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RECONNAISSANCE OF CENOZOIC SEDIMENTARY ROCKS OF NEVADA[1]

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ABSTRACT

Throughout Nevada the most reliable stratigraphic datum in sequences of non-marine Cenozoic sedimentary rocks is a distinctive suite of tuffaceous upper Miocene to middle Pliocene deposits. For convenience of discussion these rocks are referred to as the vitric tuff unit.

In eastern Nevada and adjacent Utah the vitric tuff unit is locally underlain by red and tan Paleozoic-pebble conglomerate, some of which is as old as Cretaceous. Scattered outcrops of lower Cenozoic (largely Eocene) limestone and associated reddish brown conglomerate in east-central Nevada and western Utah probably are equivalent to the Wasatch formation in Utah. A distinctive sequence of limestone and oil shale found locally in northeastern Nevada probably is Oligocene in age.

Over an extensive part of southern, central, and western Nevada, as well as locally in the northeastern part of the state, rocks below the vitric tuff unit are essentially rhyolitic to dacitic agglomerate and coarse tuff, welded tuff, and lava. This sequence apparently accumulated principally between Oligocene and late Miocene time and was associated in a general way with important deformation of the region that faulted and tilted older Cenozoic sequences.

Following a middle Cenozoic episode of deformation and erosion, the vitric tuff unit, consisting chiefly of soft unaltered tuff, bentonitic mudstone, sandstone, limestone, and diatomite, began to accumulate in late Miocene time in southern, central, and western Nevada while deposits of limestone, carbonaceous and bituminous shale, sandstone, and conglomerate, containing partly altered tuffaceous débris, formed in northeastern Nevada. In early Pliocene time, during an episode of extensive aggradation accompanied by eruption of the younger Sierran and southern Cascade andesitic rocks, the vitric tuff facies accumulated throughout most of the state, and it continued to accumulate locally in middle Pliocene time.

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Important uplift of the Sierra Nevada accompanied large-scale block-faulting and regional uplift that began in later Pliocene time and produced the present structual and topographic pattern of Nevada.

Even though a middle Cenozoic and a post-early to middle Pliocene episode of deformation may have predominated throughout much of the state, local areas had varying tectonic and depositional histories during the Cenozoic era.

INTRODUCTION

Oil companies exploring the petroleum possibilities of Nevada and western Utah (Picard, 1955; Picard and Wise, 1956; Smith, 1956) have assembled considerable information about non-marine Cenozoic fossils and sedimentary rocks of the region. Many of the unpublished data and conclusions have been made available to the writer who has reviewed and amplified them during two and one half summers of field work, principally in eastern and central Nevada. The results, supplemented by published information, much of which was summarized by Nolan in 1938 (1943, pp. 163–71), are presented here as a general survey of present knowledge of the Cenozoic geology of Nevada.

Such general treatment unfortunately obscures many of the more detailed differences and overemphasizes suggestive similarities among stratigraphic sections and fossil assemblages. Moreover, many of the conclusions are necessarily incomplete and some of the ideas undoubtedly will be proved wrong. Nevertheless, the available material is summarized in this preliminary report because it is essential to any study of the Cenozoic sedimentary and structural history of the Basin-and-Range Province.

GENERAL SETTING

Many assemblages of late Miocene and early and middle Pliocene fossils have been found in Nevada (Fig. 2). Throughout most of the state they occur in deposits consisting largely of interbedded soft gray to cream-colored vitric tuff and reworked ash, drab bentonitic mudstone, yellowish to greenish gray sandstone, cream-colored aphanitic limestone, and white diatomite (Fig. 5). As a result, this distinctive suite of upper Miocene to lower and middle Pliocene rocks serves as a useful stratigraphic datum. Numerous names, including Esmeralda, Humboldt, and Truckee (Fig. 5), have been applied to the deposits. Except for the detailed study of Axelrod (in press, 1956), however, few attempts have been made to determine their proper application and extension. In order to emphasize the regional uniformity of this relatively well dated tuffaceous facies it is called the "vitric tuff unit." Published names are used here only for convenience of reference (Fig. 6).

L. Mio → M. Plio

The primary purposes of the present report is to summarize the paleontologic record and describe briefly the regional variations in the vitric tuff unit. Although rock units assigned to it differ somewhat in age and lithologic features, they are, nonetheless, products of a generally distinctive and uniform episode of sedimentation in the Cenozoic history of Nevada.

In some areas, deposits of the vitric tuff facies are middle Pliocene in age, but more commonly middle Pliocene and younger sedimentary rocks in Nevada are predominantly buff to yellowish gray tuffaceous sandy mudstone and sandstone interbedded with conglomerate containing pebbles derived principally from Paleozoic rocks.

Cenozoic rocks that occur locally below or are older than the extensive vitric tuff unit differ lithologically from one part of the region to another and are nonfossiliferous or yield fossils indicating different ages (Fig. 4).

Study of regional relationships of the sparsely fossiliferous Cenozoic sedimentary rocks of the Basin-and-Range Province is hampered by widely scattered outcrops and only partly exposed sections. Most broad areas presumably underlain by these deposits are covered by recent alluvium and colluvium, or by extensive sheets of lava and welded tuff. Some well exposed sections are the result of erosion of basins by the Humboldt drainage system in northeastern Nevada, by the Walker drainage system in western Nevada, and by the Meadow Valley Wash and its tributaries in southeastern Nevada. Most good exposures, however, are in belts of faulted and tilted rocks along and in the ranges where incomplete sequences generally are faulted against older rocks.

PALEONTOLOGIC DATA

Geologic ages assigned to the upper Cenozoic rocks of Nevada are based largely on assemblages of fossil mammals and plants (Fig. 2). Fossil fish, snails, pelecypods, ostracods, and diatoms also occur sparingly in these deposits. Sedimentary rocks that lie below the vitric tuff unit, or are older, have been dated locally on the basis of collections of fossil snails, ostracods, and leaves. Inasmuch as the geologic age of non-marine snails and ostracods commonly is difficult to determine, correlations based on these fossils must be considered tentative. Information about the age of some of the collections has generously been furnished by D. I. Axelrod, Erling Dorf, M. F. Skinner, D. W. Taylor, and J. T. C. Yen. In addition, ages assigned to most of the collections of fossil leaves are from papers published by Axelrod (especially 1950), and those assigned assemblages of fossil mammals from western Nevada are largely from Stirton's papers (especially 1940).

This report follows the nomenclature and correlation of North American non-marine Cenozoic rocks based on fossil mammals (Wood *et al.*, 1941) in considering Barstovian age as late Miocene, and Clarendonian age as early Pliocene. Accordingly, early Clarendonian floras, considered to be transitional Miocene-Pliocene by paleobotanists (Chaney, 1944, Tables 33, 34) and so indicated by a special symbol in Figure 2, are here assigned an early Pliocene age (Fig. 6). Several of the collections of fossil mammals are inadequate for precise age determination. Nevertheless, they can be identified as being either late Miocene or early Pliocene in age and are represented by a special symbol in Figure 2.

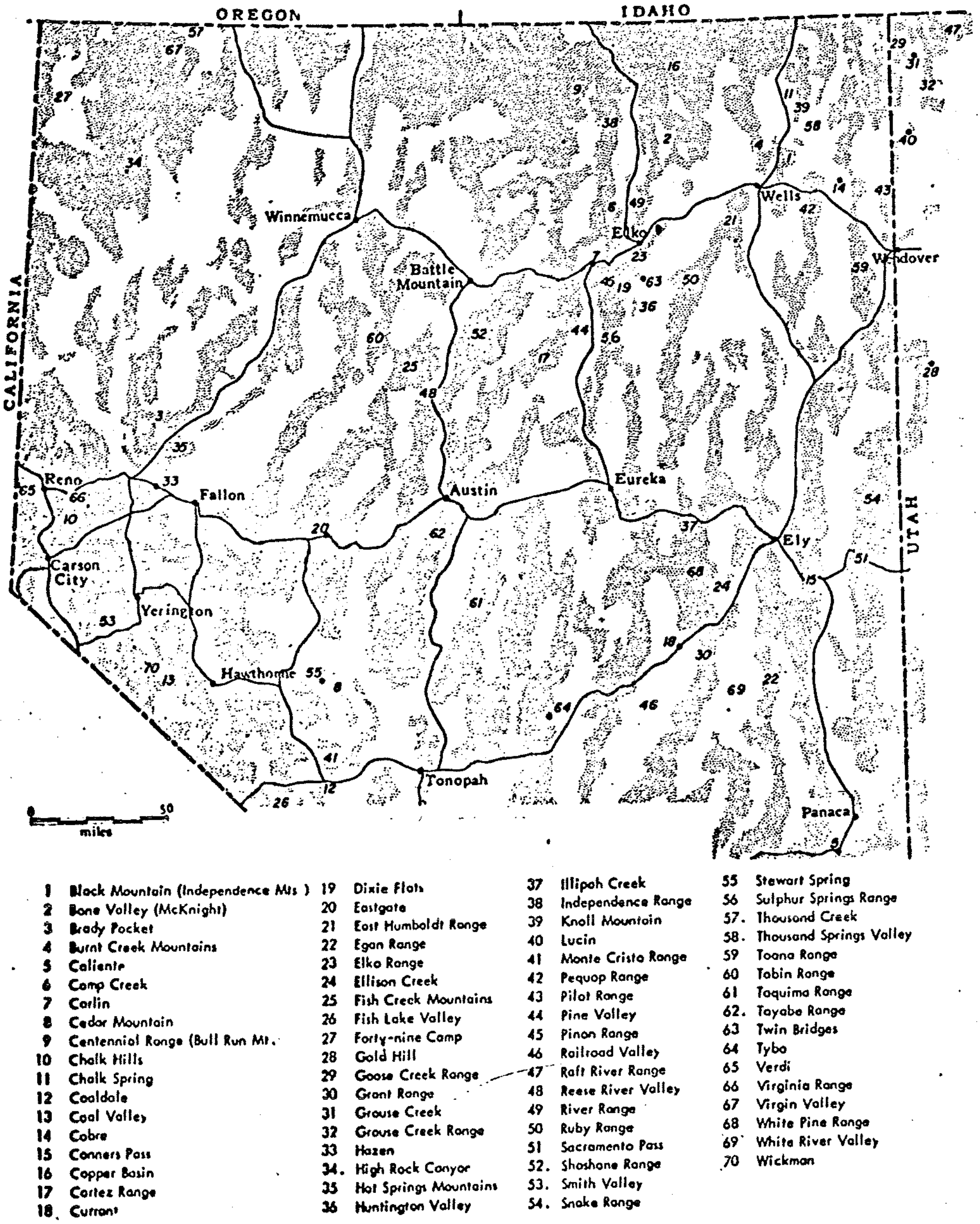

FIG. 1.—Index map. Upland areas stippled.

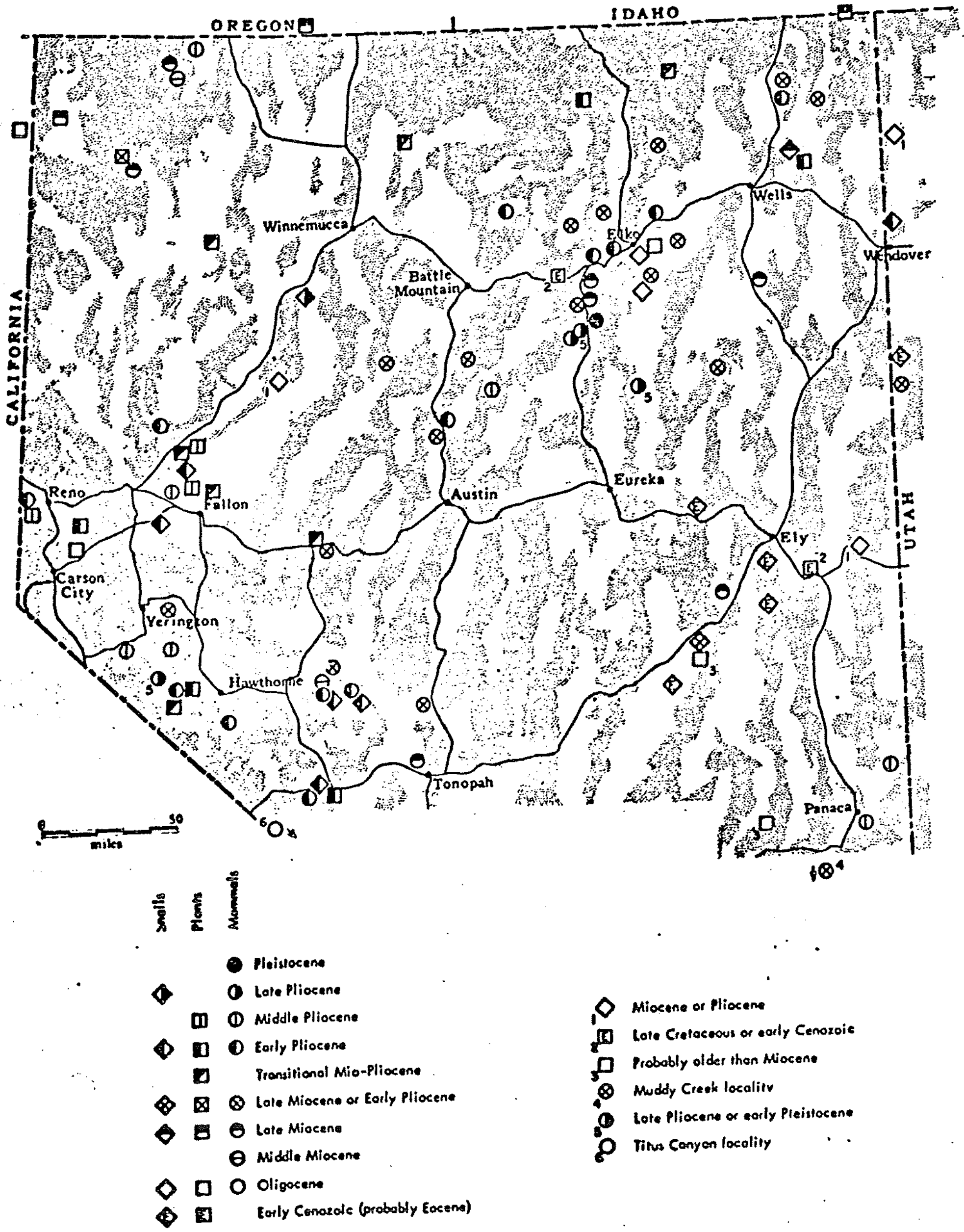

FIG. 2.—Cenozoic fossil localities.

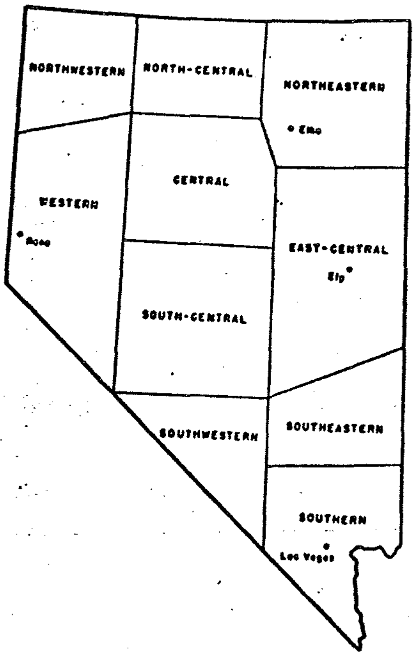

FIG. 3.—Geographic subdivisions of Nevada referred to in text and in Figure 6.

ROCKS BELOW VITRIC TUFF UNIT

Throughout its wide extent the upper Miocene to lower and middle Pliocene vitric tuff unit is underlain by four different sequences of rocks (Fig. 4) which in turn overlie Paleozoic and Mesozoic rocks. For convenience of reference in this paper, these sequences are given rather arbitrary designations.

Eastern conglomerates (Fig. 4, C).—In the area east of the Grouse Creek Range and between the Goose Creek and Raft River ranges in northwestern Utah the lower sequence consists of undated reddish brown and tan conglomerate and breccia containing pebbles and cobbles derived from Paleozoic rocks. One of these very coarse-grained deposits more than a thousand feet thick is exceptionally well exposed along the abandoned Southern Pacific Railroad (N. $\frac{1}{2}$, T. 9 N., R. 14 W.) south of Utah state route 70, 18 miles northeast of Lucin, Utah. Several thousand feet of similar undated conglomerate with lenses of limestone and quartzite breccia, overlain by upper Cenozoic tuffaceous limestone and mudstone on the east flank of the Snake Range in east-central Nevada, crops out in Sacramento Pass north of U. S. Highway 6 and 50, about 12 miles west of the Nevada-Utah border (N. $\frac{1}{2}$, T. 14 N., R. 69 E.). Here the reddish brown conglomerate interfingers with non-marine limestone and mudstone rather similar to lower Cenozoic deposits in east-central Nevada.

In these widely separated outcrops, the eastern conglomerates are nonconformably overlain by sequences assigned to the vitric tuff unit, and their coarseness and composition stand in marked contrast to the finer-grained, volcanic-rich younger deposits. Significantly, some of the coarse deposits are preserved in ranges, and others crop out in lowlands far from a range border, thus suggesting that some of the source areas did not coincide with the present ranges.

Christiansen (1952, pp. 733–35) postulated that the conglomerate on the east flank of the Snake Range and similar undated Indianola? conglomerate in the Canyon Range in central Utah, as well as conglomerate in the Lower Cretaceous Newark Canyon formation (Nolan, Merriam, and Williams, 1956, pp. 68–70) in the vicinity of Eureka, Nevada, were products of an early Cretaceous Cedar Hills orogeny (Eardley, 1951, pp. 242, 274). Clearly such extended correlation based only on lithologic similarity and general stratigraphic position is no more than suggestive. The reddish brown conglomerates in northwestern Utah and east-central Nevada, for example, may be equivalent to the Paleocene or lower Eocene "Wasatch" conglomerate of north-central Utah instead.

Lower Cenozoic sedimentary rocks (Fig. 4, L).—In numerous localities in east-

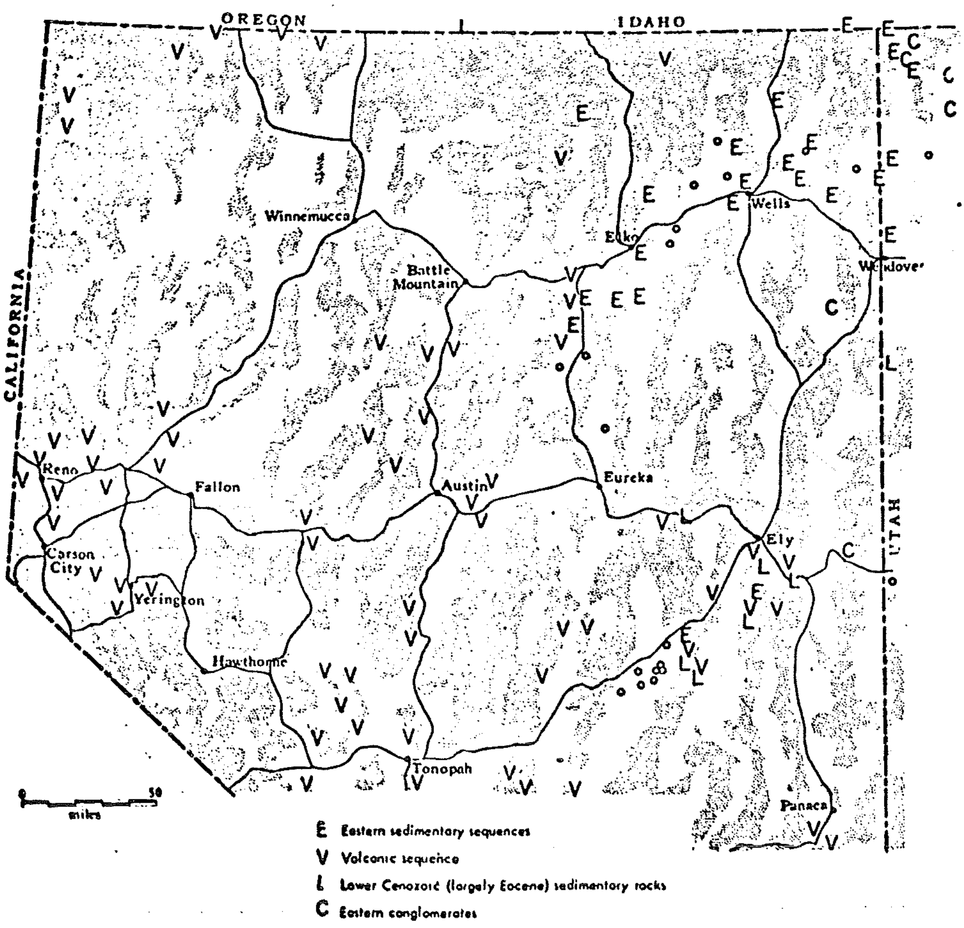

FIG. 4.—Cenozoic rocks below vitric tuff unit. o=oil wells and dry holes that penetrated thick sections of Cenozoic rock (Picard, 1955; Picard and Wise, 1956; and Smith, 1956).

central Nevada, as well as in the Gold Hill area (T. 7 S., R. 18–19 W.) of adjacent Utah (Nolan, 1935a, pp. 42–43), there are outcrops of aphanitic non-marine limestone and mudstone dated locally as early Cenozoic (probably Eocene) on the basis of fossil snails and ostracods. Commonly the lower Cenozoic limestone unit is several hundred feet thick, has a petroliferous odor, and is overlain by volcanic rocks. Moreover, the limestone generally overlies conformably, or is interbedded with, reddish brown Paleozoic-pebble conglomerate as much as several hundred feet thick, as seen in the vicinity of U. S. Highway 50 near Illipah Creek, about 35 miles west of Ely (SE. ¼, T. 18 N., R. 58 E.; NE. ¼, T. 17 N., R. 58 E.), and along the east side of the Egan Range less than 10 miles south of Ely (E. ½, T. 15 N., R. 63 E.).

Similar lower Cenozoic (possibly Upper Cretaceous) limestone and dark shale overlain by a thick section of welded tuff are present in some of the oil wells and dry holes in Railroad Valley (Fig. 4). In the non-productive stratigraphic tests drilled in northeastern Nevada, on the other hand, no lower Cenozoic rocks have been recognized. An exceptionally thick section of lower Cenozoic rocks crops out on the west side of the Egan Range (E. ½, T. 10 N., R. 62 E.), 35 miles south of Ely, where several thousand feet of limestone and shale conformably overlie a thick deposit of Paleozoic-pebble conglomerate. Outcrops of sandstone and dark shale in the vicinity of Connors Pass (SE. ¼, T. 14 N., R. 65 E.) on U. S. Highway 6, 11 miles southeast of Ely, as well as in Immigrant Pass (NE. ¼, T. 32 N., R. 50 W.) 30 miles west of Elko, have been dated tentatively as late Cretaceous or early Cenozoic on the basis of fragmentary plant remains.

On the basis of general stratigraphic position and lithologic character, the lower Cenozoic limestone in east-central Nevada may be equivalent to the limestone-bearing Horse Spring formation in southernmost Nevada and the Claron limestone[3] and Wasatch formation in western and southwestern Utah. Non-marine limestones in central Utah that apparently range in age from late Cretaceous to Eocene, also overlie or are interbedded with conglomerate (Nolan, 1943, p. 164).

Although the known lower Cenozoic sedimentary rocks are limited to eastern Nevada and adjacent Utah, their correlatives probably are present in some of the older volcanic rocks in the middle and western parts of Nevada (Gianella, 1936, pp. 50–52).

Volcanic sequence (Fig. 4, V).—Over an extensive part of central, southern, and western Nevada rocks below the vitric tuff unit are essentially volcanic deposits composed chiefly of coarse tuff and agglomerate, welded tuff, and lava. Inasmuch as these rocks commonly are mineralized (Ferguson, 1929, pp. 131–41) they have been described in detail locally. In many places they consist of several distinct sequences, including deposits of rhyolite, quartz latite, dacite, and

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[3] If this correlation is correct, the tuffaceous and saline content of the Horse Spring and Claron formations points to somewhat different conditions of deposition on the south.

acidic andesite. Moreover, some sections contain a subordinate amount of fine-grained waterlaid tuff.

The volcanic sequence has been estimated to be Miocene in age in a number of areas, but on the basis of available evidence it can only be stated that accumulation of the sequence ended sometime during the Oligocene to late Miocene interval.

In east-central Nevada the volcanic sequence generally overlies lower Cenozoic sedimentary rocks and is overlain by a thick section of volcanic-pebble conglomerate and limestone which yields fossil leaves that are probably older than Miocene. On the west side of Pine Valley (NE. ¼, T. 29 N., R. 51 E.; SE. ¼, T. 30 N., R. 51 E.) in central Nevada the volcanic sequence in the Cortez Range is overlain by a pre-late Miocene deposit of Paleozoic-pebble conglomerate. Throughout most of its extent, on the other hand, the volcanic sequence is nonconformably overlain by the vitric tuff unit, as in the vicinity of Cedar Mountain (T. 8 N., R. 37–38 E.) and in the Tonopah district (T. 2–3 N., R. 42 E.). According to Nolan (1935b, p. 16), however "the age difference between the Tonopah [at the bottom of the sequence in the Tonopah district] and Esmeralda formations may not be as great as the pronounced angular unconformity between them led the writer to suppose at first."

In western Nevada the lower Pliocene (transitional Mio-Pliocene in lowest part) Kate Peak andesite and its equivalents in the vitric tuff unit lie nonconformably on the Alta andesite (Gianella, 1936, p. 58) whose Sutro tuff member is middle Oligocene in age (Axelrod, personal communication, 1955). Older Cenozoic volcanic rocks below the Alta andesite are probably correlative with middle and upper Eocene auriferous gravels and associated volcanic rocks of the Sierra Nevada region (Gianella, 1936, pp. 50–52; MacGinite, 1941, pp. 8–10) In northwestern Nevada and adjacent California, upper Miocene deposits of the Cedarville andesitic series overlie rocks of middle Oligocene age (Axelrod, personal communication, 1955) that generally have been called the lower part of the series.

Pertinent general reports describe the volcanic sequence and its relation to the vitric tuff unit or equivalent rocks in the following areas: the Jarbidge Mountains in northeastern Nevada (Schrader, 1912), the Shoshone, Fish Creek, and Tobin ranges in central Nevada (Ferguson, Muller, and Roberts, 1951; Muller, Ferguson, and Roberts, 1951); the Tonopah (Nolan, 1930, 1935b) and Tybo (Ferguson, 1933) districts in south-central Nevada; Cedar Mountain and the eastern part of the Monte Cristo Range in south-central Nevada (Ferguson, Muller, and Cathcart, 1953); and the Silver City district at the southern end of the Virginia Range southeast of Reno (Gianella, 1936).

In east-central Nevada the volcanic sequence overlying lower Cenozoic sedimentary rocks is thick and widespread, but there are few well exposed remnants of the overlying vitric tuff unit to serve as a stratigraphic datum. The general stratigraphic relationships in this part of the state are best shown in exposures in the Egan Range southeast of Preston about 30 miles south of Ely, on the west flank of the Grant Range east of Currant 50 miles southwest of Ely, and in some of the oil wells and dry holes drilled in Railroad Valley. The Currant tuff and associated volcanic rocks (Faust and Callaghan, 1948, pp. 19–49) exposed about 29 miles southwest of Ely probably are part of the volcanic sequence.

The volcanic sequence is also well developed in southeastern and southern Nevada. In the vicinity of Caliente (T. 3 and 4 S., R. 67 E.) it is non-conformably overlain by the lower? and middle Pliocene Panaca formation. Similarly, north and west of Lake Mead the upper Miocene or lower Pliocene Muddy Creek formation lies non-conformably on a thick succession of volcanic rocks (SE. ¼, T. 21 S., R. 63 E.) that is widespread in the surrounding region (Hunt, McKelvey, and Wiese, 1942, p. 302).

Significantly, the distinctive volcanic sequence in Nevada is correlative in a general way with a rather similar suite of lower to middle Cenozoic crystal and vitric tuff, welded tuff, and lava in southwestern and southwest-central Utah (Mackin, Cook, and Threet, 1954; Callaghan, 1939), the lower part of which has been included in the Brian Head formation (Gregory, 1945, pp. 105–110; Threet, 1952).

The northeasternmost locality showing the stratigraphic relations between the volcanic sequence and overlying tuffaceous deposits is on the east flank of the Cortez Range at the north end of Pine Valley (NE. ¼, T. 31 N., R. 51 W.). Farther northeast there is no volcanic rock beneath the vitric tuff unit, except for a 50-foot sequence of tuff, pumice-tuff, and agglomerate at the base of an eastern sedimentary sequence (3, p. 2811) that probably is equivalent to the Payette formation (W. ½, T. 39 N., R. 65 E.). Nevertheless, in the Jarbridge and Copper mountains in northeastern Nevada (Schrader, 1912, pp. 36–46) several thousand feet of mineralized rhyolite and quartz latite welded tuff and lava are nonconformably overlain by lower Pliocene rhyolite lava and thin welded vitric tuff of the Snake River Plain to the north. Volcanic rocks equivalent to the Jarbidge sequence apparently were penetrated in the Gulf Oil Corporation's Marys River Federal test No. 1 (Sec. 16, T. 41 N., R. 60 E.). Moreover, a similar mineralized series of lava and pyroclastic rock is also present in the Tuscarora district (T. 39–40 N., R. 51 E.) west of the Independence Range (Ferguson, 1929, p. 133).

In north-central and northwestern Nevada, on the other hand, volcanic rocks below the vitric tuff unit consist of as much as several thousand feet of andesitic to basaltic lava. Presumably much of this flow rock is equivalent to the middle Cenozoic Columbia River basalt at the north.

Eastern sedimentary sequences (Fig. 4, E).—At scattered localities chiefly in northeastern Nevada and adjacent south-central Idaho and northwestern Utah, the vitric tuff unit is underlain by variable but rather distinctive sequences of sedimentary rocks as much as several thousand feet thick. As a group these rocks generally comprise varying amounts of tan and yellowish gray sandstone and platy silicified limestone and mudstone, cream-colored limestone, drab mudstone, and Paleozoic-pebble conglomerate that commonly is green-stained. They are also characterized by subordinate amounts of carbonaceous and bituminous shale.

Sequences included in this category probably are deposits of at least two episodes of accumulation. Moreover, some undated outcrops described here may be lateral facies of the vitric tuff unit, or equivalent deposits that accumulated in local basins. Rocks of an eastern sedimentary sequence below the vitric tuff unit apparently were penetrated in the lower part of some of the Cenozoic stratigraphic tests drilled in northeastern Nevada.

The principal sequences assigned to this category are known from outcrops in the following areas.

1. In the Goose Creek area of northwesternmost Utah and adjacent Idaho and Nevada, a 2,000-foot sequence characterized by carbonaceous and brittle bituminous shale and petroliferous limestone has been assigned to the upper Miocene Payette formation (Andrews, 1947, p. 6). These deposits are well exposed on the east flank of the Goose Creek Range (T. 13 N., R. 18 W.) 8–10 miles north-northeast of the village of Grouse Creek, Utah, as well as in scattered outcrops on the west flank of the Grouse Creek Range (S. ½, T. 12 N., R. 17 W.), several miles east of Grouse Creek.

2. On the northeast flank of the Pilot Range (SW. ¼, T. 7 N., R. 18 W.; NW. ¼, T. 6N., R. 18 W.), several miles southwest of Lucin, Utah, a 2,500-foot section, that contains some beds of organic shale, yields fossil snails of Miocene or Pliocene age.

3. At the northeast end of the Black Mountains (Independence Mountains) about 22 miles northeast of Wells, Nevada (SE. ¼, T. 40 N., R. 64 E.; SW. ¼, T. 40 N., R. 65 E.; and W. ½, T. 39 N., R. 65 E.), more than 4,000 feet of Cenozoic strata lies non-conformably below the vitric tuff unit which is widespread in the surrounding area. The lower part of the sequence comprises massive snail- and ostracod-bearing limestone, thick volcanic-pebble conglomerate, and pumice-lapilli tuff and agglomerate at the base. The upper part is principally platy silicified mudstone and limestone that yield fossil leaves and fish.

Fossil snails from a thin limestone at the base of the sequence are possibly late Miocene in age (John T. C. Yen, personal communication, 1955), and fossil leaves from the platy beds in the middle of the section are late Miocene or early Pliocene in age.

Undated bituminous shale and tuffaceous mudstone at the southern end of this outcrop area (Sec. 4, T. 38 N., R. 65 E.) are exposed in a Southern Pacific Railroad cut at the north end of the Pequop Range. These beds probably are part of the upper Miocene-lower Pliocene sequence although they are lithologically very similar to the oil-shale deposit at Elko, Nevada (6).

4. On the west flank of the Toana Range (E. ½, T. 37 N., R. 67 E.) southeast of Cobre, Nevada, and on the west flank of Knoll Mountain in the vicinity of Knoll Creek and Chalk Spring (W. ½, T. 43 N., R. 64 E.), 40–45 miles north of Wells, Nevada, the lower 1,000–1,500 feet of strata assigned to the Humboldt formation is drabber and more consolidated than the conformably overlying vitric tuff unit. Lithologically similar deposits crop out at the southwest end of Burnt Creek Mountain (SW. ¼, T. 38 N., R. 62 E.) a few miles west of Wells and at the northeast end of the East Humboldt Range (SE. ¼, T. 37 N., R. 61 E.) about 7 miles southwest of Wells. Coarse fanglomerate and breccia composed of Paleozoic fragments are especially common southwest of Wells. Significantly, no carbonaceous or bituminous shale is present in these sections.

5. In the valley between Independence Range and Centennial Range (Bull Run Mountain), about 60 miles north of Elko (in central part of T. 43 N., R. 52 E.), tan and drab sandstone, platy mudstone, and carbonaceous shale underlie the vitric tuff unit. Fossil leaves from these beds are late Miocene or early Pliocene in age.

6. South and east of Elko on the northwest flank of Elko Range (SE. ¼, T. 34 N., R. 55 E.) a 1,000-foot section consisting of well bedded yellowish gray tuffaceous mudstone and sandstone, with subordinate amounts of limestone, carbonaceous and bituminous shale, bedded chert and silicified mudstone, and Paleozoic-pebble conglomerate, includes the well known Elko oil shale (Winchester, 1923, pp. 91–102). A characteristic feature of the deposit is the presence of considerable, partly altered biotitic vitric tuff.

Very similar undated beds crop out along Coal Creek on the east flank of the River Range (NE. ¼, T. 37 N., R. 56 E.), 24 miles northeast of Elko, and on the west flank of Burnt Creek Mountain (N. ½, T. 40 N., R. 61 E.), 20 miles north-northwest of Wells. Each of these outcrops of tuffaceous oil shale is unconformably overlain by the vitric tuff unit or by younger volcanic rock.

Deposits of these oil-shale sequences yield poorly preserved leaves, fish, insects, snails, and ostracods. Fossil snails from the Elko area suggest Eocene or Oligocene age, whereas fossil leaves are early Miocene or late Oligocene in age (D. I. Axelrod, personal communication, 1954). On this evidence, the Elko oil shale is apparently correlative with the lower part of the John Day formation (Bridge Creek flora) in central Oregon, or is only slightly younger. A few insects from the Burnt Creek Mountain locality suggest that these beds may be about the same age as the Florissant formation in the Front Range of Colorado (F. M. Carpenter, personal communication, 1954) which is of Oligocene age according to MacGinitie (1953, pp. 70, 75).

At the south end of the Elko area (Sec. 34 and 35, T. 34 M., R. 55 E.) the oil-shale sequence is overlain by petroliferous limestone which yields snails of early Cenozoic (pre-Miocene) age (D. W. Taylor, personal communication, 1956).

7. In Huntington Valley and Dixie Flats, and especially well exposed in the vicinity of Twin Bridges (SE. ¼, T. 32 N., R. 55 E.; NE. ¼, T. 31 N., R. 55 E.), about 20 miles south of Elko, rocks below the vitric tuff unit consist of as much as 1,000 feet of aphanitic ostracod- and snail-bearing limestone, some of which is tuffaceous, together with some mudstone and a few layers of platy chert. The basal beds are reddish brown Paleozoic-pebble conglomerate and sandy limestone overlain by about 150 feet of dark platy petroliferous limestone and a subordinate amount of crumbly dark carbonaceous mudstone. Outcrops of the carbonaceous deposits occur as far west as the east flank of the Piñon Range, 20 miles southwest of Elko.

Snails from outcrops of the limestone in the vicinity of Twin Bridges, as well as from its northern extension at the south end of the Elko area, are early Cenozoic (pre-Miocene) in age (D. W. Taylor, personal communication, 1956).

8. In east-central Nevada tuffaceous deposits assigned to the vitric tuff unit commonly overlie an exceptionally thick section of sedimentary rocks which rests on a volcanic sequence. On the west flank of the Grant Range east of Currant (NE. ¼, T. 10 N., R. 58 E.) the lower several thousand feet of the section consists of rather well bedded sandstone and conglomerate with abundant pebbles and cobbles and scattered boulders of volcanic rock, as well as some beds of limestone. Fossil leaves from the uppermost beds in this part of the section are probably older than Miocene. The upper part of the thick Currant section is composed of platy limestone, calcareous mudstone, and beds of chert. Fossils snails from these upper beds are late Miocene or early Pliocene in age. If the dating of the lower and upper parts of the section is correct, there apparently was no important deformation in this part of the Grant Range during most of Miocene time.

9. On the west side of Pine Valley (NE. ¼, T. 20, N. R. 51 E.; SE ¼, T. 30 N., R. 51 E.) a thick deposit of Paleozoic-pebble conglomerate and sandstone whose lower beds contain abundant volcanic detritus, overlies a volcanic sequence and is overlain by tuffaceous deposits of late Miocene age (10).

Although this thick conglomerate may be correlative with some of the eastern conglomerates (Fig. 4.C) or with lower Cenozoic conglomerates and limestone (Fig. 4.L) in eastern Nevada and adjacent Utah, its stratigraphic position above a volcanic sequence suggests that it is younger than Eocene.

10. At the north end of Pine Valley (E. ½, T. 31 N., R. 51 E.; NW. ¼, T. 31 N., R. 52 E.) the lower part of a tuffaceous upper Miocene sequence consists of about 1,500 feet of coarse-grained volcanic-rich sedimentary rocks including welded pumice lapilli tuff and volcanic-pebble conglomerate. This deposit, which locally overlies the thick Paleozoic-pebble conglomerate exposed on the west side of Pine Valley (9) and lies conformably beneath beds assigned to the vitric tuff unit, is unique among the eastern sedimentary sequences in its abundant locally derived volcanic débris.

In addition to these eastern sequences, sedimentary rocks older than the vitric tuff unit are locally present farther west. On the east flank of the Tobin Range (W. ½, T. 27–28 N., R. 40 E.) in central Nevada, for example, more than a thousand feet of drab bentonitic and tuffaceous mudstone overlying a volcanic sequence is conformably overlain by the vitric tuff unit. Sedimentary sequences below the vitric tuff unit probably are also present in the lower part of sections assigned to the Esmeralda and Truckee formations in the western part of the state. In the northern Death Valley region in southwestern Nevada and adjacent California, tuffaceous mudstone, sandstone, and conglomerate of the lower Oligocene Titus Canyon formation are overlain by several thousand feet of interbedded volcanic and sedimentary rocks of the Oligocene? or lower Miocene? Artist Drive formation.

In contrast to the lower Cenozoic sedimentary rocks of east-central Nevada the eastern sequences contain considerable tuffaceous material that generally consists of partly altered shards. In contrast to the overlying vitric tuff unit they contain less unaltered volcanic material, more limestone (commonly petroliferous), more organic shale, and more coarse detrital material, and they are more consolidated. Among the eastern sequences the thick conglomeratic section in east-central Nevada (8) and the coarse conglomerate (9) and the volcanic-rich unit in Pine Valley (10) overlie a volcanic sequence whereas the eastern sequences located in northeastern Nevada overlie non-volcanic rocks.

Present evidence suggests that the oil-shale deposit at Elko, the similar rocks on the east flank of the River Range, and possibly the remnant on the west flank of Burnt Creek Mountain (6), together with the limestone in Huntington Valley and Dixie Flats (7), constitute an Oligocene? tuffaceous, bituminous-rich formation of limited geographic extent in northeastern Nevada. These rocks have commonly been considered the lower part of the Humboldt formation (Sharp, 1939, pp. 142–43), but apparently they are, instead, a distinct, older formation. There is no good evidence for assigning any other sections to this Oligocene? formation. Nevertheless, some of the undated deposits in northeastern Nevada may be proved part of it, and at least the lower part of the thick section in east-central Nevada, if correctly dated, is equivalent to it.

Although the Oligocene? formation is exposed on the flanks of the broad structural basin between Elko and Wells, no certain evidence of this sequence was found in any of the five dry holes drilled in the basin. Significantly, however, the Gulf Oil Corporation's Wilkins Ranch test No. 1 (Sec. 21, T. 38 N., R. 61 E.) had a good showing of oil in rocks which may be part of the formation. The lack of lithologic similarity between the Cenozoic sequences at the border of the basin and those within the basin suggests that the present structural outline may differ from that of middle Cenozoic time.

The lithologically similar upper Miocene to lower Pliocene deposits in the Goose Creek area (1), near Lucin (2), northeast of Wells (3), and north of Elko (5) are rather distinct from the vitric tuff unit and at least locally non-conformable below it. Tentatively, they are considered to be correlative with or part of the Payette formation of southwestern Idaho. In addition, these deposits may be equivalent to the limestone in the upper part of thick section east of Currant.

The sequences on the west flank of the Toana Range and of Knoll Mountain (4) and the volcanic-rich rocks at the north end of Pine Valley (10) are about the same age as the Payette formation and its equivalents on the northeast. But in contrast, they resemble the vitric tuff unit in containing unaltered tuffaceous material and a paucity of organic shale. Some of these sequences may reasonably be assigned to the lower part of a formation that includes the vitric tuff unit.

It should be noted that the rocks of late Miocene age in northeastern Nevada are correlative with tuffaceous, diatomaceous deposits in other parts of Nevada that are assigned to the vitric tuff unit. According to this relationship, the vitric tuff facies began to accumulate somewhat earlier in the west and south than it did in northeastern Nevada.

VITRIC TUFF UNIT

The most extensive and widely exposed sequence of Cenozoic sedimentary rocks in Nevada is late Miocene[4] to early and middle Pliocene in age (Figs. 2, 5).

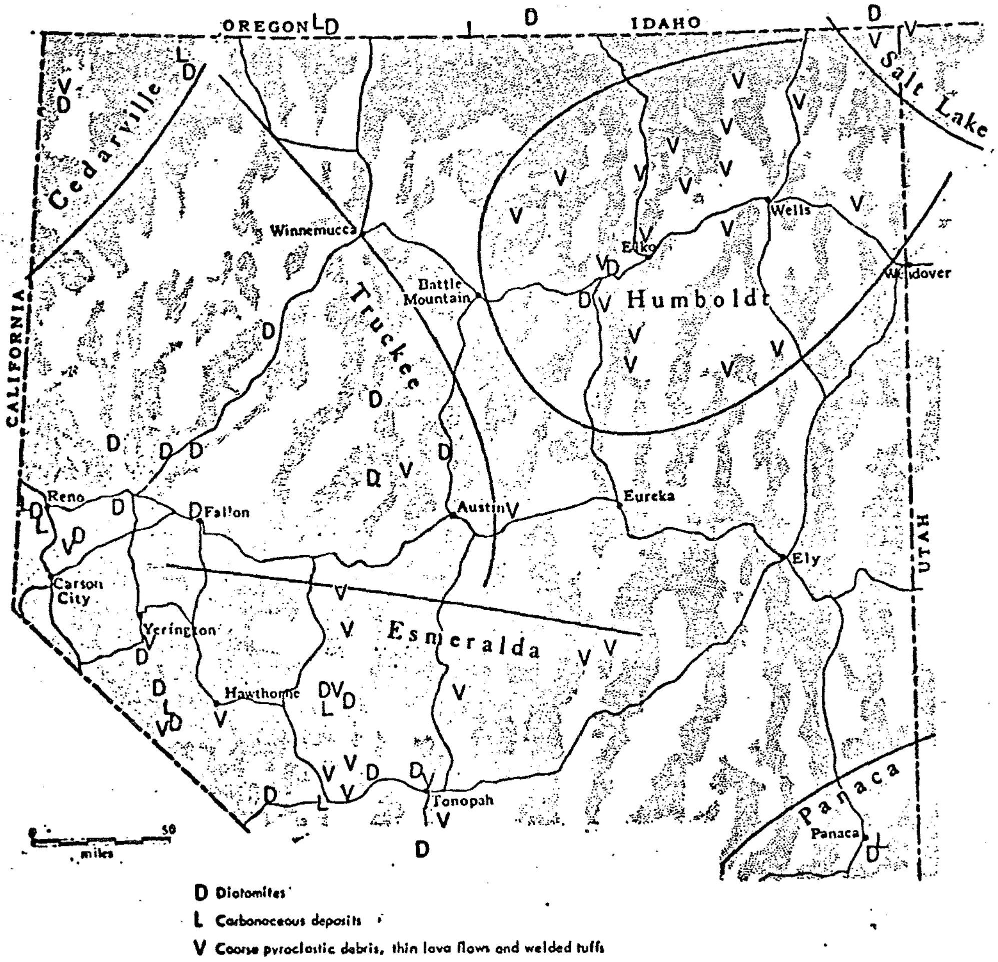

FIG. 5.—Geologic names commonly applied to vitric tuff unit, and some of its distinctive facies.

These deposits comprise as much as several thousand feet of soft gray to cream-colored unaltered vitric tuff and reworked ash, interbedded with drab bentonitic mudstone, and subordinate amounts of yellowish to greenish gray sandstone and cream-colored limestone, as well as Paleozoic-pebble conglomerate developed es-

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[4] The late middle Miocene Stewart Spring mammalian fauna from the Esmeralda formation in south-central Nevada consists of water-worn specimens now preserved in beds of early Pliocene age.

sentially as a coarse basin-margin facies. Locally there are beds of chert, diatomite, bentonite, carbonaceous shale, and crystal tuff. In some places the volcanic débris consists of pumice lapilli tuff, welded tuff, agglomerate, and volcanic-rich conglomerate, suggesting near-by sources. In spite of local sources for much of the coarse volcanic débris, however, there is a rather consistent association of orthopyroxenes and fresh acidic ash in the tuffaceous fraction throughout most of the state (K. S. Deffeyes, 1956, pp. 22–23). Rocks of the vitric tuff unit apparently have been penetrated in most of the oil wells and unsuccessful Cenozoic deep tests drilled in Nevada.

As a result of their wide distribution in contrast to older Cenozoic sequences, deposits of the vitric tuff unit overlap extensively on Paleozoic and Mesozoic rocks, and in these areas of overlap a red-stained basal conglomerate commonly is present.

In areas of volcanic activity, as well as where the strata have been tilted and faulted, the generally soft gray deposits commonly are silicified and stained green, as at the north end of Pine Valley (NW. ¼, T. 31 N., R. 52 E.) and in the middle part of Reese River Valley (N. ½, T. 23 N., R. 43 E.; S. ½, T. 24 N., R. 43 N.).

The lithologic character of the following sequences of the vitric tuff unit has been described in some detail: the Virgin Valley beds in northwestern Nevada (Merriam, 1910, pp. 33–36); the Truckee formation in western Nevada (King, 1878, pp. 412–24); the Esmeralda formation in south-central Nevada (Buwalda, 1914, pp. 342–61); the Humboldt formation in northeastern Nevada (Sharp, 1939, pp. 136–46); the Panaca formation in southeastern Nevada (Westgate and Knopf, 1932, pp. 23–26); and the Muddy Creek formation in southernmost Nevada (Longwell, 1928, pp. 90–96).

In the present report, only the middle part of the sequence generally assigned to the Humboldt formation is considered to be the vitric tuff unit. In view of the fact that the Truckee and Esmeralda formations were not examined in detail during the present study, they have not been similarly subdivided here. It should be pointed, out, however, that Axelrod's detailed work on these deposits (in press, 1956) has led to the recognition of several new formations.

The vitric tuff unit is at least as old as late Miocene (Fig. 2) in northwestern Nevada in the Virgin Valley (N. ½, T. 44 N., R. 25 E.; E. ½, T. 45 N., R. 25 E.), upper Cedarville (NE. ¼, T. 42 N., R. 19 E.), and High Rock Canyon (T. 39 N., R. 23–24 E.) exposures; in south-central Nevada north of Tonopah (W. ½, T. 4 N., R. 42 E.); in central Nevada at the north end of Pine Valley (Sec. 20, T. 31 N., R. 52 E.); in east-central Nevada at the northern end of the White River Valley, 30 miles south of Ely (NE. ¼, T. 13 N., R. 60 E.). The Muddy Creek formation in southernmost Nevada is generally considered to be late Miocene in age, but its scant mammalian fauna may be somewhat younger. In fact, the Muddy Creek formation may be equivalent to at least the lower part of the Panaca formation.

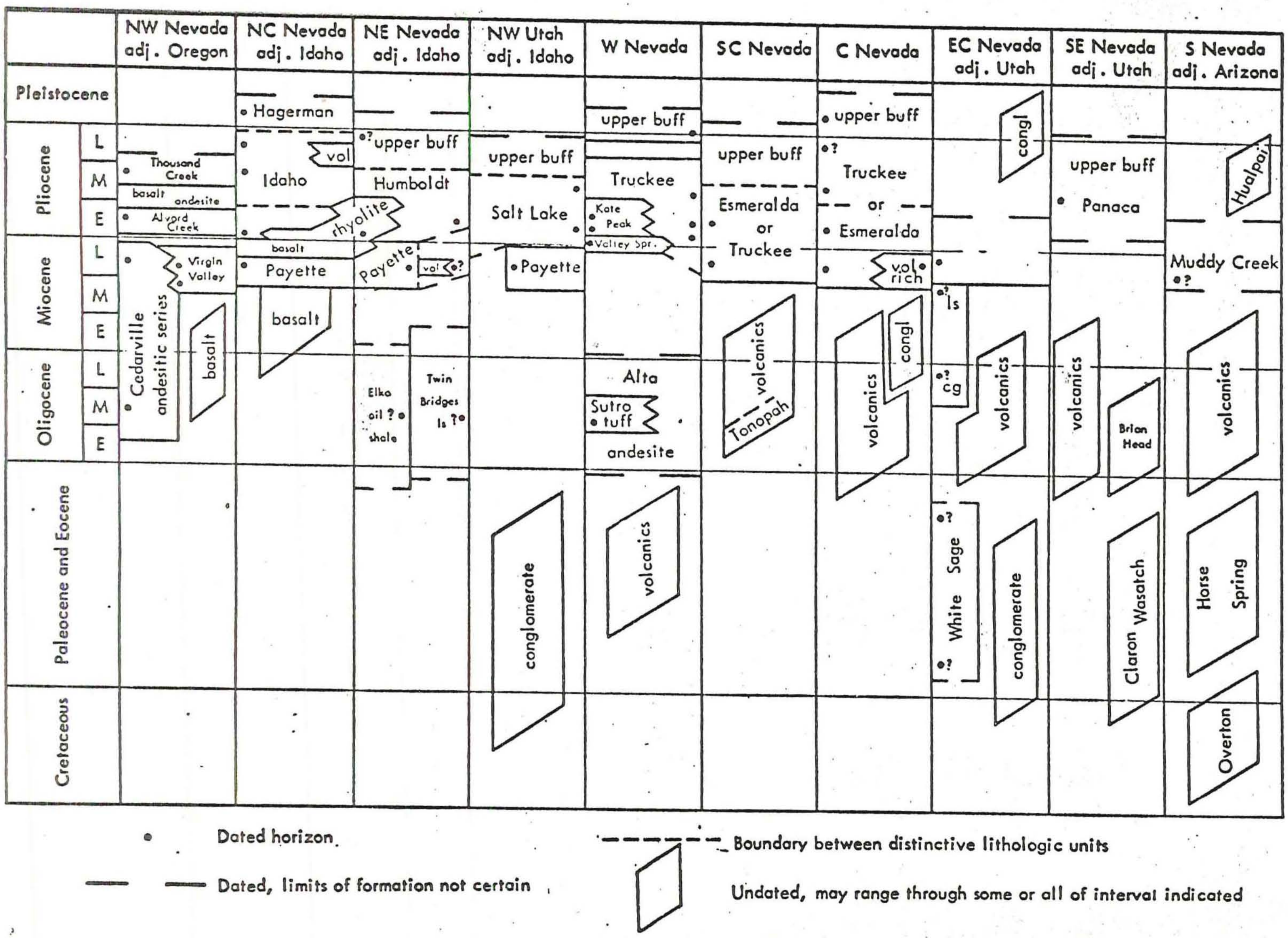

FIG. 6.—Sequences of Cenozoic rock units in Nevada. Relative stratigraphic positions shown; except where dated by fossils, precise correlation is not intended.

In contrast to these upper Miocene deposits that are part of the distinctive vitric tuff facies, upper Miocene sedimentary rocks in northeastern Nevada are lithologically rather unlike the overlying vitric tuff unit.

In the Thousand Creek area (T. 46 N., R. 27 E.) in northwestern Nevada, in western Nevada at the north end of the Hot Springs Mountains (T. 22 N., R. 27 E.), near Hazen east of Reno (T. 20 N., R. 26 E.) and Verdi west of Reno (T. 19 N., R. 18 E.), and south of Yerington (T. 11 N., R. 24 E.), as well as in the vicinity of Panaca (T. 2 S., R. 68 E.; E. ½, T. 2 N., R. 69 E.; W. ½, T. 2 N., R. 70 E.) in southeastern Nevada, deposits of the vitric tuff facies yield middle Pliocene fossils. Significantly, however, the Thousand Creek and the upper Panaca beds are more buff-colored and contain more sandstone and conglomerate and less uncontaminated vitric tuff than do lower Pliocene sections of the vitric tuff unit.

In northeastern, central, and south-central Nevada the vitric tuff unit commonly is overlain by deposits of poorly sorted buff mudstone and sandstone and Paleozoic-pebble conglomerate, with few thin layers of gray vitric tuff. These beds, which locally are unconformable on the vitric tuff unit, yield middle Pliocene to Pleistocene fossils in a few localities (Fig. 2). In Pine Valley a marginal facies of upper buff sandstone and conglomerate grades basinward into finer-grained deposits characterized by white and cream-colored limestone and diatomite, and drab bentonitic mudstone. In the vicinity of Sacramento Pass on the east side of the Snake Range in easternmost-central Nevada (N. ½, T. 14 N., R. 69 E.), Miocene or Pliocene tuffaceous limestone and mudstone deposits tentatively assigned to the vitric tuff unit are overlain by several thousand feet of undated gray Paleozoic-pebble conglomerate.

Although the general lithologic character of the vitric tuff unit is remarkably uniform over a wide area the characteristic beds of vitric tuff are not well developed in east-central Nevada. Moreover, several distinctive rock types or lithofacies in it exhibit important regional variations. The widespread, conspicuous vitric tuff, for example, is coarser-grained in western Nevada, as seen in outcrops in Coal Valley (E. ½, T. 8 N., R. 27 E.; W. ½, T. 8 N., R. 28 E.) south of Yerington, and in the northeastern part of the region from north of Battle Mountain to northwesternmost Utah.

In northeastern Nevada thick beds of pumiceous tuff characterized by high-angle, large-scale cross-bedding and the presence of orthopyroxene, commonly are interbedded with buff tuffaceous mudstone and sandstone. Northward toward Idaho this sequence interfingers with the younger orthopyroxene-bearing rhyolitic lava and welded tuff (Fig. 5, V in the northeast) of the Snake River Plain (Schrader, 1912, pp. 42–46).

There are numerous deposits of coarse pumice lapilli, welded tuff, agglomerate, and volcanic-rich conglomerate (Fig. 5, V except in northeast) in the vitric tuff unit. Generally the areas of coarse volcanic débris, here listed, are in or along range flanks: on the east flank of the River Range (S. ½, T. 35 N., R. 55 E.), a few miles northwest of Elko and extending south to overlap on the Elko oil-shale sequence; on the east flank of the Piñon and Sulphur Springs ranges southwest of Twin Bridges (T. 26–31 N., R. 53–54 E.); in the Muddy Mountains area of southernmost Nevada; generally throughout the Tonopah and Hawthorne quadrangles in south-central Nevada and especially in the southern part of the Toquima and Toyabe ranges; in western Nevada southwest of Yerington and farther west where the Truckee formation interfingers with the Kate Peak andesite (Gianella, 1936, p. 73). Moreover, the vitric tuff unit is correlative with the rhyolitic Valley Springs formation and the overlying Mehrten and equivalent andesitic deposits in the Sierra Nevada (MacGinitie, 1941, p. 8; Axelrod, 1955).

Local development of diatomite, bentonite, and bedded chert is partly related to the nature of the alteration of vitric ash during and soon after deposition. In some settings alteration of the ash produced silica that was available to, and partly responsible for, flourishing diatoms. Under somewhat different local conditions the silica released accumulated as chert. In still different local environments, the ash was altered to clay minerals of the montmorillonite group. The close interstratification of these rock types strongly suggests, however, that they resulted from relatively slight differences in conditions of deposition and alteration.

Beds of diatomite (Fig. 4, D) in the vitric tuff unit are thick and widespread in western Nevada, whereas they are thin and sporadic in eastern Nevada. Bentonitic mudstone is common throughout Nevada but only locally are there beds of relatively pure bentonite. In Huntington Valley (NE. ¼, T. 31 N., R. 55 E.) and on the west flank of Knoll Mountain (SW. ¼, T. 43 N., R. 64 E.), in northeastern Nevada, more than a hundred feet of bentonite and bentonitic mudstone is present in the upper part of the unit.

Limestone occurs in most sections of the vitric tuff unit, but nowhere are the beds as thick or predominant as in some of the underlying Cenozoic sequences.

Most of the carbonaceous shale (Fig. 5, L), like the diatomite, is found in the western part of the state. The rather consistent occurrence of diatomite and carbonaceous shale in the same section, as in northwestern Nevada, in the Coal Valley area (E. ½, T. 8 N., R. 27 E.; W. ½, T. 8 N., R. 28 E.), and in the Cedar Mountain area (T. 7 N., R. 37 E.; T. 8 N., R. 36–37 E.), indicates that these facies developed in a rather similar environment.

The only evaporite associated with the vitric tuff facies is in the Muddy Creek formation in southernmost Nevada. Beds of evaporite also occur in the correlative Barstow formation in the adjacent Mohave Desert area of southeastern California, thus indicating distinctly drier conditions here than in central and northern Nevada in late Miocene time.

Lenses and layers of Paleozoic-pebble conglomerate several feet thick occur sporadically in sections of the vitric tuff unit. They are commonest and coarsest in the following areas: Grouse Creek Valley (E. ½, T. 12 N., R. 18 W.; W. ½, T. 12 N., R. 17 W.) in northwesternmost Utah; on the east flank of the East Humboldt Range (NE. ¼, T. 36 N., R. 61 E.; SE. ¼, T. 37 N., R. 61 E.); Huntington Valley west of the Ruby Range (NE. ¼, T. 31 N., R. 55 E.; NW. ¼, T. 31 N., R. 56 E.; S. ½, T. 32 N., R. 56 E.); and in the Cedar Mountain area of south-central Nevada (T. 7 N., R. 37 E.; T. 8 N., R. 36–37 E.). As evidence of active erosion of near-by uplands these coarse deposits suggest concomitant faulting in some areas. In the Panaca and Muddy Creek areas in the southeastern part of the region, on the other hand, abundant conglomerate accumulated as a coarse border facies apparently associated with active block faulting during the interval of deposition of the vitric tuff unit. Significantly, this was the last important faulting in southeastern and southern Nevada, for to-day these formations lie in essentially the same position as when they were deposited.

CENOZOIC HISTORY

Uplift and vigorous erosion of large structural blocks in western Utah and eastern Nevada prior to late Miocene time had produced thick deposits of red and tan gravel, probably during several episodes of deformation. Some of this coarse detritus, as in the vicinity of Eureka, accumulated in Cretaceous time, some during early Cenozoic time.

In early Cenozoic time, and perhaps principally in the Eocene epoch, lake and swamp sediments consisting largely of calcareous mud and fine-grained sand, together with local floodplain deposits of sand and gravel derived from near-by uplands, accumulated in east-central and southern Nevada and adjacent Utah in a warm temperate to subtropical lowland. Apparently this broad area of aggradation marked the western limit of early Cenozoic accumulation that prevailed throughout the Rocky Mountain province on the east. In the southern part of the lowland region, a somewhat drier climate led to deposition of an evaporite facies.

Central and western Nevada, in contrast, stood somewhat higher in Eocene time and was the site of local volcanic activity, some of which took place concurrently with later Eocene volcanism in the Sierra Nevada region. External drainage from the higher western country flowed westward and southwestward across the site of the Sierra Nevada (Axelrod, 1950, p. 226) into early Cenozoic seas of California.

By Oligocene time some local structural basins had been formed, but the deformation apparently did not interfere with external drainage to the west or alter the climate or vegetation significantly (Axelrod, 1950, p. 227). Volcanism during the Oligocene epoch spread thick masses of débris across lowlands in western and northwestern Nevada and may also have produced the older volcanic sequences that accumulated in the central and east-central parts of the state. In addition, ash-rich mud, sand, and gravel were deposited in local basins recently outlined by faulting, as in southwestern Nevada and adjacent California and in east-central Nevada where a thick sequence of sand and volcanic-rich gravel and interbedded calcareous mud accumulated on a thick deposit of welded tuff and lava. Coarse gravel that was deposited on a volcanic sequence in central Nevada may also have accumulated during this episode.

In Oligocene time, and perhaps continuing in early Miocene time, part of northeastern Nevada became a lowland site of accumulation where ash-rich sand and mud, bituminous and carbonaceous mud, and calcium carbonate were deposited in lakes and swamps. Much of the ash that fell here probably was blown from volcanoes farther west.

During the Miocene epoch the lowland surface of western Nevada probably stood about 2,000 feet above sea-level while the central and northern Sierra Nevada region was a broad upland only about 1,000 feet higher (Axelrod, 1955). The southern Sierra Nevada, in contrast, was sufficiently high in middle Miocene time to form an effective climate barrier to southern Nevada and impose a semi-arid climate on the Mohave desert region (Axelrod, 1940, p. 479; 1950, p. 233).

By middle Cenozoic time, widespread volcanism accompanied by mineralization had produced similar suites of lava flows, glowing avalanche deposits, and air-borne ash from local sources throughout a vast area of western, southern, and central Nevada, and adjacent Utah, and in the Jarbidge area of northeastern Nevada. Some of this activity may have begun in early Cenozoic time; some of it had occurred in the Oligocene epoch. The principal outbursts waned before late Miocene time. Apparently much of the volcanic débris accumulated in a rather brief period preceding or accompanying important differential movement of the basins and ranges. But the regional uniformity of the volcanic sequence suggests that there were no high ranges to impede its spread.

Meanwhile, in early and middle Miocene time, outpouring of thick basaltic to andesitic lava flows covered vast areas of the northwestern part of the Basin-and-Range Province in Idaho and Oregon, as well as in north-central and northwestern Nevada.

During one or more episodes of deformation after Eocene and before late Miocene time, and perhaps principally in middle Miocene time, the older Cenozoic sedimentary and volcanic sequences were faulted and tilted in many places. Then there followed an interval of widespread erosion. In east-central Nevada, on the contrary, the great thickness of gravel, sand, and calcareous mud that had accumulated after early faulting and the emplacement of a thick sequence of welded tuff, remained little deformed until after Miocene time.

By late Miocene time most of Nevada was a low plateau with scattered mountains and many lakes and swamps. The climate had become drier with more seasonal distribution of rain and greater ranges and extremes of temperature, and it showed progressive desiccation southward (Axelrod, 1950, pp. 237–38). Deposition on this interior plateau apparently began rather locally, and was marked by distinctive regional facies. In the northeast calcareous mud with abundant ostracods, and bituminous and carbonaceous deposits were common. In east-central Nevada calcareous mud predominated. Farther west and south diatomaceous ooze and carbonaceous mud were the characteristic deposits. Still farther southwest and south, in southernmost Nevada and adjacent California, where uplift of the southern Sierra Nevada and faulting of the local ranges had been more active, deposits of the interior basins included a coarse peripheral alluvial fan facies and a central evaporite facies. Concomitantly, repeated explosions of volcanoes in the Sierra Nevada and southern Cascades began to spread vitric ash across Nevada (Deffeyes, 1956, pp. 32–41). In the west and south, much of the ash accumulated unaltered, whereas in the eastern lakes and swamps much of it was partly altered after deposition.

Early Pliocene time was a period of relatively little deformation and widespread aggradation. Although there was less rainfall now and it was more seasonally distributed than in Miocene time, the climate was not yet dry enough to support desert vegetation (Axelrod, 1950, pp. 242–43). This was the setting of exceptionally uniform conditions of deposition throughout most of Nevada, and locally these conditions continued unchanged into middle Pliocene time. Most of the uplands during this interval were relatively low and played no dominant role in affecting the nature of the sediments which accumulated in many separate but commonly connected basins. As a consequence in many places deposits spread across faulted and tilted older Cenozoic rocks and overlapped extensively on Paleozoic and Mesozoic rocks of the uplands. Significantly, some basins differed from the present ones in both structural and topographic outline at this time.

In broad lakes and swamps calcareous mud, silt, diatomaceous ooze, and carbonaceous sediments predominated. On floodplains and deltas sand and gravel accumulated. Repeated showers of orthopyroxene-bearing vitric ash and pumice lapilli from eruptions of the Sierran and southern Cascade andesites fell on the vast area where much of it was reworked on floodplains and in lakes. Some of the pyroclastic débris was preserved unaltered, some of it was weathered to bentonite, while some altered ash released silica which, along with silica leached from diatomaceous mud, formed layers and nodules of chert as well as replacing some calcareous deposits. Near local sources, especially common in south-central and western Nevada, bombs and lapilli, glowing avalanches, and lava flows accumulated. In northeastern Nevada, in contrast, lava flows, thin layers of welded tuff, and pumiceous ash, also characterized by the presence of orthopyroxene, were derived from local sources.

During the remainder of Cenozoic time large-scale block-faulting and gradual regional uplift, accompanied locally by accumulation of coarse pyroclastic débris and lava flows, occurred throughout much of the Basin-and-Range Province. At the west there was important uplift of the Sierra Nevada (Axelrod, 1955), while movement of the ranges and basins in many places, including local reversal of their relative positions, faulted, tilted, and locally folded the vitric tuff unit as well as older Cenozoic rocks. It was this episode of structural break-up that established the present structural and physiographic pattern of most of the province. Locally, however, as in parts of northeastern and southeastern Nevada, there was little deformation at this time.

In this setting of more active faulting, middle Pliocene aggradation continued in lowlands dominated by grasslands and semiarid savannas (Axelrod, 1950, p. 244). In central and northeastern Nevada coarser flood-plain and stream-channel sediments replaced early Pliocene swamp and lake deposits. In western and southern Nevada, on the other hand, sedimentation continued little changed from early Pliocene conditions. With the waning of explosive volcanic activity in the Sierra Nevada the amount of vitric ash that reached eastern Nevada decreased markedly.

Grasslands apparently prevailed through late Pliocene time, and then were replaced by the present desert environment in the Pleistocene epoch (Axelrod, 1950, p. 266). Accumulation of buff sandy mud and Paleozoic-pebble gravel persisted into Pleistocene time, and in addition, there were extensive lakes resulting from continental glaciation on the north. But during this epoch continued regional uplift as well as further differential movement, initated a cycle of pedimentation and degradation which led to dissection of upper Cenozoic deposits in basins with external drainage. In basins with internal drainage pedimentation of the range flanks was accompanied by the development of alluvial fans and playas.

As a result of combined regional elevation, differential uplift of ranges, and excavation of basins, topographic relief along basin-margins reached its maximum. In this setting of degradation and increased relief, masses of fractured Paleozoic rock and rubble along fault scarps and range flanks slid basinward (Gilluly, Waters, and Woodford, 1951, p. 239). In the eastern part of Nevada, as along the west front of Knoll Mountain in Sec. 31, T. 44 N., R. 65 E., west of Spruce Mountain in T. 31 N., R. 62 E., and north of the Ruby Hills in N. ½, T. 27 N., R. 59 E., some broad breccia lobes of this sort came to rest on exhumed lower Pliocene deposits (Hazzard and Moran, 1952).

CONCLUSIONS

From this brief review of the Cenozoic sedimentary history of Nevada several significant generalities emerge.

Except for the thick, coarse red and tan Paleozoic-pebble conglomerate and conglomerate associated with lower Cenozoic limestone in eastern Nevada and adjacent Utah, most of the pre-middle Pliocene sedimentary rocks accumulated under relatively quiet conditions, including repeated episodes of lake and swamp deposition and accumulation of uncontaminated vitric tuff. Other thick coarse deposits present generally contain abundant volcanic detritus.

Concentrations of carbonates in the sequence of swamp and lake sediments, both in early Cenozoic and later Cenozoic time, are more common in eastern Nevada. Prevalence of calcareous rocks in the east may be related to the fact that Paleozoic limestone sources of carbonates were largely limited to the miogeosynclinal province in eastern Nevada (Bradley, 1948, pp. 64–65).

As in southern California on the southwest and the Colorado Plateau on the east, aggradation apparently was restricted during the Oligocene epoch.

In the general setting of the Cenozoic depositional history of Nevada, the extensive distribution of vitric tuff, diatomite, and bentonitic mudstone in late Miocene and early and middle Pliocene time is much more significant than the development of several local facies. Moreover, the widespread, uniform deposition in Nevada was part of an even more extensive episode of lowland aggradation that extended into adjacent areas, as evidenced by deposits such as the upper Cedarville and Alturas formations in northeastern California, the Alvord Creek formation in southeastern Oregon, the Payette and lower Idaho formations in southeastern Oregon and southwestern Idaho, the Salt Lake formation in southeastern Idaho, the Cache Valley formation in northern Utah and equivalent diatomaceous deposits in southwestern Utah, the Bidahochi formation in northern Arizona, and the Barstow and Ricardo and related formations in southeastern California. Further evidence of the extent of this episode of aggradation is found in the lower Pliocene Imperial formation in southernmost California which accumulated in the last marine invasion of that area.

At least locally the present structural pattern of ranges and basins differs from that which prevailed during much of Cenozoic time. Some areas that are basins now were uplands during the episodes of aggradation or they were uplifted and eroded after deposition, as implied by the following evidence. Lower Cenozoic sequences in wells and dry holes in Railroad Valley are much thinner than apparently equivalent rocks in a near-by range; Oligocene? sedimentary rocks, present at basin-borders in northeastern Nevada, have not been recognized in the stratigraphic tests drilled in basins; and the vitric tuff unit is involved in the structure of some ranges.

Because the exposures of Cenozoic rocks in ranges and at basin-borders are not necessarily marginal facies of older basin deposits, the thickness and completeness of sequences of Cenozoic sedimentary rocks in a basin can not be predicted accurately from observations of the exposed sections of these rocks.

The evidence assembled here supports Nolan's general conclusion (1943, p. 183) that Cenozoic faulting in the Basin-and-Range Province probably began in early Cenozoic time and continued intermittently throughout the era. According to present data, however, two episodes of deformation appear to have been more intense and widespread: one in middle Cenozoic (middle Miocene?) time associated with accumulation of the extensive pre-late Miocene volcanic sequence of welded tuffs and lava flows in Nevada and western Utah and the extrusion of an important part of the Columbia River basalt flows on the northwest; and the other after early to middle Pliocene time following the principal eruptions of the younger Sierran and southern Cascade andesitic volcanic rocks and accompanying the rise of the Sierra Nevada to its present elevation.

Although this general succession of tectonic events apparently occurred throughout much of Nevada, it clearly did not prevail everywhere. In some areas, as in the southern part of the state and in the Jarbidge district in the northeast, important deformation preceded or accompanied deposition of the vitric tuff facies, and then there was very little faulting after early to middle Pliocene time. In other areas, as in the Grant Range and southern Egan Range, there apparently was no large-scale deformation of Cenozoic rocks until Pliocene time.

Northeastern Nevada provides further exception to the general pattern of tectonic and sedimentary history. In contrast to the area on the south, apparently no lower Cenozoic limestone is preserved in the northeast. Moreover, in middle Cenozoic time predominantly fine-grained detrital and chemical deposits accumulated locally during several episodes while lava and coarse pyroclastic débris were erupted in other parts of the state. Significantly, northeastern Nevada was also the site of deposition of the distinctive bituminous shale facies.

In contrast to the rugged, linear ranges and rather sharply demarcated basins suggestive of intense basin-range faulting that are common in central and western Nevada, for example, the ranges of northeastern Nevada generally are less rugged, with irregular outcrop patterns and numerous small outliers overlapped by upper Cenozoic deposits which also lap high on the less rugged range cores.

These relationships suggest that northeastern Nevada was less intensely deformed than other parts of the state during much of Cenozoic time. As a result of less displacement on basin-range faults in the northeast, late Cenozoic structural and topographic conditions, including maturely eroded range cores and extensive overlap of upper Cenozoic deposits, have been little altered. Preservation of these conditions provides suggestive evidence that upper Miocene to middle Pliocene sedimentary rocks may also have accumulated high on the flanks of maturely eroded ranges in other parts of Nevada. But in these areas, in contrast to northeastern Nevada, the overlapping upper Cenozoic deposits have been eroded away as a result of greater differential movement of the ranges in later Pliocene and Pleistocene time.

Evidence of this sort suggests that the present general physiographic and structural unity of Nevada obscures significant local differences in tectonic background and depositional history.

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