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Surficial geology of the Las Vegas quadrangle, Nevada

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SURFICIAL GEOLOGY OF THE
LAS VEGAS QUADRANGLE, NEVADA

by

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SURFICIAL GEOLOGY OF THE LAS VEGAS QUADRANGLE, NEVADA

ABSTRACT

The Las Vegas 15-minute quadrangle, located in the south part of the state of Nevada, includes about 240 square miles in and around the city of Las Vegas; it is in the Basin and Range Province. The quadrangle includes a broad valley floor that was once a lake bottom, a bordering area of badlands and rolling hills developed in Tertiary and Quaternary deposits, an outer marginal area of alluvial fans, and the surrounding mountains.

The mountains constitute about three per cent of the total land surface and are composed of rock ranging in age from Precambrian to Tertiary. The remainder of the area is underlain with Pliocene(?), Pleistocene, and Recent "unconsolidated" sediments. The lowermost of these deposits is the Pliocene(?) Muddy Creek Formation which is composed largely of sand and silt with some clay, gravel, and evaporites. Much of the sand and silt is indurated to form caliche. A fanglomerate of Pleistocene(?) age is the oldest unit exposed above the Muddy Creek Formation.

In late Pleistocene time a deep lake occupied Las Vegas Valley. According to C. V. Haynes (1965), beds deposited by this lake have yielded radiocarbon dates ranging from 35,000 B. P. to 15,000 B. P. C. R. Longwell and others have named these beds the Las Vegas Formation. The youngest deposits in the area are very late Pleistocene

and Recent gravels and eolian sand.

Several prominent escarpments are seen on the surface of the Las Vegas and Muddy Creek Formations. These scarps apparently are of either fault or wave-cut origin or perhaps were formed by a combination of faulting and erosion. Evidence available at the present time does not conclusively prove their origin.

Sand and gravel for construction use is obtained from eolian sand and Recent alluvium. Building foundation conditions are, in general, very good, but local problems are created by expansive soil and sulfate salts. The area's water supply is derived almost entirely from wells. The Las Vegas valley floor has subsided more than two feet during the past 30 years, and since 1960 localized fissuring of the land surface has occurred. Malmberg (1964) presented evidence which indicates that these land movements are due to the withdrawal of ground water.

INTRODUCTION

Location

The Las Vegas, Nevada, 15-minute quadrangle (fig. 1) is situated in southern Nevada at the southwest end of the Las Vegas Valley. The valley trends northwesterly and is about 50 miles long and more than 20 miles wide. Several side valleys extend to the north; Three Lakes Valley, the largest of these, is roughly 25 by 8 miles and is floored by several playas.

Las Vegas Valley is bordered on the southwest by the lofty Spring Mountains which rise to an elevation of 11,912 feet (Charleston Peak). The northeast boundary of the valley is composed of a number of north-trending mountains that have crest altitudes ranging from 4,000 to nearly 10,000 feet; the Pintwater, Desert, Sheep, and Las Vegas Ranges and Sunrise and Frenchman Mountains. A low divide separates the valley from Indian Springs Valley to the northwest. A belt of Tertiary volcanic mountains having crest elevations in excess of 3,500 feet - Black Mountain Range and River Mountains - form the southeastern valley wall.

Purpose of the Investigation

During the four-year period from August, 1961 to August, 1965 the author was engaged in geological consultation on approximately

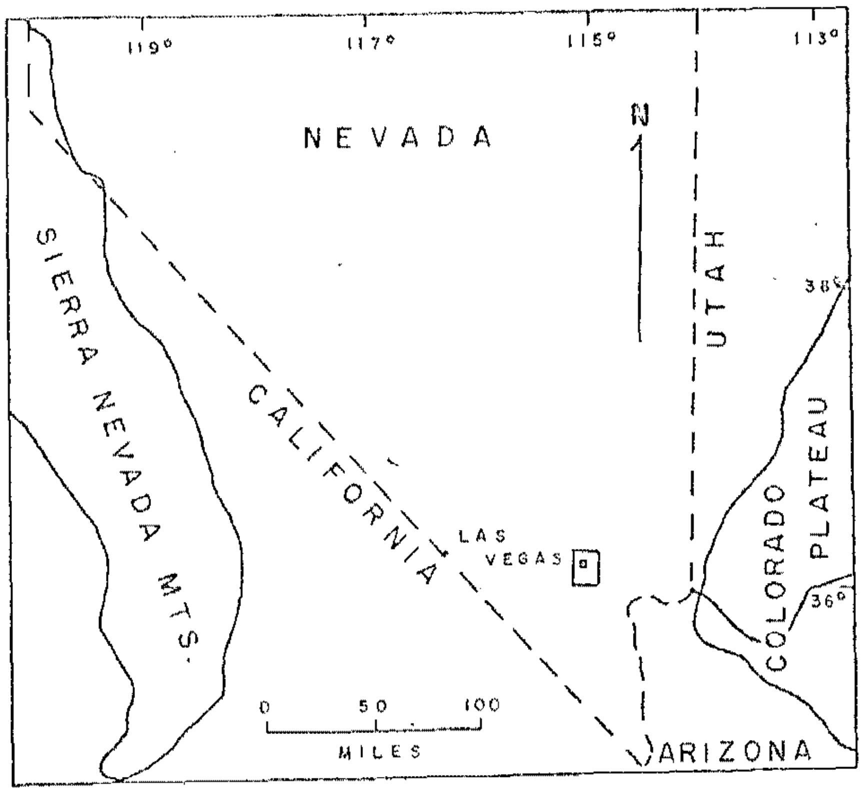

Figure 1.--Index map. Small rectangle encloses the Las Vegas quadrangle.

thirty different ground water and foundation projects in the area. The present study was done (1) to summarize the findings of these various projects and (2) to determine the stratigraphic relationships of the surficial deposits, thereby establishing a stratigraphic framework for correlations.

Previous Work

The earliest account of the geology of the Las Vegas region is contained in a report by Grove Karl Gilbert dated 1875. References published from that time until 1947 are described in detail in Nevada Water Resources Bulletin No. 5, by Maxey and Jameson. Of these references, the present author has found the 1926 soil survey report by Carpenter and Youngs to be especially helpful.

The more notable geological investigations completed after 1947 include: (1) papers by Glenn T. Malmberg (1961, 1964, and 1965) on the ground water and land subsidence of the area, (2) a paper by Domenico, Stephenson, and Maxey (1964) on an analog model of the aquifers, (3) a soil survey covering about 85 per cent of the map area by Langan and Larsen in 1954, and (4) a summary of the stratigraphy, structure, and mineral deposits of Clark County by C. R. Longwell, E. H. Pampeyan, Ben Bowyer, and R. J. Roberts (1965).

Acknowledgments

Without the encouragement provided by the Geology and Geophysics Departments of the University of Utah, this paper would not have been undertaken. Dr. Wm. Lee Stokes, Chairman of the Geology Department, provided guidance in determining the scope of the investigation. Drs. J. K. Costain, A. J. Eardley, H. D. Goode, and W. L. Stokes kindly read preliminary drafts of the paper.

Messrs. Hugo N. Halpert and Louis J. Lee, both formerly of Hugo N. Halpert Associates Division of Woodward, Clyde, Sherard, and Associates, gave freely of their time to discuss foundation problems. While the author was in the employ of the same firm (1963-1965) he undertook a number of geological investigations in the Las Vegas area for various clients - chief among these were: Ernest A. Becker Enterprises, Clark County School District, Colorado River Commission of Nevada, Ben O. Davey Construction Company, Engelstad Construction Company, First Ward of the Church of Jesus Christ of Latter Day Saints, Frank L. Hope and Associates, King's Crown Hotel, Las Vegas Insurance Adjusters, Layne-Texas Company, Longley Construction Company, Clarence E. Morris Company, Muddy Valley Irrigation Company, Nevada Savings and Loan Association, Pioneer Builders of Nevada, St. Viator Catholic Church, Schofield Construction Company, Tobler and Oliver Construction Company, and Wells Cargo, Inc.

Gratitude is due to Mr. Stanley O. Bokelmann, Construction

Director, Clark County School District for permitting the author to release chemical and other data on the Whitney Mesa Vocational-Technical School site. Mr. R. P. Effinger, a Las Vegas well driller, contributed much information on the ground-water development of the Las Vegas Valley.

GEOGRAPHIC SETTING

Major Landforms

The Las Vegas quadrangle includes a broad valley floor that was once a lake bottom, a bordering area of badlands and rolling hills developed in Tertiary and Quaternary deposits, an outer marginal area of alluvial fans, and the surrounding mountains. The topography of the Las Vegas quadrangle is shown on Plate 1; a part of the Henderson quadrangle is also included in this illustration because it is essential to a later discussion (see "Escarpments").

VALLEY FLOOR-- The lower portions of the Las Vegas quadrangle are floored by a plain that has a slope of 20 to 40 feet per mile over most of its extent. The vegetation shows considerable range in composition and density with the dominant varieties being iodine bush (Allenrolfa occidentales), mesquite (Prosopis juliflora and P. pubescens), white bur-sage (Franseria sp.), creosote bush (Covillea tridentata), and shadscale (Atriplex canescens) (Langan and Larsen, 1954). Recent alluvium, which is commonly salt encrusted, underlies almost all of the valley floor.

HUMMOCKY LAND-- The valley floor is bordered by badlands (fig. 4) and rolling hills that have formed largely on sediments of the Muddy Creek and Las Vegas Formations and on the "Unnamed gravel". This topographic association has an over-all slope ranging from about 50 to 200 feet per mile. It has a sparce vegetal cover, the dominant plants being creosote bush (Covillea tridentata), shadscale (Atriplex canescens), and white bur-sage (Franseria sp.). Dune fields cover several per cent of the hummocky land. Escarpments, the positions of which are shown on Plate 1, are prominent features on this landform.

ALLUVIAL FANS-- Upslope from the hummocky land are alluvial fan slopes that are largely underlain by Pleistocene and Recent fanglomerate and gravel. These fans have over-all slopes ranging from about 50 to more than 150 feet per mile. The vegetation is sparce with the dominant varieties being creosote bush (Covillea tridentata), white bur-sage (Franseria sp.), and Spanish bayonet (Yucca mohavensis).

MOUNTAINS-- The extreme eastern and southeastern parts of the quadrangle contain steep mountainous areas having altitudes in excess of 3,700 feet, or some 1,500 feet above the valley floor. Precambrian, Paleozoic, Mesozoic, and Tertiary rocks crop out on the flanks of these areas.

Vegetation

Desert shrubs and herbs dominate the native plants. Creosote bush (Covillea tridentata) and white bur-sage (Franseria sp.) are prevalent over nearly all of the area; most of the common plants, however, are somewhat selective as to topographic and soil conditions (Langan and Larsen, 1954). The discussion of major landforms mentioned the major topographic-plant associations. Soils of a sandy or silty type support shadscale (Atriplex canescens) and iodine bush (Allenrolfa occidentales). Sandy and gravelly soils, particularly those that contain gypsum, are favorable for the growth of mesquite (Prosopis juliflora and P. pubescens) and catclaw (Acacia greggii). Spanish bayonet (Yucca mohavensis) is present on the higher gravelly slopes.

Drainage

Las Vegas Valley drains into Lake Mead through Las Vegas Wash which leaves the quadrangle about 1½ miles north of Pittman (pl. 1). The wash contains the only perennial stream of consequence; during the period 1957-1964 the mean annual flow was about 15,000 acre-feet. The water is largely sewage effluent from treatment plants of the City of Las Vegas located in sec. 10, T. 21 S., R. 62 E. and in sec. 25, T. 20 S., R. 61 E., and from Clark County Sanitation District No. 1 plant located in sec. 22, T. 21 S., R. 62 E. The water contains about 4,000 parts per million total dissolved solids, principally magnesium, sodium, chloride, and sulphate.

Prior to the discharge of waste water into Las Vegas Wash the stream was ephemeral, but as Carpenter (1915, p. 10) noted, "there is good evidence that at one time it was a stream of considerable size."

Climate

Las Vegas Valley is one of the driest and warmest communities of the nation. The climate is continental with hot summers, cool winters, a moderately strong diurnal temperature range, and wide fluctuations in annual rainfall. Cloudless skies are the rule with the area receiving about 85 per cent of the possible amount of sunshine (U.S. Department of Commerce, 1964, p. 2). Strong winds are frequent and evaporation is high. Summer temperatures above 105° F and winter temperatures below freezing are common. Normal annual precipitation during the period 1931-1960 was 3.9 inches (U.S. Dept. Comm., 1964, p. 2).

The mean wind velocity is 9 mph with prevailing winds downslope toward the lowest part of the valley (U.S. Dept. Comm., 1964, p. 1, 2). Strong winds with velocities in excess of 50 mph are experienced several times a year during the passage of major frontal systems. These blow from the southwest or northwest, and are strongly influenced by the mountain topography.

Topography also affects minimum temperatures which on clear, calm nights may be 15° to 25° less in the lower portions of the valley than at the McCarran Field weather station. Summer maximums are usually above 100° F, the majority of the summer minimums are between 70° and 75° F. Winter maximums average near 60° F and the winter minimums average 35° F (U.S. Dept. Comm., 1964, p. 1).

History

Indians are known to have lived in the area at least 11,000 years ago (Wormington, 1957, p. 197-198). In the late 1700's the Spaniards visited southern Nevada and gave the name Las Vegas (The Meadows) to the valley because of grass patches in the vicinity of springs. Also during this period the Spanish Trail was in use through the valley.

The first white settlement was a mission sent out and maintained by the Mormon Church from 1855 to 1858; this was in sec. 27, T. 20 S., R. 61 E. Its primary functions were to minister to the Paiute Indians and to aid travelers emigrating to San Bernardino, California. It also served as a base for explorations into surrounding regions. The missionaries were successful despite the nuisance of numerous thefts of livestock and food by wandering Indians. In 1858, however, the Mormon settlers were recalled along with those in other outlying missions of the L.D.S. Church (Hulse, 1965, p. 76-77).

After the L.D.S. settlement was abandoned, cattle raising became the dominant industry and the more fertile land was used for alfalfa production. Prior to 1905 the valley supported only a few families. In that year the San Pedro, Los Angeles, and Salt Lake City Railroad was constructed through the valley (Hulse, 1965, p. 207).

In 1909, Clark County was organized from part of Lincoln County, and Las Vegas was made the county seat. According to the 1910 census the population was about 1,000 persons. In 1940, about 10,000 people resided in the area, and at the present time the population is estimated to be 150,000. These people represent about one-third of Nevada's total population.

Economic Geography

The area lies on the main highway and railroad route from Salt Lake City to southern California. It is served by seven major airlines having non-stop flights to many major cities in the United States. Pipelines which originate in other states provide natural gas and liquid fuel to the area.

Most localities in the quadrangle have all-weather roads and a two-wheel-drive vehicle can be driven over most of the roadless land. Sand, during the drier periods, and loose evaporite surfaces impede traffic locally. Roads are relatively dust-free except for those on the Las Vegas Formation.

The principal industries are tourism and national defense activities. The area annually attracts about ten million tourists who spend in excess of 200 million dollars. National defense establishments have an annual payroll of 25 million dollars. About 1,600 acres of land are in irrigated crops and pasture. The hotels, industries, and homes have an assessed valuation of $1.5 billion.

STRATIGRAPHY AND STRUCTURE OF PRE-PLIOCENE(?) ROCKS

Pre-Pliocene(?) rock within the Las Vegas quadrangle consists of metamorphic, igneous, and sedimentary formations ranging in age from Precambrian to Tertiary. Outcrops of these stratigraphic units are restricted to mountains of the eastern one-third of the map area. A detailed study of these outcrops has been in progress for many years by Dr. C. R. Longwell and a report is now being prepared (personal communication). Well logs indicate that the top of the pre-Pliocene(?) rock is at depths in excess of 1,000 feet under most of the area.

The west base of Frenchman Mountain, in the northeast sector of the Las Vegas quadrangle, contains Lower Cambrian beds unconformable above a crystalline complex (Longwell, 1963, p. E5, and Bowyer, Pampeyan, and Longwell, 1958). All Paleozoic systems except the Silurian and perhaps the Ordovician are represented in Frenchman Mountain, and they have a total thickness of approximately 8,000 feet. These strata and the overlying Triassic and Jurassic(?) beds are tilted steeply eastward (Longwell, 1963, p. E5). The lithologies are largely limestone (including dolomite), sandstone, and shale.

A portion of the McCullough Range is located in the southeast section of the map area. This range is composed chiefly of volcanic rocks cut by dikes and other intrusive bodies (Longwell, 1960, p. 17). The lavas of the range are largely basalt and andesite.

Streams entering the map area from the west and north drain terrain composed largely of limestone, dolomite, sandstone, and shale, with minor amounts of gypsum. These strata are largely correlative with those exposed in Frenchman Mountain. The Paleozoic formations thicken to the northwest, and at a distance of about 50 miles from Frenchman Mountain they exceed 22,000 feet in thickness (Longwell, 1960-b, p. 193).

All pre-Quaternary formations are cut by normal faults. Pre-Cretaceous rocks throughout the Las Vegas Valley region are also folded and displaced by thrust faults.

STRATIGRAPHY OF SURFICIAL DEPOSITS

Correlation of the surficial materials is difficult because of poor exposures, rapid facies changes, and lithologic resemblances. Stream channels rarely expose more than 15 feet of section. Many localities are devoid of stream dissection, but man-made cuts, trenches, and test pits commonly reveal material to a depth of 5 to 10 feet.

The techniques used in this study are much like those employed in mapping "bedrock"; the deposits were separated into rock-stratigraphic units, superposition of the units was determined, and the contacts were mapped. The better exposures were given principal attention and rock-stratigraphic units were then mapped through the intervening areas of poor exposures, mostly by noting soil characteristics, including their appearance on aerial photographs. The older sediments are generally capped by paleosols having a thicker profile, stronger structure, and C_{ca} horizons with more secondary calcium carbonate than those soils capping younger sediments. The agricultural soil maps by Carpenter and Youngs (1926) and by Langan and Larsen (1954) were very helpful in locating formational contacts. Because of the poor exposures, however, many of the contacts must be regarded as approximate, particularly within the more populated portions of the cities of

Las Vegas and North Las Vegas. The geologic map of the area is on plate 1 and geologic cross sections appear on plate 2 (plates in pocket).

Color terms used follow the Munsell rock color chart and refer to the material in a wet state unless noted otherwise. Limestone, as used in this report, also includes dolomite. The term "caliche" refers to sand and silt cemented by porous calcium-magnesium carbonate, and also the the carbonate cement itself; this is in keeping with general usage in the southwestern United States (American Geological Institute, p. 42, Stokes and Varnes, p. 19).

R. B. Morrison (1964, p. 21) in his work on the geology of the Lake Lahontan area, gave an excellent summary of several definitions that pertain to soil structure:

> "Soil structure is an especially diagnostic property. It refers to the shape of aggregates of primary soil particles, called peds, which are separated from each other by surfaces of weakness. Their size, shape, and distinctness vary widely with different genetic factors. The following terms describe... soil-structure types... : Columnar, arranged in vertical prisms, having small horizontal dimensions compared to their vertical dimensions; vertical faces well defined and vertices angular; rounded caps. Prismatic, same as columnar but without rounded caps. Platy, relatively thin horizontal plates. Blocky, block-like; blocks or polyhedrons having plane or curving surfaces. Granular, hard or soft but cohesive

small aggregates, angular or rounded. ...Degree of development of these types is denoted by the terms 'strong', 'moderate', 'weak', and 'structureless' ..."

Tertiary System

PLIOCENE(?) SERIES

Muddy Creek Formation. Clastic deposits of late Tertiary age are widely exposed in southeastern Nevada. These deposits are commonly coarse-grained near the mountains, but grade basinward into beds of sand, silt, and clay. Stock (1921-a) named these deposits the Muddy Creek Formation from representative exposures on the southwest side of Muddy Valley, between Overton and Logan, Nevada.

In the Las Vegas quadrangle, sand and silt beds of the Muddy Creek Formation are exposed about 8 miles southeast of Las Vegas on Whitney Mesa (pl. 1, fig. 2) (Bowyer, Pampeyan, and Longwell, 1958). Similar sediments are also exposed in the vicinity of Vegas Heights (T. 20 S., R. 61 E.) and a few miles northeast of Vegas Heights; these beds may also be part of the Muddy Creek Formation, and in this report are included in that unit.

Stratigraphic sections 1 and 2 (appendix) each include descriptions of the Muddy Creek Formation. Typically it is silt and

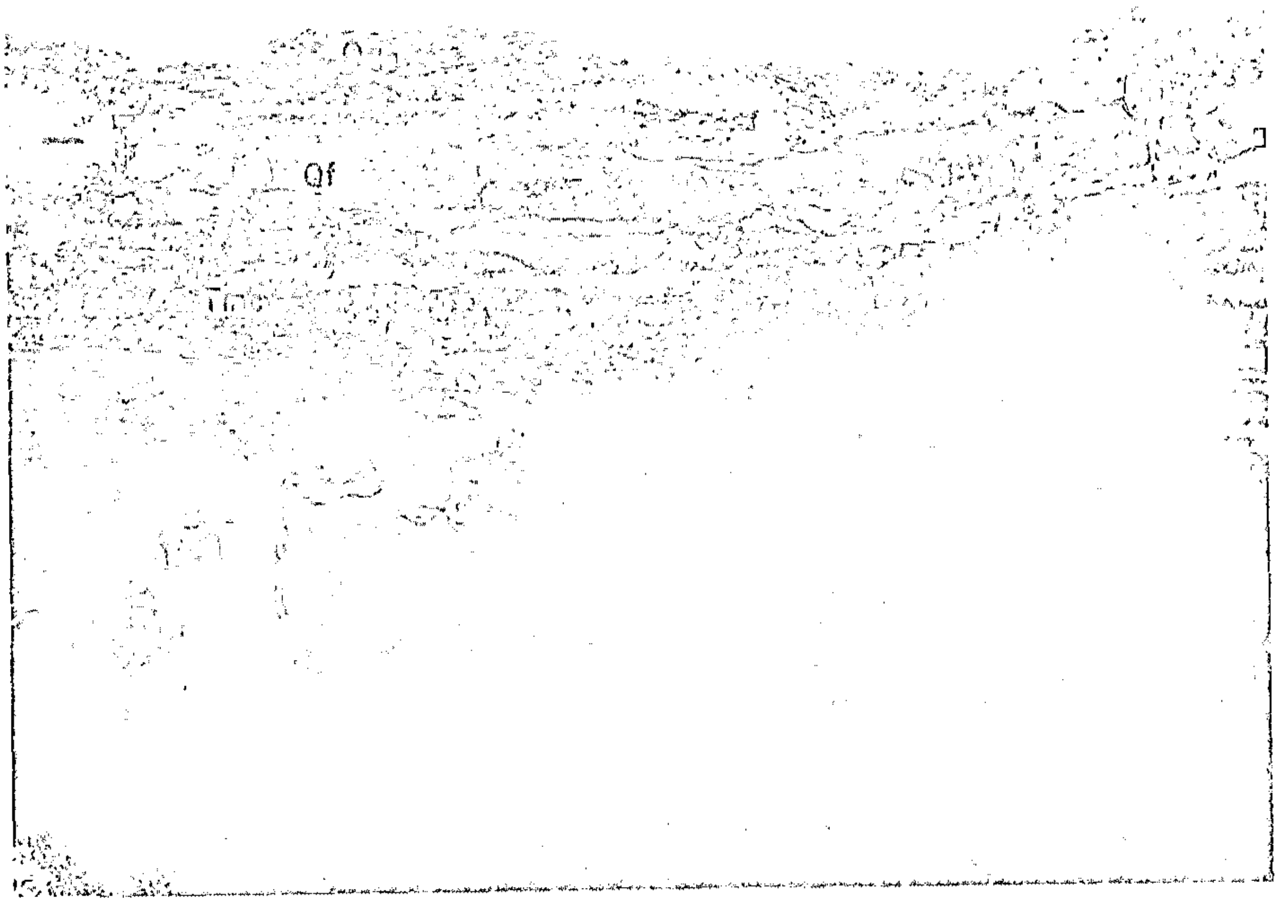

Figure 2.

Canyon wall cut into Whitney Mesa showing the Muddy Creek Formation (Tmc) overlain by "unnamed fanglomerate" (Qf) and the gypsiferous facies of the "unnamed gravel" (Qg_g). Site of stratigraphic section 1, east section line, sec. 32, T. 22 S., R. 62 E., 0.4 mile north of south section line. Fanglomerate is 15 feet thick at this exposure.

sand with: (1) moderate brown strata having a strong ped structure, interbedded with (2) light brown caliche-indurated beds. Many of the strata are thin bedded and laterally very continuous, suggesting deposition in a lake. The maximum exposed thickness of the formation is 85 feet; this occurs at the location of stratigraphic section 1.

A few of the beds in the vicinity of stratigraphic section 1 undulate slightly, indicating that soluble material may have been removed from some beds after deposition, permitting the overlying strata to settle non-uniformly. Minor faulting or slumping has involved the beds in the E½, sec. 8, T. 21 S., R. 62 E. Several exposed faults have dips ranging from 50 to 65 degrees to the east; one has a displacement in excess of 10 feet, the remainder have lesser movements.

The only fossils reported from the Muddy Creek Formation are a tooth of a Merychippus(?) sp. and limb elements of an Alticamelus(?) or Procamelus(?) sp. (Stock, 1921-b); these were collected from the type locality near Overton, Nevada. Stock considered them to be of doubtful value but suggestive of a Miocene date. Longwell and others (1965, p. 49), in summarizing the available evidence for the age of the unit, stated:

> "The Muddy Creek Formation has striking physical resemblances to two groups of basin deposits that are definitely dated as Pliocene. One of these is the Panaca Formation, whose type section is in Lincoln County about 75 miles north of Muddy Valley (Stock, 1921-a, p. 147); the other is a thick sequence of lake beds and associated slope deposits that are widely exposed in

Big Sandy Valley, Arizona, a southward extension of Grand Wash trough (Morrison, 1940). In Lincoln County (C. M. Tschanz and E. H. Pampeyan, written communication, 1959) similar deposits were arbitrarily mapped as the Muddy Creek Formation for about 50 miles north of the Clark-Lincoln County line, and as the Panaca Formation from there northward, for there are no discernable lithologic or stratigraphic differences between the two units. The Muddy Creek Formation, therefore, should probably be assigned a Pliocene(?) Age".

Quaternary(?) System

PLEISTOCENE(?) SERIES

"Unnamed Fanglomerate". A pebble-boulder fanglomerate is exposed along much of the western border of the quadrangle and in a few localities near the north and south borders (pl. 1). Slopes underlain by the fanglomerate are drained by numerous shallow washes with a pronounced closely spaced dendritic pattern. The fanglomerate constitutes the caprock of Whitney Mesa (fig. 2), however, its outcrop area there is too narrow to show on the geologic map of Plate 1.

The fanglomerate is composed largely of basaltic gravel in the southeastern part of the map area - elsewhere it consists of dolomite and limestone with minor amounts of chert, quartzite, rhyolite, and sandstone. The pebbles are subangular to sub-rounded and are well indurated with light gray or light brown calcareous cement (fig. 3). The maximum exposed thickness is 15 feet.

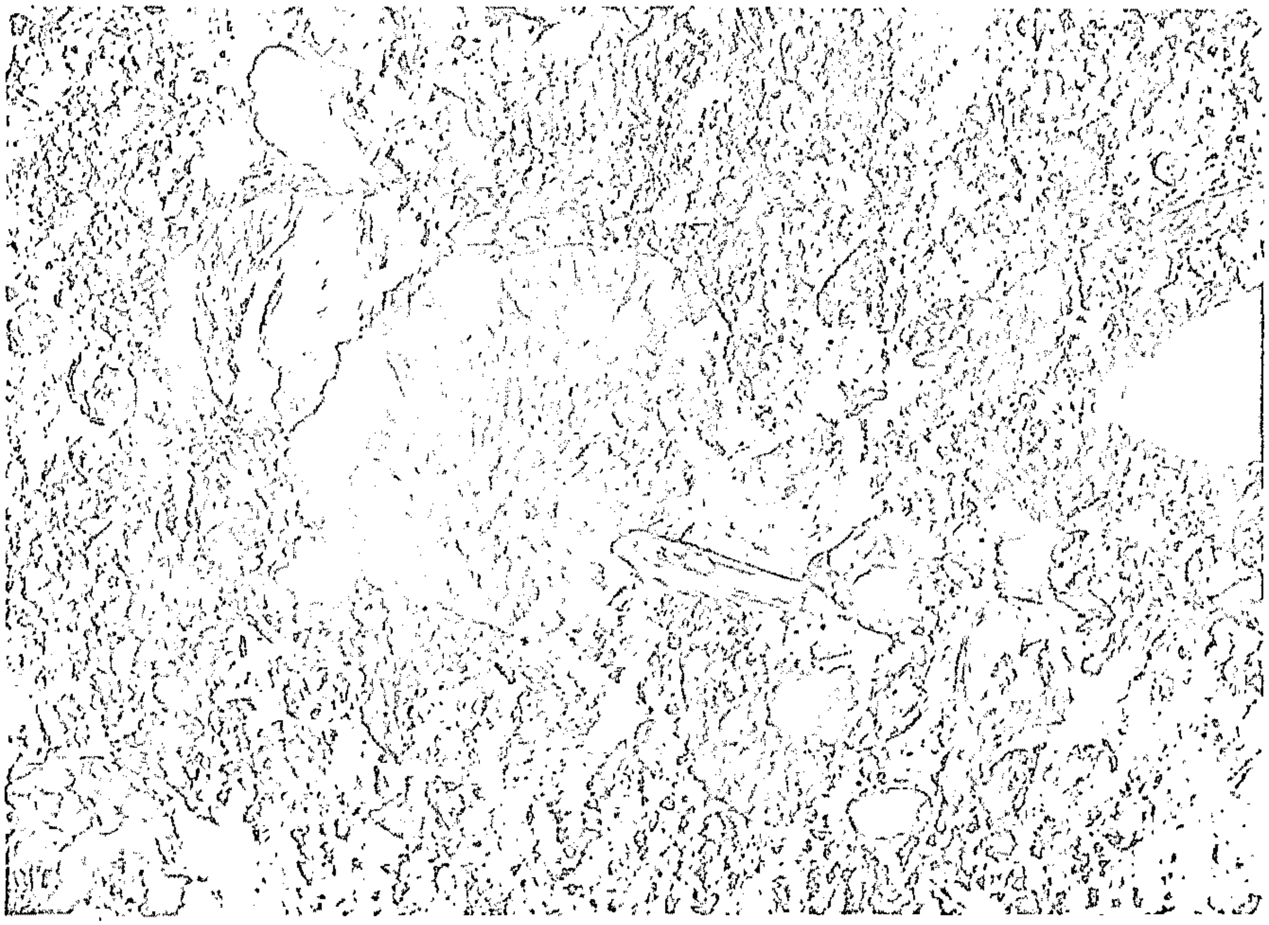

Figure 3.

Fanglomerate exposure showing well indurated gravel beveled by erosion. SW¼, SW¼, SW¼, sec. 26, T. 21 S., R. 60 E. Large limestone cobble apparently sculptured by wind-blown sand.

Poor exposures make detailed joint studies laborious, however, as part of an intensive foundation study on Whitney Mesa in 1964, the author measured 45 prominent joints in the N½, sec. 32, T. 21 S., R. 62 E. For this study, prominent joints were defined as those that could be traced for a distance of 10 feet or more. About 80 per cent of the fractures trend between due north and N. 50° E. They are commonly filled with plates and crystals of calcite up to 1/8-inch thick. The fracture planes are nearly vertical and have undulating walls.

Fossils were not found in the unit. It overlies the Pliocene(?) Muddy Creek Formation at Whitney Mesa and that contact is sensibly conformable (fig. 2, stratigraphic sections 1 and 2, appendix). The Muddy Creek-"unnamed fanglomerate" contact is not elsewhere exposed. The fanglomerate is older than the late Pleistocene Las Vegas Formation. Thus the "unnamed fanglomerate" could be Pliocene(?) to late Pleistocene in age. The lithologic character of the unit suggests deposition during a moist climate, therefore, a Pleistocene(?) age is indicated.

Quaternary System

PLEISTOCENE SERIES

Las Vegas Formation. Light-colored deposits of sand, silt, and clay are prominently exposed in Las Vegas Valley and in Indian Springs Valley, which is located about 50 miles northwest of Las

Vegas. Longwell and others (1965, p. 50) have named these beds the Las Vegas Formation. The type section is about 10 miles northwest of Las Vegas in the NE¼ of T. 19 S., R. 60 E.

Lacustrine and alluvial beds of the unit form a nearly continuous belt along the western part of the Las Vegas quadrangle and constitute scattered exposures elsewhere in the map area.

Stratigraphic sections 3 and 4 (appendix) include descriptions of the strata. At section 3 the greatest exposed thickness of the unit occurs, 45 feet. In most localities the upper few feet of the beds are moderately indurated with porous light gray to moderate brown lime carbonate. Some of the resulting caliche is nodular and irregular in external form. Bedding planes in the upper 10 feet are commonly indistinct. Gypsum crystals are present but rare in these strata. The normal topographic expression is in gentle slopes, but where erosion has breached the protective caliche, a badland topography is developed (fig. 4).

Below the upper 10 feet, the sediments have a few green-colored or rust-stained beds. At three widely separated localities, fossil molluscs are found in these lower beds. One locality is at the site of stratigraphic section 3 (appendix). Another fossil locality is in the NE¼, sec. 13, T. 21 S., R. 60 E. The third locality is in the S½, sec. 36, T. 19 S., R. 60 E.

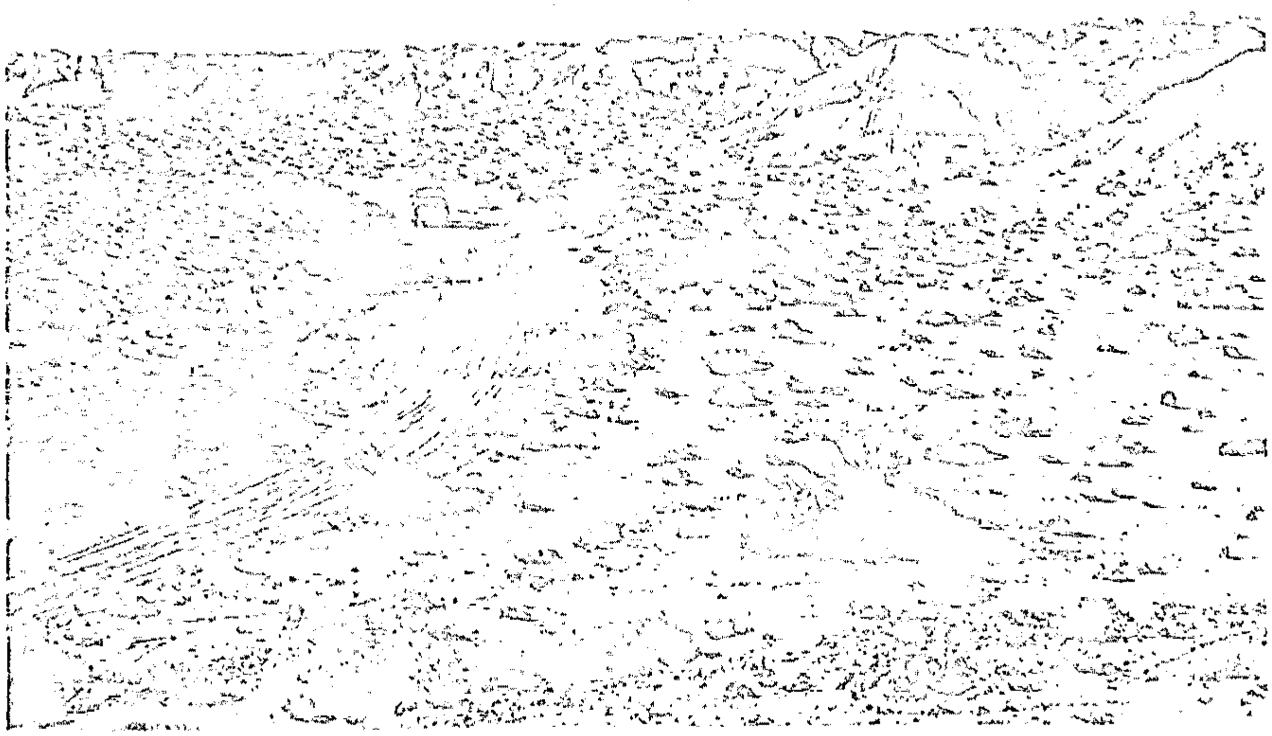

Figure 4.

Badlands cut into Las Vegas Formation, SE¼, NE¼ sec. 24, T. 21 S., R. 60 E.

Mollusc samples from the latter two localities were examined by Ernest J. Roscoe of the Field Museum of Natural History, Chicago. A summary of his report follows:

S½, sec. 36, T. 19 S., R. 60 E.	Environment
Pelecypods	
Pisidium sp. or spp.	Freshwater
Gastropods	
Euconulus sp.	Terrestrial
Lymnaea sp.	Freshwater, may inhabit very moist terrestrial environments, e.g., mud banks
Physa sp.	Freshwater
Pupilla(?) sp.	Terrestrial

NE¼, sec. 13, T. 21 S., R. 60 E.	
Pelecypods	
Pisidium sp. or spp.	Freshwater
Gastropods	
Euconulus sp.	Terrestrial
Gyraulus sp.	Freshwater
Lymnaea(?) sp.	Freshwater, may inhabit very moist terrestrial environments
Pupilla(?) sp.	Terrestrial
Zonitid(?)	Terrestrial

According to Roscoe these collections could represent a "lake shore environment with some components washed in by streams from an adjacent moist terrestrial environment."

The molluscs in the lowermost unit of stratigraphic section 3 (sec. 15, T. 22 S., R. 61 E.) are largely dissolved by weathering processes and no complete specimens were obtained. The unit also contains abundant ostracod valves, however, and Dr. D. J. Jones has identified them as late Pleistocene varieties.

The strata are parallel and essentially horizontal except at the site of stratigraphic section 3 and in sec. 9, T. 22 S., R. 62 E. At stratigraphic section 3 the base of the exposure has varying strikes with some of the beds dipping as much as 30°. This dip is very likely due to either slumping or to local collapse brought about by solution of underlying materials. In the SW¼, sec. 9, T. 22 S., R. 62 E. the beds dip 15° to the N 45° E.

Radiocarbon dates in the Tule Springs area, about 5 miles north of the northwest corner of the quadrangle, show that the lake occupied that area from 35,000 years ago until about 15,000 years ago (Haynes, 1965, p. 124). During the time interval that the lake was being lowered by draining, the Tule Springs area (elevation: 2,500 feet) must have been drained before the lower parts of the Las Vegas quadrangle (which extends down to an altitude of 1,570 feet) were laid bare. Therefore, deposition of lake sediments in the map area may have continued after the 15,000 B. P. date.

Isolated, small growths of tufa were found attached to the upper surface of fanglomerate at an elevation of about 2,500 feet in sec. 3, T. 22 S., R. 60 E. and in sec. 34, T. 21 S., R. 60 E. The tufa is abundant but is only about 0.2 to 1-inch thick. It may have formed on the bottom of the lake.

Possible lacustrine shore line and discharge channel features are discussed in detail under the heading "Escarpments". These features, at elevations up to 2,200 feet, indicate that the depositing lake had a maximum depth in excess of 600 feet. A search was made for beach deposits but none were identified. It seems unusual that such a lake - existing for 20,000 years and disappearing only 15,000 B. P. - did not leave many impressive beaches.

PLEISTOCENE-RECENT SERIES

"Unnamed Gravel". Moderately cemented gravel, with constituents ranging in size from boulders to silt, is widely distributed in the eastern two-thirds of the area. It overlies the Las Vegas Formation.

Many of the pebbles have lime carbonate coatings, particularly on their lower sides, that are rarely in excess of 1/32-inch thick. The gravel is subangular to subrounded. Much of the land surface is covered with desert pavement and some of the siliceous pebbles on the surface display desert varnish. This unit exceeds 15 feet in thickness.

Three lithofacies of the gravel were mapped:

1. A limestone gravel facies consisting almost entirely of limestone fragments with some sandstone and chert,
2. A basaltic gravel facies consisting predominately of basaltic gravel, and
3. A gypsiferous facies consisting of gravel, sand, and silt that contain prominent coatings and impure beds of gypsum (fig. 5). The gravel in this facies is largely limestone except in the southwest part of the

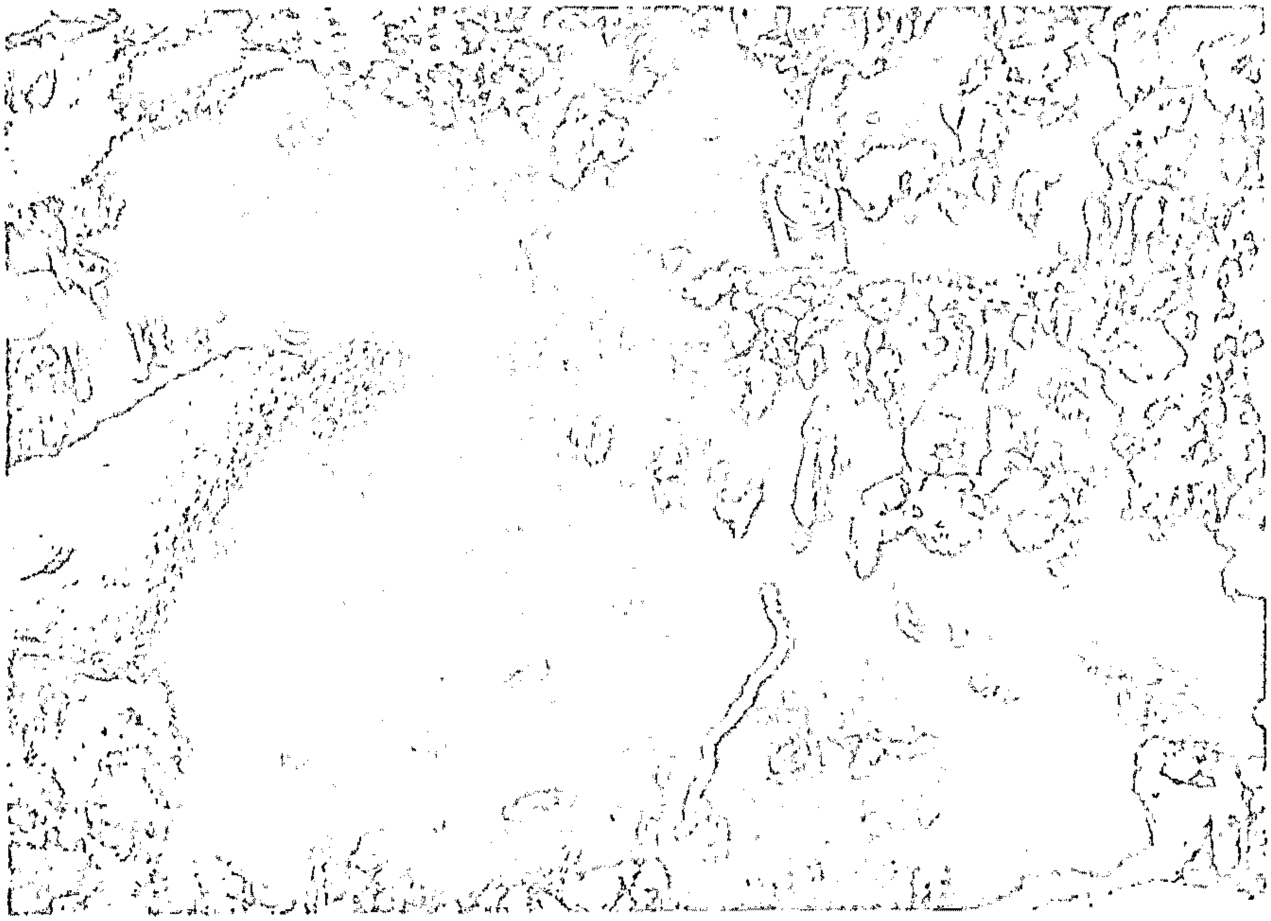

Figure 5.

Gypsiferous facies of "unnamed gravel". Top of view is 1 ft below land surface. White material is impure gypsum. Dark colored rocks are basalt. NW¼NW¼SW¼ sec. 34, T. 21 S., R. 62 E.

quadrangle where basaltic rocks are prominent.

Distribution of the limestone and basaltic gravel units was controlled to a large extent by the character of the bedrock in the surrounding mountains. The gravel generally contains gypsum where it is topographically lower than the Las Vegas Formation; most of the gypsum was probably derived from this formation. It is also possible that the "unnamed gravel" is partly of littoral origin and that some of the gypsum was deposited directly from saturated lake water. Several of the bedrock formations in the surrounding mountains are gypsiferous, particularly those on the east side of the valley; these may have contributed significantly to the gypsum content of the gravel.

The upper 1 to 3 feet of the gypsiferous facies is low in gypsum content except in the vicinity and south of Whitney Mesa. At those localities the upper two to six feet of the unit is commonly composed of light brown or gray impure gypsum with scattered gravel and sand grains and rare cobbles and boulders. The gypsum has the appearance of a honeycomb and the bulk density generally ranges from 45 to 60 pounds per cubic foot. The material has negligible bearing capacity; a two-wheel drive vehicle cannot be driven over the land surface except where it has been compacted by prior traffic. The "honeycomb" collapses and largely dissolves when subjected to running water for a period of a few seconds. Many of the pebbles are basaltic and some of these within and below the "honeycomb zone" are split into several pieces. These fragments show evaporite crystal growth along their fracture surfaces; the splitting was probably due to crystal growth and perhaps to volume change of the crystals with changes in moisture content. As part of a foundation study in September, 1964 the author collected two samples of gypsiferous material for chemical analysis; the results appear in Table 1, p. 30.

Because the gravel overlies the Las Vegas Formation, it was deposited after the 15,000 B. P. date given by Haynes (1965, p. 124) for the upper part of that unit. Impure gypsum layers within one facies of the gravel suggest a possible littoral origin for some of the gravel; this proposed environment of deposition in turn suggests a late Pleistocene date, while Lake Las Vegas still occupied the lower part of the valley.

RECENT SERIES

Eolian Sand. Wind-blown sand has accumulated in dunes as much as 20 feet high. Several hundred acres of dunes have been mapped between Whitney Mesa and the City of Las Vegas. Another small dune field is located immediately northwest of Skyhaven Airport.

Most of the dunes are longitudinal in plan, some however, have an irregular shape, perhaps due to the coalescing of longitudinal forms. The principal axes of the longitudinal dunes are generally oriented between N. 45° E. and N. 90° E. Stronger winds in the valley are from the southwest or northwest, and these exceed 50 mph

Table 1.

Chemical analyses of impure gypsum in the "unnamed gravel" (gypsiferous facies). Samples collected from near center of sec. 32, T. 21 S., R. 62 E.

Analyst: M. P. Christensen, Chem-Met Associates, San Diego, California.

Procedure: A.S.T.M. C471-61. Results reported in per cent by weight.

Constituent	Sample A [a/]	Sample B [a/]
Free water @ 113°F. - 2 hours:	0.3	0.6
Combined water @ 430°F. - constant weight:	16.4	14.7
Carbon dioxide (CO_2):	0.3	0.4
Insoluble constituents:	15.4	21.9
Iron and aluminum oxides:	6.4	2.1
Lime (CaO):	27.4	24.8
Magnesium oxide (MgO):	0.7	2.3
Sulfur trioxide (SO_3):	31.1	31.7
Sodium chloride (NaCl):	1.9	1.0
Undetermined, by difference:	0.1	0.5
	100.0	100.0

a/ Channel samples, A collected between the surface and a depth of 16 inches, B collected between a depth of 18 inches and 36 inches. Sample A from a "honeycomb" zone, sample B from a medium-dense gypsum sand.

(U.S. Dept. of Commerce, 1964, p. 1). The dune fields tend to be located to the north of the larger drainage ways, especially where the streams spread out over gently sloping surfaces. These stream beds are the most logical source areas for the sand.

The sand is fine and well-sorted, essentially all of it passing the 60-mesh sieve and being retained on the 200-mesh. It has a dry color of moderate orange pink and a moderate brown wet color; it is siliceous with some calcareous grains.

The sand is fresh in appearance, showing no evidence of cementation by soil forming processes, therefore, a Recent age is indicated.

Dunes have been extensively used as borrow areas for construction projects so at the present time they have a somewhat smaller extent than they had a few years ago.

Alluvium. Deposits that range in texture from boulders to clay underlie washes and the valley floor. The lithology and grain size distribution of the wash alluvium reflects the materials in the adjacent older stratigraphic units. The alluvium in the eastern half of the map area tends to be high in alkali salt content, and large areas have a salt crust.

The alluvium is uncemented and has little soil development, therefore, it is classified as Recent. Much of the alluvium is suitable for construction gravel, and has been extensively used for this purpose.

ESCARPMENTS

Prominent scarps, unrelated to present day streams, are shown on the geologic map (pl. 1) by a special map symbol; these rise 25 to 100 feet in a horizontal distance of 500 feet. Carpenter (1915, p. 31-32 and pl. 2) described and mapped the escarpments and regarded them to be erosional in origin. Maxey and Jameson (1948, p. 33, 69, and 70) thought it more likely that these are fault scarps and cited several reasons for this conclusion:

1. water-well logs indicate displacement and slight tilting of a blue clay bed that is located several hundred feet below the surface. On their cross section B-B' they show the bed to be tilted for a distance of a mile or more from the nearest scarp.
2. west and southwest of Whitney the terrace surface of each scarp appears to tilt downward against the face of the next scarp west. One of these scarps "abuts beds of Muddy Creek Formation, which are flexured and probably broken at the point of abutment."
3. "west of the city of Las Vegas, brecciated caliche and caliche-cemented gravel were observed in excavations along one of the scarps in that vicinity."

Maxey and Jameson postulated that the faults are the result of differential compaction of sediments, the finer-grained materials that underlie the more central part of the valley settling considerably more than the coarser-grained beds which underlie the fanslopes. In referring to these scarps, Domenico, Stephenson, and Maxey (1964, p. 14) state:

> "Depth of faulting is unknown but deposits are disturbed at least as deep as 500 feet... The lineation of these faults coincides with major changes in lithology from coarse materials on the west to finer-grained materials eastward. Thus, it is believed that they are compaction faults although faulting from deep-seated sources is not entirely ruled out by presently available evidence.
>
> Throw on these faults is as much as 150 to 200 feet with the east side down relative to the west side. This can be seen from (a)... structural contour map... drawn on the surface of the blue clay horizon... buried an average depth of 450 feet below the surface."

All of the scarps are cut into the Las Vegas Formation except the cliff at Whitney Mesa and the scarp in the NE¼ sec. 22, T. 20 S., R. 61 E. - the Whitney Mesa cliff is on the Muddy Creek Formation and the scarp in sec. 22 is on sediments that appear to be part of the Muddy Creek Formation.

The toe elevation of the western-most scarps is approximately 2,240 feet. Scarps located about two miles east of these have toe elevations of about 2,100 feet. Still further east, a third row of scarps have toe elevations of about 1,920 feet. Between the second and third rows is a gently sloping bench that ranges in altitude from 2,000 to 2,100 feet. The base of the Whitney Mesa scarp ranges from 1,750 to 1,800 feet in elevation.

The uniformity of the toe elevations within the three western rows of scarps suggests that wave cutting may have aided in shaping them. In this connection, Haynes (p. 124) found that the Eglington scarp, located immediately north of the Las Vegas quadrangle, was formed, at least in part, about 14,000 years ago. This is approximately the same time that Lake Las Vegas drained.

In an attempt to determine standstill elevations during the lowering of Lake Las Vegas, a search was made for drainage channels. Such channels may exist in the Rainbow Gardens vicinity to the southeast of Frenchman Mountain (pl. 1 and fig. 6), but lack of detail on the 15-minute map prevents the discernment of critical physiographic features. Several of the northeast trending passes have elevations between 1,920 and 2,100 feet, which roughly correspond to the toe elevation of several scarps located in the map area and the elevation of the bench that extends between 2,000 and 2,100 feet. A possible lower channel exists about one mile north of Las Vegas Wash, through secs. 16, 20, and 21 of T. 21 S., R. 63 E. (pl. 1). It has a pass elevation of approximately 1,760 feet which corresponds roughly to the toe elevation of the Whitney Mesa scarp. Using the available maps, it is not possible to postulate the routes taken by water discharging from the lake stand at about 2,250 feet (toe elevation of western-most scarps). Comparison of exact channel altitudes, when known, with lacustrine features in the Las Vegas Valley may provide a very sensitive measure of regional tilting during post-lake time.

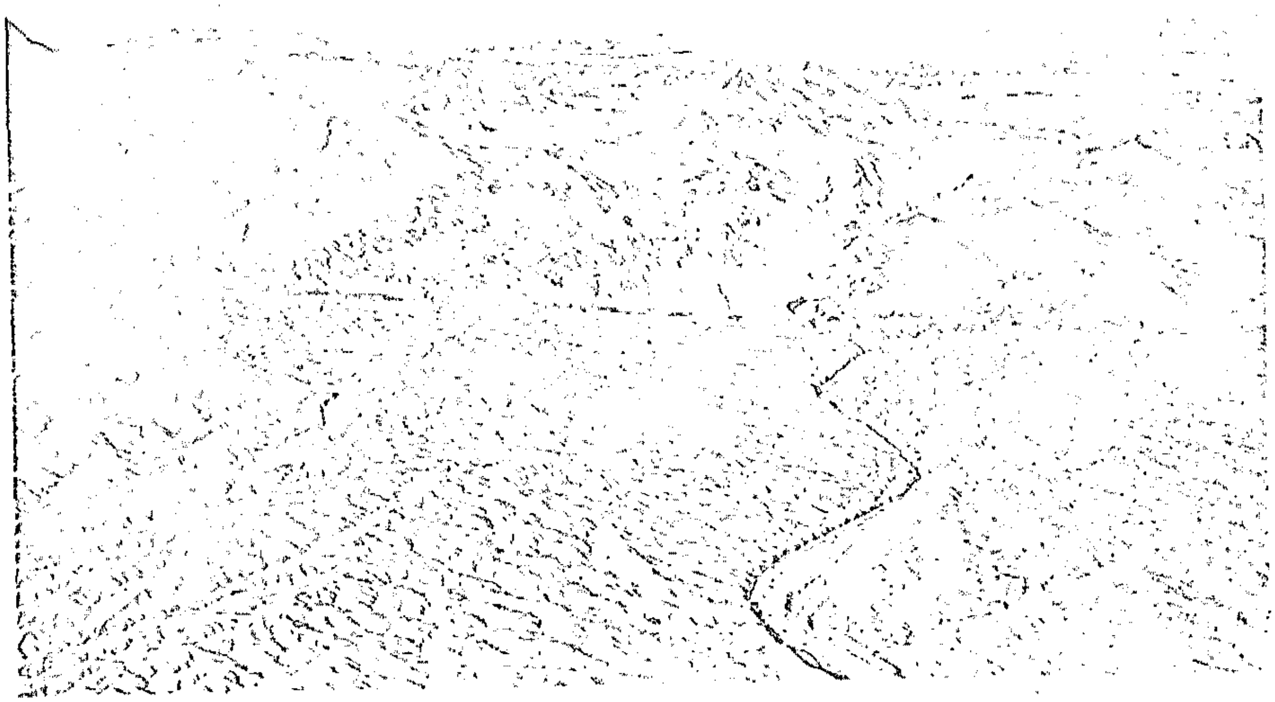

Figure 6.

Oblique aerial view of the northwest portion of Rainbow Gardens between the White Eagle and Frenchman mines (T. 21 S., R. 63 E.). Mountains are composed largely of Permian and Mesozoic sediments. Photograph by William Belknap, Jr. of Boulder City, Nevada.

The evidence bearing on a fault origin (Maxey and Jameson, 1948, p. 69) should be closely examined. The blue clay horizon has been identified by Domenico, Stephenson, and Maxey (1964, p. 15): (a) between the two sets of scarps which are at elevations of approximately 1,920 and 2,100 feet, and (b) east of the 1,920-foot scarps. Thus, displacement is indicated only on the 1,920-foot scarps. Possibly the blue clay marker bed was deposited on a non-horizontal surface and/or underwent erosion before being buried. If so, the surface of the bed may partially represent the paleogeography rather than structure.

Maxey and Jameson described the flexuring in the Muddy Creek Formation on Whitney Mesa. At the locality of stratigraphic section 1 (appendix) beds of unit 3 undulate slightly with wave lengths on the order of one to two times the thickness of the caliche beds. Solution of underlying beds could produce such flexuring. Minor faulting that is unrelated to scarp formation could also be responsible for the flexuring described by Maxey and Jameson.

Additional evidence cited in favor of a fault origin (Maxey and Jameson, 1948, p. 69), is the brecciated caliche and caliche-cemented gravel near one scarp. These deposits may possibly be due to water abrasion and soil-forming processes or other agencies unrelated to faulting.

Three additional field relationships could possibly be thought to favor a fault origin for these scarps:

1. Most springs in the area are located at the base of the scarps,
2. A soil horizon, part of the Las Vegas series (Carpenter and Youngs, 1926, p. 208) is lower on the toe side than on the upper side of those scarps cut into the Las Vegas Formation, and
3. The trends of the scarps are roughly parallel to major faults in the surrounding mountains.

These facts do not especially favor a fault interpretation because, as discussed below, a wave-cut origin would almost of necessity produce features 1 and 3 and could produce feature 2.

Throughout about half of the area the water table is within 100 feet of the land surface and is roughly parallel to the average slope of the land. Springs discharge where the water table intersects the land surface - topography tends to localize this intersection at the toe of scarps. Man-made cuts similarly give rise to springs in modern day excavations.

The Las Vegas series soil forms the upper 5 feet of the regolith on both sides of those scarps cut into the Las Vegas Formation. If the soil was formed after the scarp originated, it would be lower on the toe side of the scarp - regardless of the manner in which the scarp was created.

In the western half of the quadrangle, the topographic contours are parallel to major faults in the mountains. Because the scarps follow lines of equal elevation, they too are parallel to the major faults; the parallelism may be merely a factor of topography, rather than caused by tectonic forces.

In summary, the scarps may be due to faulting as suggested by Maxey and Jameson (1948), but no available evidence seems to favor this interpretation over an erosional theory. The various scarps may not have a common origin, or an individual scarp may have been caused by more than one geological agency. For example, faulting may have raised a block of land in such a way that it controlled the position of a beach line - lacustrine activity then could have cut the scarp toe and induced slumping. Information having an important bearing on the escarpments could be obtained by drilling in the toe areas to determine the depth to distinctive beds exposed in the scarps.

GEOLOGIC HISTORY

Following is a chronological summary of the salient events that have influenced the terrain of the Las Vegas quadrangle and vicinity:

<u>Paleozoic</u>:

A. The area was part of the Cordilleran miogeosyncline which subsided slowly throughout most of the Paleozoic era (Eardley, 1962, p. 63-75). During much of the era the Las Vegas area was occupied by a broad sea. The Paleozoic sediments are largely limestone, sandstone-quartzite, and shale. Minor amounts of gypsum were deposited during the Permian (Longwell and others, 1965, p. 152). The geosynclinal beds have an aggregate thickness of about 10,000 feet and include the Tapeats Sandstone, Pioche Shale, Chisholm Shale, Sultan Limestone, Monte Cristo Limestone, Bird Spring Formation, Callville Limestone, Toroweap Formation, and the Kaibab Limestone.

B. Uplift occurred near the end of the Paleozoic and the Kaibab and Toroweap Formations were cut and, in part, removed by erosion (Longwell and others, 1965, p. 38).

<u>Mesozoic and Tertiary</u>:

C. During the Triassic period, 1,500 to 2,000 feet of marine and continental shale, limestone, sandstone, and minor amounts of gypsum accumulated. These beds have been divided into the Moenkopi, Shinarump, and Chinle Formations.

D. The Jurassic(?) is represented by the cross-bedded eolian Aztec Sandstone that exceeds 2,400 feet in thickness. It is normally red in color.

E. During the middle and late Cretaceous and during the Tertiary the area was involved in folding, thrust faulting, normal faulting, and volcanism (Laramide Revolution). A number of continental formations totaling several thousand feet in thickness was laid down. These are composed of chemical precipitates and clastics and include the Thumb, Horse Spring, and Muddy Creek Formations (Longwell and others, 1965, p. 49).

Quaternary

F. About 35,000 years ago damming formed a lake having an elevation in excess of 2,500 feet (Haynes, 1965, p. 124). The cause of the damming is unknown; volcanic or other tectonic activity in the lower part of the valley may have blocked the drainage, or Lake Las Vegas may have been an arm of a much larger lake that was formed by damming of the Colorado River. During part of its life the lake may have discharged through various channels over the surrounding low passes in mountains to the south and east of the map area.

G. Lake sediments consisting mainly of sand, silt, and evaporites mantle much of the valley. Shoreline erosion apparently cut benches and escarpments at several different levels. The lake disappeared from the higher parts of the quadrangle about 15,000 years ago (Haynes, 1965, p. 124).

H. Post-lake erosion and alluviation re-deposited some of the lacustrine sediments and evaporites. Eolian activity built dune fields.

ECONOMIC GEOLOGY

Sand and Gravel

The limestone and basaltic facies of the unnamed gravel and some of the Recent alluvium provide a fair source of sand and gravel. None of the material is well sorted, however, and much of it has objectionably soft caliche coatings. Commercial gravel pits are all located on slopes having gradients in excess of 40 feet per mile. At most localities the usable gravel mantles the surface to a depth of 5 to 10 feet and is underlain by one of the older cemented formations. Because of the shallow burial of the gravel it is commonly stripped off from areas many acres in extent, leaving a smooth slope with a gradient parallel to the original surface.

Dune sand is extensively used as "topsoil" on lawns. It is poorly suited for construction because: (1) it is fine-grained, (60-200 mesh), and (2) it contains sufficient concentrations of sulfate to be hazardous to standard concrete (Langan and Larsen, 1954).

Ground-Water Development

The ground-water resources of Las Vegas Valley have been the subject of study by several public agencies, more notably the U.S. Geological Survey (Maxey and Jameson, 1948; Malmberg, 1961, 1965; and Loeltz, 1963) and the University of Nevada (Domenico, Stephenson, and Maxey, 1964). The present author has long been interested in well-drilling methods used in the area (Price, 1962).

An estimated 2,500 water wells have been drilled in the quadrangle. The mean depth of these wells is approximately 200 feet. Static water levels range from above land surface to about 200 feet below land surface; composite piezometric surfaces are shown on the cross sections of plate 2. Nearly all wells that penetrate 100 feet below the water table yield between 1/2 and 25 gallons per minute per foot of drawdown. The wells produce from sand and gravel aquifers that are interbedded with silt and clay; many of the aquifers are confined.

Water quality is generally good, although water from a few aquifers is unsuitable for human consumption because of poor chemical quality. Fortunately, in most areas where poor quality water exists, good water is also present in either deeper or shallower aquifers and can be developed by properly constructed wells. The maximum depth at which potable water occurs has not been determined anywhere in Las Vegas Valley.

Well construction and water utilization is closely controlled by State laws. Some of the statutes date back to 1913, but the early laws have been amended a number of times, and not until 1954 was the ground water code approved in its present form. The code was enacted principally to: (1) assign priority rights for ground-water usage, and (2) ensure that water wells will be constructed in accordance with accepted standards. Prior to drilling a well for the long-term withdrawal of more than 1,440 gallons per day, a permit must be obtained from the State Engineer. New irrigation wells have not been permitted since about 1952, except where the well is to be used for a golfing green.

State law requires that any new well be cased throughout its depth with a steel casing having a diameter of ot less than six inches. The casing wall thickness must be not less than 8 gage (0.17 inch) for 10- and 12-inch diameter casings, and not less than 1/4-inch for larger diameter casing. The upper 50 feet or more of the casing must be cemented to the formation. Flowing wells must be equipped with an effective shut-off valve, and the driller is responsible for the well's control.

During the period 1954-1956 (immediately following the passage of the present laws in 1954), some of the drillers went to great efforts to circumvent these codes. Some property owners who were unable to obtain permits for high yield wells had a driller construct such a well, 500 feet or so deep, and report to the State Engineer that the well was to be used for a single household. Because a well of that depth would cause State inspectors to infer that the well would be used for high yield production, the driller's report to the State showed the well to be somewhat shallower. As a precaution against the true depth being detected by sounding, the driller placed a sieve in the well at its reported depth, or drove a roll of chicken wire to that depth. In a well so constructed, a sounding weight will stop at the reported depth, but the well has the yield characteristics of a much deeper hole. Reportedly, more than 100 wells in the map area have been constructed with false bottoms. Other wells drilled in the 1954-1956 period deviate from the reported casing depth, casing diameter, casing wall thickness, and grout thickness and depth. This practice of falsifying construction reports was largely, if not entirely, stopped in 1956, principally by: (1) observing night-time drilling procedures without the drillers' knowledge, (2) using wire feelers to determine casing depths and diameters, and (3) core drilling adjacent to wells to determine grout depths.

Cable-tool equipment has been used to drill most of the wells and the remainder have been drilled with rotary rigs using straight mud circulation. Well caving is minor during drilling, and an estimated 90 per cent of the wells were drilled to their total depth before any casing was set.

Sand pumpage is insignificant except from wells in the immediate vicinity of Nellis Air Force Base and in a few other isolated spots. Some troublesome sand beds occur 80 to 200 feet below the land surface to the west of the City of Las Vegas.

Normally, wells in this area are constructed with blank casing to the base of the sand beds, and water is produced from gravel beneath the sand strata.

Casing perforations are generally torch-cut to produce 1/8-inch or 1/4-inch wide slots. Finer torch-cut slots have been used in casing set through sand in the Las Vegas Valley, but incrustation and corrosion products tend to seal off these fine slots.

Foundation Problems

EXPANSIVE SOIL

The most common foundation problem in the area is that caused by expansive soils. Expansion is caused by clay and salts, usually intermixed, that swell on the addition of water. Essentially all of the finer grained soils are inorganic clays or silts that have Atterberg liquid limit values of between 20 and 50; many of these soils are critical with respect to expansiveness. Roportedly, some of the more salty soils also swell when cooled. The expansive salts are believed to be largely sodium sulfate. Most of the more expansive soils are mottled with lighter colored material, indicating modification under an environment of restricted drainage.

Expansive soils are widely distributed in the Muddy Creek Formation, in the Recent alluvium, and to a lesser extent in the upper strata of the Las Vegas Formation. The most troublesome vicinities are the outcrop area of the Muddy Creek Formation(?) in Vegas Heights (T. 20 S., R. 61 E.), and the areas of Recent alluvium in the East Charleston Boulevard district. The Vegas Heights material is a mottled clay, while the East Charleston soil is a silt that is reportedly high in sodium sulfate content. Some of the soil in both localities will swell in excess of twenty per cent under a 150 psf load, when compacted at in situ moisture content. Under these same conditions, the expansive pressure at zero swell may be 2,000 psf, or more.

In laboratory consolidometers the silty soils will complete their swelling period during a few hours of contact with water; some of the clayey soils require from one to several days to complete their swell period.

After compaction in the field, the more salty soil may expand so that after a period of one year, the per cent of compaction of the upper two feet has diminished by ten per cent or more.

SULFATE SALTS

Sulfate salts, in addition to causing soil expansion, also create other building problems. The gypsiferous facies of the "unnamed gravel" contains beds of impure gypsum that are several feet thick. Where ground-water conditions are conducive to the percolation of waste water through these strata, sufficient solution may occur to lead to the differential settlement of structures. A plumbing leak beneath the kitchen of the Stardust Hotel (SW¼, sec. 9, T. 21 S., R. 61 E.) apparently caused such solution and resulted in the settlement of a portion of the floor.

Much of the sand and finer grained material throughout the quadrangle contains sufficient concentrations of soluble sulfate to be deleterious to standard Type II cement concrete. The widespread use of sulfate fertilizers on lawns increases the potential for damage to concrete.

HIGH WATER TABLE

The regional piezometric surface is near or above the land surface throughout much of the area (Composite piezometric surfaces are shown on the cross sections of pl. 2). Foundation and other excavations that extend below this surface may produce small but troublesome quantities of water.

The Landmark Tower foundation excavation in the SE¼, sec. 9, T. 21 S., R. 61 E. was about 25 feet deep and 100 feet in diameter - the bottom of the excavation was at least 10 feet below the water table. It produced several hundred gallons of water per minute, an unusually large amount for such a pit in the Las Vegas area.

More commonly, building excavations yield less than 50 gallons per minute. As an example, the Four Queens foundation excavation in the NW¼, sec. 34, T. 20 S., R. 61 E. was 21 feet deep and 145 feet wide by 165 feet long. The water table was at an average depth of fourteen feet below the surface. The hole reportedly had a yield of between 35 and 40 gallons per minute.

LAND SUBSIDENCE AND FISSURING

During the 1935-1963 period, bench marks in the cities of Las Vegas and North Las Vegas subsided as much as two feet in relationship to bench marks located outside of the quadrangle (U.S. Coast and Geodetic Survey data cited by Malmberg, 1964, fig. 4). The maximum subsidence is, in general, in the area of greatest population density and is apparently related to human activity. The U.S. Geological Survey (Malmberg, 1964, p. 1) has suggested that most of the subsidence has resulted from the compaction of unconsolidated valley fill due to the decline of water content (and thus artesian pressure) by water well usage.

In the vicinity of the Nellis Air Force Base, wells in the E½, sec. 3, T. 20 S., R. 61 E., pumpage has caused many roughly parallel cracks to open up (fig. 7). This fissure zone can be traced on the surface for a total distance of about 1,000 feet. Each break is 0.5 to 1 foot wide. The locality is heavily vegetated, so field relationships are difficult to establish. It appears, however, that the cracks are restricted to the east of the two wells shown on pl. 1. The fissures trend generally northwest but are somewhat arcuate with the concave side of the arcs facing southwest. No vertical displacement was observed on any of the cracks. It is possible to see into the openings to a depth of ten feet, but undoubtedly they extend to depths several times as great. According to G. T. Malmberg (1964, fig. 6) the piezometric surface in the well field dropped about 60 feet between 1944 and 1963.

Another fracture that is similar in appearance to those just described is located near the boundary of secs. 22 and 27, T. 20 S., R. 61 E. It trends north and is several hundred feet west of a prominent scarp. It can be traced on the surface for about 300 feet and is less than one foot wide throughout this distance; there is no appreciable vertical displacement. This crack may be due to pumpage of a nearby North Las Vegas city well.

Figure 7.

Fissuring of the land surface in the Nellis A.F.B. well field, NE¼ sec. 3, T. 20 S., R. 61 E., about 100 yards east of northern-most well shown on Pl. 1. Fissuring is apparently in response to local lowering of the piezometric surface by about 60 feet in the 1944-1963 period. Fissures trend northwest.

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APPENDIX

Stratigraphic Sections

SECTION 1

East section line, sec. 32, T. 21 S., R. 62 E. 0.4 mile north of south section line (photograph, fig. 2). Stratigraphic section exposed in west and south side of canyon; top of section at altitude of about 1,880 feet. The gypsiferous facies of the "unnamed gravel" overlies the fanglomerate, but the gravel is covered except in inaccessible vertical cliffs.

	Thickness (feet)	Depth (feet)
"Unnamed Fanglomerate":		
1. Conglomerate consisting of lenses of cobble gravel in pebble gravel. Scattered boulders. Dry color is very light gray. Parallel and horizontal beds to 1 ft. thick. Channels extend 1-2 ft. into unit below. Well indurated, forms overhanging cliffs.	15±	15±
Muddy Creek Formation:		
2. Sand and silt with scattered gravel lenses. Dry color is very pale orange. Thickness ranges from 1 to 4 ft. because of channels cut into bed by unit 1 and because unit 2 has a pebble gravel lense that extends into unit 3. Massive except for gravel lenses, which have nearly parallel bedding. Moderately indurated with lime, forming a caliche unit. Cliff former.	4±	19±

SECTION 1 - continued

Muddy Creek Formation - continued

	Thickness (feet)	Depth (feet)
3. Silty sand with trace of clay, light brown. Beds undulate slightly, particularly those in middle of unit. About 80 per cent of beds are indurated with lime, forming resistant layers of caliche as much as 2 ft. thick. Uncemented interbeds are as much as 1 ft. thick. These uncemented beds have moderate blocky structure superimposed on a strong prismatic structure. Blocky peds to 1 in. across, prisms to 6 in. high. Scattered evaporite crystals present.	26±	41±
4. Fine to medium sand, light brown. Almost cohensionless. Moderate prismatic structure. Prisms to 1 ft. high. Massive.	4±	45±
5. Silty fine sand with caliche nodules, light brown. Similar to unit 3 but with less cementation. About 20 per cent of unit is concretionary and bedded caliche. Parallel and horizontal beds 1 to 6 in. thick. Prismatic structure.	24±	69±
6. Largely covered. In situ(?) material indicates sediments similar to unit 5.	31±	100±

SECTION 2

E½ NE¼ sec. 32, T. 21 S., R. 62 E. Stratigraphic section exposed in south side of canyon; top of section at altitude of about 1,885 feet.

SECTION 2 - continued

	Thickness (feet)	Depth (feet)
"Unnamed Fanglomerate":		
1. Conglomerate and siltstone, interbedded, light brown. Poorly sorted, containing rounded basaltic boulders as much as 24 in. across, with much interstitial sand and silt, well indurated. Bedding thin to thick. Locally crossbedded. Form over-hanging cliffs.	15±	15±
Muddy Creek Formation:		
2. Clay and silt, interbedded. Clay is moderate brown. Silt is pinkish gray. Lacustrine. Strongly developed prismatic columns as much as 4 in. across are developed in the clay beds, with sides of columns showing slickensides. Fractures in the clay are filled with fibrous crystals of sodium sulfate(?), individual crystals being as much as 0.4 in. long. The silt beds are well indurated and in weathering, slabs about 1-in. thick become separated from the rock mass and hollows to 8 in. X 4 in. X 2 in. are formed behind the slabs.	6.5±	21.5±
3. Covered. Colluvium indicates silt and clay similar to Unit 5.	26±	47.5±
4. Sand, fine, well sorted, moderate brown, poorly exposed.	2±	49.5±
5. Silt, with a few beds of clay and gypsum, scattered basaltic pebbles. Silt is light brown, clay is moderate brown, and the gypsum is very light gray. The silt and clay have weak to strong prismatic structure. The gypsum has a weak nodular structure. The beds of clay and gypsum are as much as two ft. thick.	36±	85.5±

SECTION 3

SW¼ NE¼ sec. 15, T. 22 S., R. 61 E. Stratigraphic section exposed in southeast bank of canyon. Top of section at altitude of about 2,160 feet.

	Thickness (feet)	Depth (feet)
Las Vegas Formation:		
1. Silt, moderate brown. Strong blocky structure to about 0.4 in. across. Beds about 1 ft. thick. Bottom 4 in. are strongly cemented. Remainder of unit is weakly cemented except for strong nodules of caliche up to 1 ft. across which are common.	8±	8±
2. Sandy silt, moderate brown. Strong prismatic structure with peds to 2 in. high. Massive.	4±	12±
3. Sand with scattered pebbles, moderate to light yellowish brown and yellowish green. Some interbedded granule gravel in strata less than 2 in. thick. Cohesionless to weakly cemented. Moderately sorted. Thin to thick parallel beds. The green sand has some rust stain, more prominent along bedding planes.	25±	37±
4. Granule-pebble gravel with fragments of unit below. Varicolored, principally moderate brown. Nearly cohesionless. No continuous bedding planes within unit but pebble lenses show that bed has not been contorted.	4±	41±

Angular unconformity.

SECTION 3 - continued

Las Vegas Formation - continued

	Thickness (feet)	Depth (feet)
5. Silt, dusky yellow green, except for upper 1 ft. which has weathered to moderate brown. Upper 1 ft. contains scattered pebbles. Beds highly contorted with dips up to 30°. Abundant mollusk and ostracod shells and fragments of wood. Beds parallel and 0.1 to 2 in. thick. High in iron content. Structureless. Moderately consolidated, difficult to break except along bedding planes where it parts with ease.	4±	45±

SECTION 4

SW¼ SE¼ sec. 24, T. 21 S., R. 60 E. Stratigraphic section exposed in south bank of unnamed stream. Top of section at altitude of about 2,280 feet.

	Thickness (feet)	Depth (feet)
Las Vegas Formation:		
1. Sand, medium to fine, light brownish gray, strong blocky structure, peds less than 1 in. across. Slight to moderate lime induration, about 80 per cent of bed consisting of nodules of caliche. Massive.	6±	6±
2. Sand, medium to fine, light to moderate brown. Weak angular blocky structure. Weakly cemented. Upper 3 ft. has scattered pebble gravel and some		

SECTION 4 - continued

Las Vegas Formation - continued (2)

	Thickness (feet)	Depth (feet)
iron staining. Indistinct beds are 2 to 3 ft. thick, parallel and horizontal.	12±	18±
3. Silt and clay, greenish to brownish gray. Top 6 in. and bottom 6 in. have lime accumulations. The bottom 6 in. have prism-like structure with peds 3 to 6 in. across. The remainder of the bed has angular blocky structure with peds less than 0.5 in. across. Induration of limy strata is moderate, remainder of unit is weakly cemented.	6±	24±
4. Pebble-cobble gravel and sand, multi-colored, some green and brown iron staining. Massive. Weakly cemented.	2.5±	26.5±

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