, and tridymite. These minerals are also present in the welded tuffs. Both these rocks were probably expelled from the same vent or vents.

Distribution, thickness, and stratigraphic relations: The welded tuffs underlie the surface of most of the mapped area (Pl. 1). They are also exposed along the sides of O'Neil Creek Canyon, the sides of Canyon Creek Canyon, and along the scarps west of the roads to the Twin Meadows ranch and the Robinette prospect.

The welded tuffs rest unconformably on porphyritic rhyolite and locally they "puddle" in erosional or structural valleys within this rock. The welded tuffs commonly rest conformably on the vitric volcanic ash; however, some of the vitric volcanic ash is interbedded within this rock along the north side of Canyon Creek Canyon. The orthopyroxene-bearing yellowish-brown tuffs associated with the welded tuffs are exposed chiefly on the west side of O'Neil Creek Canyon. Here, these tuffs are in both sharp and gradational contacts with the welded tuff beds. The welded tuffs may grade laterally into the orthopyroxene-bearing tuffs, but this relationship was not determined because of talus cover.

The welded tuffs occur in one to seven units and are the thickest along O'Neil Creek Canyon, where the seven units present have an aggregate thickness of about 350 feet. West and northwest of the mapped area, these rocks are at least 1100 feet thick. The welded tuff beds as a group thin gradually and irregularly southward, and only one to three units are present south of Canyon Creek. The units of welded tuff are of different thicknesses; beds with thicknesses of 5, 29, 35, 86, and 96 feet respectively were measured. The beds are conformable with each other.

Petrology and petrography: The welded tuffs are resistant to erosion and crop out as ledges and steep cliffs; that is, they form rim rocks. The welded tuffs do not display columnar jointing, and the rock is not divided and separated by numerous fracture planes as is the porphyritic rhyolite. The welded tuffs characteristically display parting planes parallel to the top and bottom of a bed. Weathering along the parting planes forms platy fragments. Most of the talus debris derived from these rocks is composed of these platy fragments.

Sections of the welded tuff were measured on the west side of O'Neil Creek Canyon, on the north side of Canyon Creek Canyon, and on the scarp exposed one-fourth of a mile west of the road to the Robinette prospect. These sections are presented below. The contacts between the subdivisions of stony welded tuff within the sections measured are gradational. The black, glassy welded tuff layer at the base of the stony welded tuff is also gradational upward into this rock.

Section of welded tuffs exposed on west side of O'Neil Creek Canyon, one-half mile north of Canyon Creek.

Unit No.	Description	Thickness
5 a	Welded tuff, dark reddish-brown, stony, platy parting characteristic.	3.5 feet
5 b	Welded tuff, grayish-red, massive, stony.	7.0 feet
5 c	Welded tuff, reddish-purple, stony, finely "flow-banded", vesicular locally, porphyritic locally, platy to slabby partings characteristic.	63.0 feet
5 d	Welded tuff, reddish-brown, massive, stony.	5.5 feet
5 e	Welded tuff, blackish-red, vesicular, stony, spherulitic.	4.0 feet
5 f	Welded tuff, black, glassy, massive, perlitic, spherulitic, crumbly; gradational into 5 e.	2.5 feet
	Total	85.5 feet
	Covered	
4 a	Welded tuff, light-gray, massive, earthy luster, contains pumice fragments; in sharp contact with 2.5 feet of yellowish-brown pumiceous tuff above unit.	1.5 feet
4 b	Welded tuff, dark gray, glassy, banded, lithic and crystal fragments, contains 5-inch lens of yellowish-brown tuff with lithic fragments; gradational into 4 a, and in sharp contact with 6 inches of yellowish-brown tuff with fragments of pumice and obsidian.	4.0 feet
	Total	5.5 feet
	Covered	
3 a	Welded tuff, dark reddish-brown, stony, platy parting characteristic, few feldspar crystals.	8.0 feet
3 b	Welded tuff, dark reddish-brown, massive, stony.	14.0 feet
3 c	Welded tuff, stony, dark reddish-brown at base, yellowish-brown towards top, vesicular, porphyritic, "flow-banded", some platy parting.	17.0 feet
3 d	Welded tuff, stony, yellowish-brown, highly vesicular with irregular vesicles 2.5 inches across maximum diameter.	2.5 feet
3 e	Welded tuff, dark-gray, glassy, crumbly, perlitic, laminated at base, gradational into underlying tuff of unit two and gradational into 3 d.	3.0 feet
	Total	50.5 feet

Section of welded tuffs exposed on west side of O'Neil Creek Canyon, one-half mile north of Canyon Creek (Cont'd.).

Unit No.	Description	Thickness
2	Partly covered; tuff, grayish-brown, laminated fragments of black glassy tuff and pumice; black glassy tuff fragments increasing towards top of unit. Gradational into black glassy welded tuff at base of unit three. Contact with unit one is covered.	19.0 feet
	Total	19.0 feet
1 a	Welded tuff, grayish-red, massive, stony, porcelaneous luster, faintly "flow-banded"; contact with overlying tuff covered.	28.0 feet
1 b	Welded tuff, dark reddish-brown, stony, platy parting characteristic.	6.0 feet
1 c	Welded tuff, grayish-red, stony, vesicular with flattened vesicles, porphyritic, "flow-banded".	22.0 feet
1 d	Welded tuff, black, glassy, crumbly, porphyritic; gradational into 1 c.	3.5 feet
	Total	59.5 feet

Bottom of section

Total thickness of exposed and partly covered welded tuffs and tuffs. 219.0 feet

Section of a unit of welded tuff exposed on north side of Canyon Creek Canyon, one-half mile east of O'Neil Creek.

Subdivision	Description	Thickness
j	Welded tuff, reddish-brown to reddish-purple, stony, massive; contact with overlying vitric volcanic ash is covered.	3.5 feet
k	Welded tuff, pale-brown to light-gray, stony, "flow-banded".	11.0 feet
l	Welded tuff, black, glassy, massive, spherulitic, perlitic; spherulites up to 4.5 inches in diameter; in contact with baked, light-gray, porcelaneous claystone of underlying vitric volcanic ash.	14.5 feet
	Total	29.0 feet

Section of a unit of welded tuff exposed one-fourth of a mile west of the road to the Robinette prospect and three and one-fourth miles northwest of the O'Neil ranch.

Subdivision	Description	Thickness
u	Welded tuff, dark reddish-brown, stony, finely "flow-banded", platy parting characteristic.	23.0 feet
v	Welded tuff, very dusky-red, vitreous luster, "flow-banded".	12.0 feet
w	Welded tuff, yellowish-brown, stony, highly "flow-banded", porphyritic with feldspar crystals measuring at least 4 mm in length.	5.5 feet
x	Welded tuff, dark reddish-brown, stony, spherulitic, lithoidal, coarsely vesicular with irregular vesicles measuring up to 2 inches along the maximum diameter.	3.5 feet
y	Transition between welded tuff and black glassy welded tuff, medium-gray, massive, contains fragments of reddish-brown lapilli tuff.	1.5 feet
z	Welded tuff, black glassy, perlitic, porphyritic with feldspar phenocrysts.	1.0 foot
	Total	46.5 feet

The rocks in the measured sections show the highly variable eutaxitic structure of the welded tuffs. They consist of alternating bands of rock with differences in color, degree of crystallinity, and texture. An exposure of a welded tuff, unit five of the O'Neil Creek Canyon section, is shown by Plate 14, figure 2.

Samples from the welded tuff subdivisions of the unit measured near the road to the Robinette prospect and from unit four of the O'Neil Creek Canyon section were examined with the microscope. Additional samples from other units were also examined in thin section; however, these were not in stratigraphic sequence. The specimens examined show some of the textures outlined by Ross (in Mansfield, 1952, p. 50-54) as follows:

> ...various degrees of welding and distortion of the tuff fragments, due to the various degrees of accommodation of the shape of one grain to another while still in a plastic condition...
>
> Tuff grains are commonly fragments of broken bubbles and glassy plates; moon-shaped fragments, Y-shapes, and occasional hollow spheres are to be observed.... The completely collapsed and welded fragments are now in the form of wavy plates, or grotesquely distorted forms, but occasionally even these show a typical Y-shaped form.

The welded tuffs typically have a layer of spherulitic or perlitic, porphyritic, gray to black, glassy welded tuff at the base that ranges in thickness from a few inches to as much as 15 feet. The glassy welded tuff usually grades upward to a dense, stony, dark reddish-brown rock which locally is highly vesicular. Figure 1, Plate 14 shows coarsely spherulitic, black, glassy welded tuff beneath stony welded tuff. A sample of the glassy welded tuff at the base of the welded tuff unit exposed near the road to the Robinette prospect contains highly contorted fragmental glass (Pl. 16, fig. 1). Figure 2, Plate 16 is a photomicrograph of the black, glassy welded tuff of unit 4b, O'Neil Creek Canyon section. It also illustrates the fragmental character of the glass within the black, glassy welded tuff.

The black, glassy welded tuff is usually porphyritic and contains phenocrysts of sanidine, augite, andesine, quartz, hypersthene, and magnetite in a fragmental glassy groundmass. Andesine phenocrysts are more numerous than sanidine phenocrysts. Some of the sanidine and andesine crystals are corroded and are embayed by the glassy groundmass. Much of the sanidine is micrographic. Quartz occurs as rounded or globular masses and in well developed euhedral crystals. Pyroxene minerals are highly altered and resorbed. Pigeonite may be present, as much of the pyroxene has a small optic angle. Magnetite phenocrysts are distributed throughout a slide.

The groundmass consists almost entirely of glass shards. Much of the glass is highly distorted and resembles microscopic chevron folds. The glass shards are compacted and flattened around phenocrysts. Larger fragments of glass within the groundmass are dark-brown to medium-brown, whereas smaller fragments are clear, yellowish-brown, or light-brown. Tridymite occurs in the groundmass as weakly polarizing aggregates that are concentrated chiefly between the glass fragments.

The stony welded tuff subdivisions also contain fragmental glass. A photomicrograph (Pl. 15, fig. 1) of a thin section from unit 4a, O'Neil Creek Canyon section, shows the diagnostic Y-shaped fragments. A slide from subdivision "v" of the Robinette road section contains elongated, compacted, glass fragments and a few Y-shaped fragments. The slide also contains fragments of flattened pumice as is shown by Figure 1, Plate 17.

The welded tuffs usually contain a yellowish-brown porphyritic layer that superficially appears to be "flow-banded" as is exemplified by subdivision "w" of the Robinette road section and unit 3d of the O'Neil Creek Canyon section. The porphyritic layer is usually near the middle of a unit or about two-thirds of the distance downward from the top of a unit.

Thin sections of this rock do not contain discrete glass fragments. The glass, which is usually devitrified and microvesicular, is not broken, but is continuous across the slide (Pl. 17, fig. 2). It is compacted around fragmental or resorted phenocrysts of sanidine or andesine. This rock may represent extreme compaction of the fragmental glass or flowage in a glassy froth. Dr. Ernest Lund (personal communication, 1960) showed the writer a thin section of pumice from the upper part of an obsidian flow at Newberry Crater, Oregon, which resembles the glass of this rock in its continuity of structure across the slide.

The lithoidal or stony subdivisions of the welded tuffs differ from the black glassy subdivisions in that they do not contain quartz. These rocks contain sanidine, andesine, and tridymite. Where the rock is porphyritic the sanidine and andesine phenocrysts make up as much as 20 percent of the rock. Andesine phenocrysts are the most abundant. Magnetite is also abundant in these rocks.

Schrader (p. 41) referred to these rocks as tridymite rhyolites. The tridymite is generally present within vesicles or between devitrified glass fragments. The tridymite has a dusty appearance and is weakly polarizing. Some wedge-shaped twins were noted. The devitrified areas which contain tridymite also have potassic feldspar which is believed to be sanidine as it has negative elongation.

Spherulites are present in the layer of black, glassy welded tuff at the base of the stony welded tuff. They are also present in the coarsely vesicular layer of stony welded tuff above the black glassy layer. The white to greenish-gray spherulites in the black welded tuff are usually spherical, whereas those in the stony welded tuff are irregular in outline and are prevailingly reddish-brown. The constituents of some spherulites are arranged radially around a single center. In other spherulites, the constituents are grouped around several centers. The writer was unable to determine the exact mineralogical make-up of the spherulites because of the small-grain size of the constituents. The spherulites have an index less than balsam, and they contain potassic feldspar with a refractive index less than 1.530 and greater than 1.515. The spherulites in the stony welded tuffs project into the glass fragments within the groundmass of this rock. Dr. Aaron Waters (personal communication, 1960) has performed X-ray analyses on the spherulites from welded tuffs and reports that they consist of intergrowths of sanidine and cristobalite.

The vesicular and devitrified nature of the welded tuffs and the spherulites present in these rocks is suggestive of hot gaseous action. In this connection Ross (in Mansfield, 1952, p. 52) states:

> Many of the pyroclastic rhyolites with eutaxitic texture have been completely devitrified, through the crystallization of the glass. These show that minute crystals have grown inward from borders of the tuff grains. In many specimens of this type spherulites have also developed....
>
> The only recognizable minerals in the devitrified rhyolite tuffs are feldspar and tridymite. In many specimens tridymite crystals project into cavities...
>
> The completeness of devitrification, the character of the minerals formed (feldspar and tridymite), and the terminated crystals projecting into cavities are all phenomena indicative of crystallization in the presence of hot gases. ...

The spherulites within the coarsely vesicular, stony, reddish-brown welded tuff layer above the black, glassy welded tuff have been torn and broken in a manner similar to that described by Mansfield and

Ross in the explanation of Plate 11 of their 1935 report. According to these authors, this feature is supposed to be caused by strong gaseous action after deposition of the welded tuff.

Schrader (p. 44) classified these rocks as rhyolite on the basis of chemical analyses. The rocks may be more basic than rhyolite as andesine phenocrysts are more abundant than those of sanidine. However, as chemical analyses are more definitive than modal analyses, these rocks are probably better classified as rhyolite welded tuffs.

Two fragmental dikes which are genetically related to the welded tuffs intrude vitric volcanic ash and welded tuffs north of Canyon Creek (Pl. 18, fig. 1). The larger of the two dikes, which is nearest to the left margin of the above cited figure, was examined in some detail, and a closer view is shown by Plate 18, figure 2. This dike, which is vertical, is exposed for a distance of 153 feet along its strike and becomes thinner towards the upper part where it pinches out about 60 feet below a welded tuff bed. It is not traceable into a welded tuff. The nearly horizontal, stratified vitric volcanic ash which the dike cuts has been deformed by the dike and dips away from it at angles as high as 70 degrees. Measurements taken about 50 feet from the bottom of the exposed part of the dike indicate that it is at least 39 feet wide. The megascopic characteristics of the rocks within the dike at the point of measurement are shown by figure 2 below.

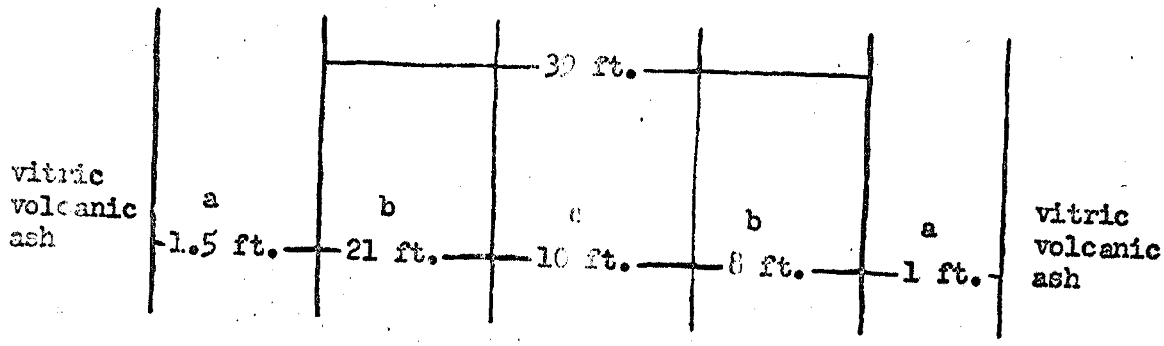

Figure 2. Megascopic characteristics of fragmental and/or welded tuff dike exposed north of Canyon Creek, about one mile west of the Buckhorn Ridge road. a, Silicified and opalized tuff; b, welded tuff, dark-gray to black, glassy, perlitic, crumbly, porphyritic, massive; c, silicic rock resembling welded tuff, light-gray and brownish-gray to reddish-brown; contains obsidian and pumice fragments as long as 2 mm. The measurements were taken across the dike at a point about 50 feet above the lowest exposed part of the dike.

The fragmental silicic rock near the center of the dike is not present in the upper part of the dike. The dark-gray to black, glassy welded tuff is massive and porphyritic with feldspar crystals as long as 1 mm. Locally this rock is coarsely perlitic and the onion-like partings give the rock a pillow-like structure. Some of the rock has a pitchy luster and may be pitchstone in part. Samples of the dark-gray to black, glassy welded tuff from the dike and from the base of the welded tuffs have marked lithogical similarities.

The dark-gray to black, glassy welded tuff is porphyritic and consists of phenocrysts of sanidine, andesine, quartz, and augite which are surrounded by a fragmental glassy groundmass. Sanidine phenocrysts are corroded, and they are embayed by the groundmass. Some of the sanidine phenocrysts are twinned according to the Carlsbad law. Andesine phenocrysts are by far the most abundant. These phenocrysts, which are not zoned, usually are corroded and have a subhedral outline. Some grains display cross-twinning. Some of the andesine phenocrysts are angular in shape and appear to be fragmental. Some grains have been broken and the parts separated by the groundmass. Augite phenocrysts are smaller and less abundant than phenocrysts of the other minerals.

The glass within the groundmass includes larger (at least 1 mm across the maximum dimension) grains of light-brown glass and smaller grains of gray glass. The larger grains are highly contorted and have been bent, broken, and stretched or drawn out (Pl. 19, fig. 2). The glass grains have a subparallel arrangement, and bow around the phenocrysts. A few of the light-brown glass grains have a Y-shaped form. With crossed nicols the perlitic texture which cuts across the glass grains is apparent. The glassy groundmass is devitrified locally into weakly polarizing irregular areas which contain feldspar and possibly tridymite. In places the rock is microvesicular. Between the glass grains are weakly polarizing minute crystals which make up 40 percent of the sample. The minute crystals, which the writer believes to be tridymite, occur as dusty or sooty aggregates. Many of the minute crystals radiate away from a common center in a spherulitic or fan-shaped manner. Diagnostic wedge-shaped twins were not observed and the crystals have a refractive index higher than the surrounding glass but lower than balsam.

Estimated percentages of the constituents observed in a slide from the fragmental brownish-gray to reddish-brown silicic rock are: 60 percent fragmental glass; 20 percent lithic fragments; 15 percent andesine; and 5 percent of quartz, sanidine, zircon, and magnetite (Pl. 19, fig. 1). The slide contains lithic fragments of obsidian and pumice which are as much as 1 mm in the maximum dimension. The obsidian is dark-brown and is separated by minute lines which give the fragments a banded appearance. The pumice fragments are gray and have drawn out vesicles which traverse a fragment and appear as dusty lines. Highly altered, indeterminate lithic fragments with angular feldspar crystals were also observed. The glass fragments, which are yellowish-brown or light-brown, appear in a variety of forms: Y-shapes, lunar shapes, broken vesicles, and elongated grains. The fragmental glass and the pumice and obsidian fragments have a subparallel arrangement across the slide. The vesicles within some of the pumice fragments are arranged normal to the subparallel grains of glass and obsidian. Minute crystals, which may be tridymite, are also present between the glass fragments in this rock. Andesine crystals are not zoned, and they are predominantly fragmental with angular edges. Randomly dispersed grains of quartz and sanidine were observed.

The silicic rock is predominantly brownish-gray to reddish-brown; but it also has a light-gray variety. The light-gray variety contains fragmental glass, lithic fragments of obsidian and pumice, plagioclase, sanidine, and quartz. The glass has, in addition to Y-shaped and lunar shaped forms, fragments in the shape of unbroken vesicles. The major difference between this rock and the brownish-gray to reddish-brown silicic rock is in the color of the glass which is clear to gray or locally is tinted yellowish-brown. The iron within the glass of the reddish-gray to reddish-brown rock is probably more highly oxidized, which would account for the color difference.

Although the dike is not traceable into a welded tuff, there can be little doubt that the dike is genetically related to these rocks because (1) the dike contains rocks that are microscopically fragmental, with glass fragments that are similar in form to those described in the welded tuffs; (2) the rocks in the dike are megascopically similar to those contained in the welded tuffs; and (3) the dike, as well as the welded tuffs, contains sanidine, andesine, quartz, pyroxene, and tridymite. Dr. Aaron Waters (personal communication, 1960), states that he has mapped similar welded tuff dikes southeast of Prineville, Oregon, and that one of the dikes was traceable into a welded tuff flow.

The welded tuffs within the thesis area were not mapped in sufficient detail for the writer to propose a detailed theory for the origin of these rocks. However, the writer does not favor a pyroclastic origin as outlined by Mansfield and Ross because of the associated fragmental and/or welded tuff dikes. The writer believes that the welded tuffs are flows of highly gaseous, vesiculating, plastic, pumiceous glass that ruptures and breaks into fragments because of pressures exerted by the entrapped gases and stresses exerted on the glass during flowage. Prior to complete solidification, the plastic hot glass was compacted because of the loss of gases and the weight of pumiceous material.

Age and correlation of Tertiary rocks: Definite ages cannot be assigned to the Tertiary volcanic rocks exposed within the southeastern part of the Jarbidge 1 quadrangle, as fossils were not found associated with them. The porphyritic rhyolite is an extension of similar rock in the Jarbidge Mountains (Jarbidge quadrangle) which Schrader (1912) called the older rhyolite and assigned a Miocene(?) age. The porphyritic rhyolite seems to be definitely of Miocene age and probably of late medial or early late Miocene age.

Robert T. Coats, U. S. Geological Survey, currently is mapping in the Jarbidge quadrangle to the west of the mapped area and provisionally calls the older rhyolite of Schrader the Jarbidge rhyolite. In reference to the age of the Jarbidge rhyolite, he states (written communication, December, 1959):

> Both Axelrod (personal comm.) and Stirton now call equivalent(?) beds under the Jarbidge rhyolite middle Miocene. This would suggest that the Jarbidge is late middle or early upper Miocene. The beds that furnish the leaves to Axelrod and those from which the vertebrates come that Stirton identified are separated by some distance, and are not quite identical lithologically, but both are unconformable beneath the Jarbidge.

The vitric volcanic ash and welded tuffs are probably of late Miocene or early Pliocene age and possibly include rocks of medial Pliocene age. Van Houten (1956, p. 2814-2819) describes a late Miocene to medial Pliocene "vitric tuff unit" that is extensively exposed in Nevada. His "vitric tuff unit" includes vitric tuff, reworked ash, interbedded sediments, and welded tuffs derived from local sources. He states (p. 2815) that the "vitric tuff unit" forms part of the middle member of the Humboldt formation as outlined by Sharp (1939) in his description of exposures near Twin Bridges on Huntington Creek, south of Elko, Nevada.

Near Twin Bridges, the Humboldt formation, as measured by Sharp, is 5800 feet thick, and on the basis of lithology is divisible into three members. The lower member consists of a breccia of Paleozoic limestone, fresh-water limestone, shales, and conglomerates. The middle member is made up of volcanic ash deposited predominantly in fresh-water lakes. The upper member consists of coarse fanglomerates and conglomerates. Sharp indicates that the Humboldt formation crops out at least as far north as Contact, Nevada, about 18 miles east of the mapped area. On the basis of vertebrate fauna and fossil flora, the Humboldt formation was assigned a late Miocene or early Pliocene age by Sharp.

Van Houten (p. 2811), from information furnished by Axelrod, intimates that rocks within the lower member of the Humboldt formation of Sharp are Oligocene(?) or early Miocene(?). Harold E. Malde, U. S. Geological Survey, (written communication, November, 1959) reports that Dwight W. Taylor of the U. S. Geological Survey regards some mollusks collected from limestone low in the Humboldt formation near Twin Bridges on Huntington Creek as probably Oligocene, but possibly late Eocene or early Miocene age.

Apparently the Humboldt formation is divisible into many units and has been used as a basis for comparison of rocks of such a wide range of ages that correlating the vitric volcanic ash deposits in the mapped area with it does not lead to a very precise age determination. The writer believes that the vitric volcanic ash and welded tuffs are correlative with the "vitric tuff unit" (middle member of the Humboldt formation) as outlined by Van Houten.

Lovejoy (1959, p. 555-558), on the basis of mammalian fossils from vitric tuffs, assigns a late Miocene age to vitric tuffs and welded tuffs exposed in the Lone Mountain area, about 22 miles northwest of Elko, Nevada, and about 70 miles southwest of the mapped area. He correlates the vitric tuffs and welded tuffs exposed in the Lone Mountain area with Van Houten's "vitric tuff unit."

Coats (op. cit., written communication) has mapped vitric tuffs beneath welded tuffs in the adjacent Jarbidge quadrangle as Jenny Creek tuff (unpublished). In discussing the age of the Jenny Creek tuff Coats states:

> The age of the "vitric tuff unit" is, as you say, probably Late Miocene to early Pliocene. A very small flora (two species) was identified by R. W. Brown as upper Miocene. Kenneth Lohmann identified the diatoms as "early Pliocene or possibly Late Miocene with a preference for early Pliocene." These beds I am calling the Jenny Creek tuff, after exposures near the junction of Jenny and Jack Creeks, in the Jarbidge quadrangle.

The welded tuffs exposed within the area were described as Pliocene(?) younger rhyolite by Schrader (1912) and, as mapped by him

(Plate 1 of his report), this rhyolite is continuous from east to west across the Jarbidge, Jarbidge 1, and Contact quadrangles. Schrader also indicates that the younger rhyolite is traceable across the Nevada state line into Idaho.

Recent investigators believe that the younger rhyolite of Schrader is composed predominantly of welded tuff. Harold E. Malde and Howard A. Powers of the U. S. Geological Survey are currently mapping the Tertiary rocks of the Snake River Plain in south-central and southwestern Idaho. Malde (op. cit., written communication) reports:

> ...Where I have worked with Harold A. Powers between Twin Falls, and Mountain Home, Idaho, the oldest rock unit is silicic latite occurring mainly as welded tuff, but including some bedded vitric tuff and lava flows, correlative with the younger rhyolite of Schrader. Thus, even though our reconnaissance includes observations of older rocks at margins of the Snake River Plain, the only formation we have studied in detail that can be correlated with the Elk Mountains is the silicic latite. In a report now in preparation, this rock unit is included in a regional formation named Shoshone volcanics.

According to Malde, the Shoshone volcanics at Jump Creek and Reynolds Creek, Idaho, are overlain by the Poison Creek formation that contains Clarendonian (lower Pliocene) mammals.

The Shoshone volcanics as described by Malde are usually porphyritic with phenocrysts of andesine, clinopyroxene, hypersthene, zircon, and magnetite, but no sanidine, hornblende, or biotite. The welded tuffs exposed in the mapped area are different mineralogically from the Shoshone volcanics in that, in addition to the minerals listed by Malde, they also contain quartz and sanidine.

Coats gives the name "Cougar Point volcanics" to welded tuffs exposed in the Jarbidge quadrangle. This is the younger rhyolite of Schrader. Coats correlates these rocks with the Shoshone volcanics of Malde and Powers. He states:

> ...I cannot put the Cougar Point very high in the Pliocene, because it is overlain unconformably by the Banbury formation in the Jarbidge quadrangle.

The welded tuff may possibly be equivalent to the welded tuffs described by Mapel and Hail (1956, p. 9-16) in the Goose Creek district, Cassia County, southern Idaho. According to these authors, four welded tuff beds are intercalated within volcanic ash of the lower part of the Salt Lake formation which measures about 1550 feet. The welded tuffs as described by Mapel and Hail are gray or black to dark reddish-brown, and commonly have a layer of black obsidian at the base that ranges in thickness from a few inches to as much as 10 feet. These authors, by fossils, date the lower part of the Salt Lake formation as early and/or medial Pliocene.

Youngquist and Haegele (1956, p. 15) describe welded tuff with a 6-inch bed of fragmental obsidian-like rock at the base in the Cassia Mountain region, Twin Falls and Cassia Counties, Idaho (about 40 miles northeast of the mapped area). These authors, in referring to the regional distribution of these rocks, state:

> ...Also, a very thick section of welded tuff is present to the west of the Cassia Mountains in the vicinity of Salmon Falls Creek and on the northern flank of the Elk Mountains which rose into Idaho from Nevada south of the Idaho village

of Three Creeks (Fig. 2). Accordingly, welded tuffs are apparently very abundant in most of Idaho south of the Snake River. We would like to state frankly that we are uncertain as to the true origin and nature of many of the flow-like rocks in the Cassia Mountain area, for closer inspection and studies have shown that many of what we regarded in the field as true flows are probably welded tuffs. We suggest this as an interesting field for further research.

In summary, the porphyritic rhyolite is of Miocene age and probably of late medial or early late Miocene age. It is correlative with and forms part of the older rhyolite of Schrader and/or the Jarbidge rhyolite of Coats. The vitric volcanic ash and welded tuffs are probably of late Miocene or early Pliocene age and possibly, in part, of medial Pliocene age. In Nevada, these rocks are correlative with the "vitric tuff unit" and/or middle member of the Humboldt formation as outlined by Van Houten and with the Jenny Creek tuff and Cougar Point volcanics which are currently being mapped by Coats in the adjacent Jarbidge quadrangle. The Cougar Point volcanics are predominantly welded tuffs and were mapped as younger rhyolite by Schrader in 1912.

The welded tuffs are traceable northward into Idaho (the thesis area is 7 miles south of the Idaho state line) and are probably correlative to the Shoshone volcanics, a regional formational name proposed by Malde and Powers for rocks exposed between Twin Falls and Mountain Home, Idaho. This rock unit is silicic latite occurring mainly as welded tuffs, but including some bedded vitric tuff and, according to Malde and Powers, is correlative with the younger rhyolite of Schrader.

The welded tuffs may also be correlative with welded tuffs in the lower part of the Salt Lake formation as described by Mapel and Hail in the Goose Creek district, Cassia County, Idaho. However, as the Goose Creek district is at least 70 miles from the mapped area, a precise correlation will have to await more field work in the surrounding areas.

Quaternary alluvium: Rocks of this age mantle earlier rocks as unconsolidated stream deposits, local detritus, and alluvial fan material. Alluvium is present along the stream valleys of Lime, Canyon, and Cottonwood creeks where it includes gravels and finer-grained sediments derived chiefly from Tertiary volcanic rocks. The alluvium is at least 10 feet thick near the O'Neil ranch, as dredged irrigation ditches penetrate it at this distance.

An alluvial fan, which is less than 100 feet thick, is present near the range front fault that bounds Mahogany Elephant and White Elephant buttes on the southeast. The alluvial fan consists predominantly of cobble- to boulder-sized fragments of silicified fault breccia derived from the zone of cataclastic rocks which delineate the range front fault.

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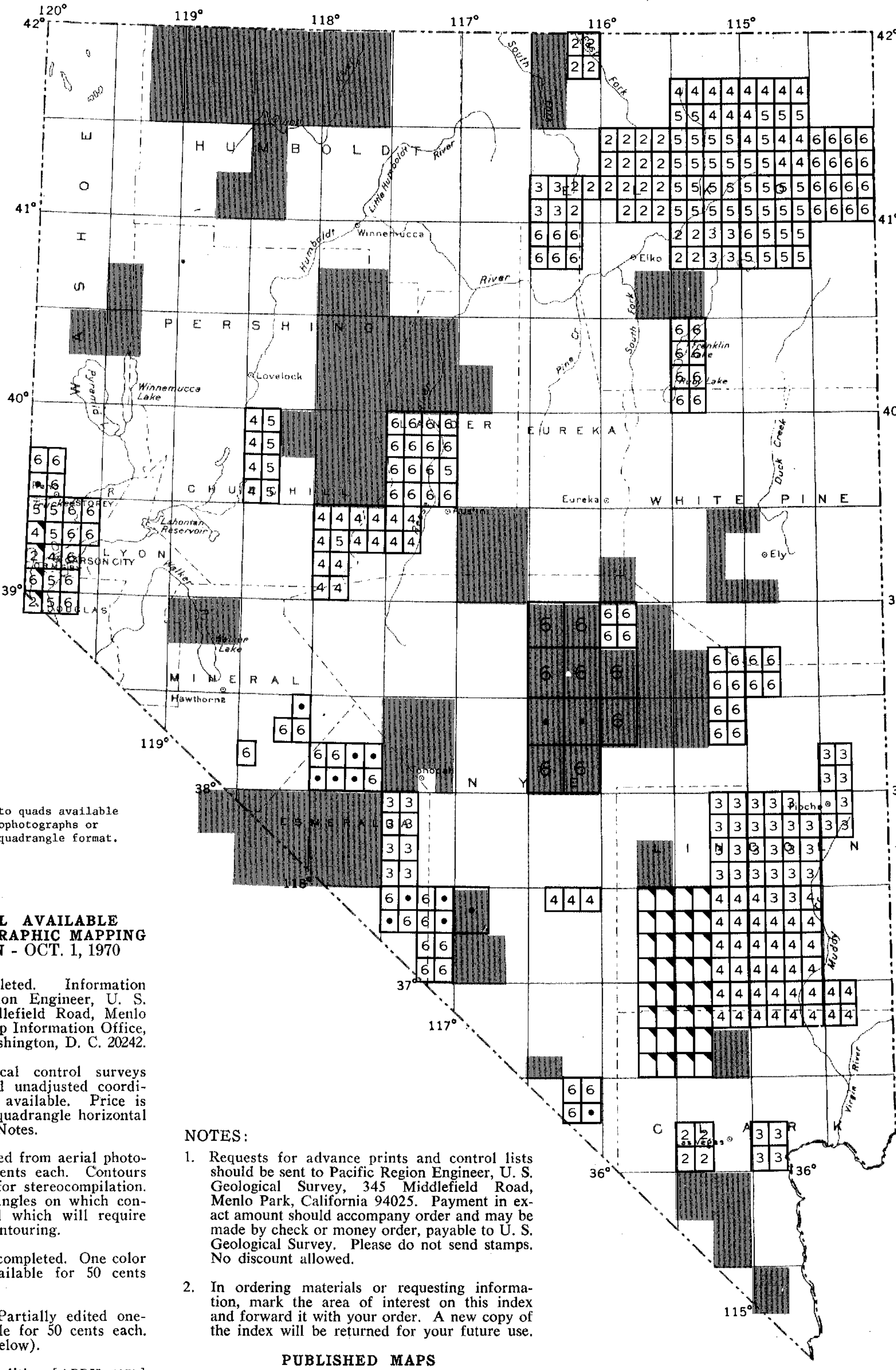
\# 6-5/72

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

NEVADA

TOPOGRAPHIC DIVISION
PACIFIC REGION
MENLO PARK, CALIFORNIA



Corner ticks indicate orthophoto quads available at $5.00 each. These are orthophotographs or orthophotomosaics in standard quadrangle format.

ADVANCE MATERIAL AVAILABLE FROM CURRENT TOPOGRAPHIC MAPPING QUARTERLY EDITION - OCT. 1, 1970

2 — Aerial photography completed. Information available from Pacific Region Engineer, U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, or Map Information Office, U. S. Geological Survey, Washington, D. C. 20242.

3 — Basic horizontal and vertical control surveys completed. Descriptions and unadjusted coordinates and/or elevations are available. Price is 50 cents for each 15-minute quadrangle horizontal or vertical control list. See Notes.

P 4 — Prints of manuscripts compiled from aerial photographs are available at 50 cents each. Contours are shown in areas suitable for stereocompilation. Letter "P" indicates quandrangles on which contouring is not complete and which will require fieldwork to complete the contouring.

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1. Requests for advance prints and control lists should be sent to Pacific Region Engineer, U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025. Payment in exact amount should accompany order and may be made by check or money order, payable to U. S. Geological Survey. Please do not send stamps. No discount allowed.
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UNITED STATES
DEPARTMENT OF THE INTERIOR
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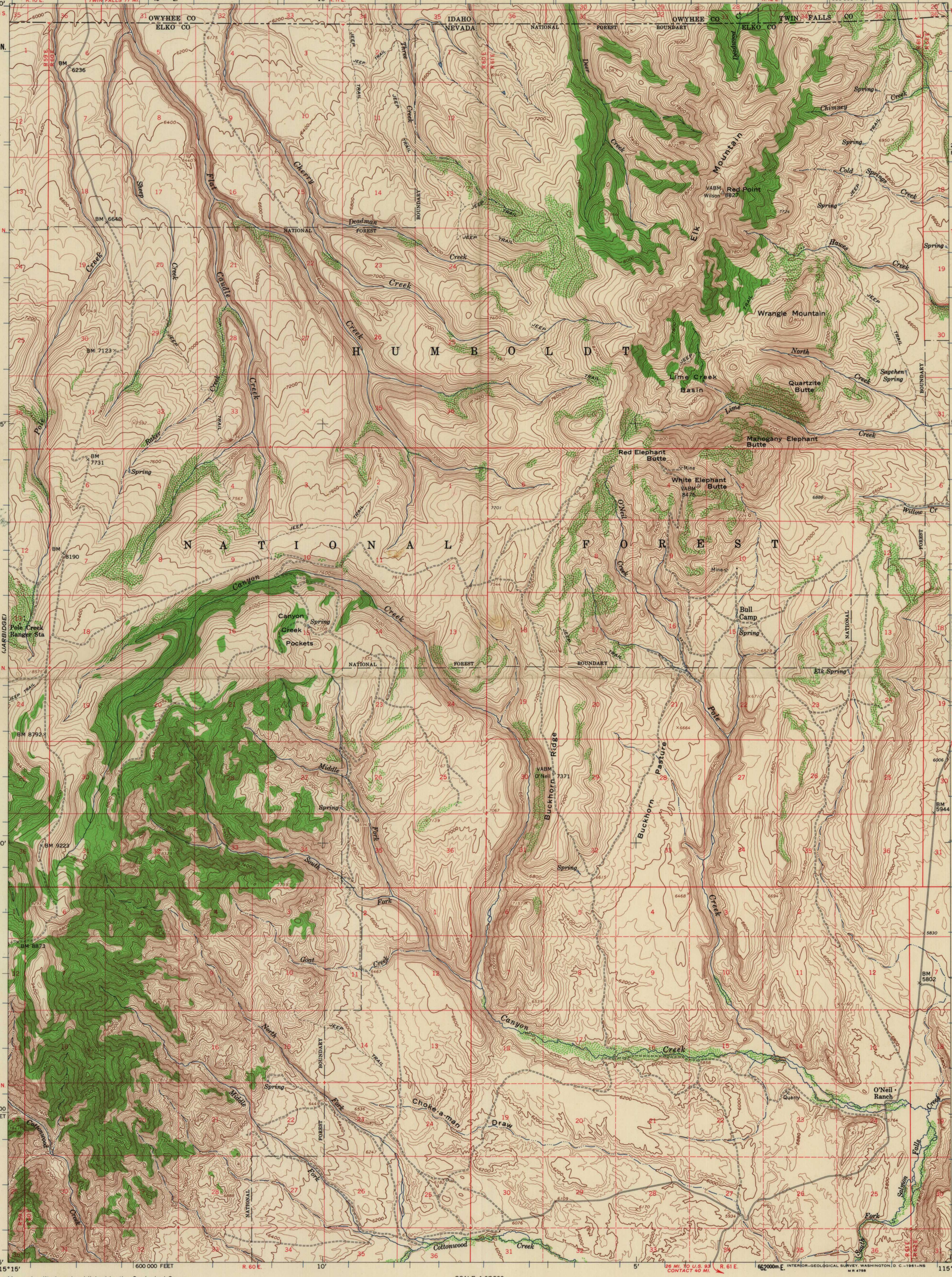
ELK MOUNTAIN QUADRANGLE
NEVADA–IDAHO
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

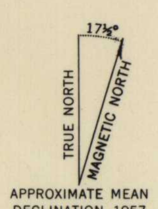
Control by USGS and USC&GS

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1956. Advance field check 1957

Polyconic projection. 1927 North American datum
10,000-foot grid based on Nevada coordinate system, east zone
1000-meter Universal Transverse Mercator grid ticks,
zone 11, shown in blue

Dashed land lines indicate approximate locations

Land lines unsurveyed in T. 47 N.–R. 61 E.



APPROXIMATE MEAN
DECLINATION, 1957

SCALE 1:62500

1 ½ 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER 25, COLORADO OR WASHINGTON 25, D. C.
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QUADRANGLE LOCATION

ROAD CLASSIFICATION

Light-duty ———— Unimproved dirt ========

ELK MOUNTAIN, NEV.–IDAHO
N4145–W11500/15

1957