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DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
Carson City, Nevada

WATER RESOURCES BULLETIN NO. 21

HYDROGEOLOGY OF THE LOWER HUMBOLDT RIVER BASIN, NEVADA

by

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Prepared Cooperatively by
The Desert Research Institute
University of Nevada

(D.R.I.—Technical Report No. 3)

JUNE 1963

LETTER OF TRANSMITTAL

*To His Excellency, THE HONORABLE GRANT SAWYER, Governor of Nevada,
Carson City, Nevada.*

DEAR GOVERNOR SAWYER: There is transmitted herewith a copy of Water Resources Bulletin No. 21 entitled "Hydrogeology of the Lower Humboldt River Basin" by Dr. John D. Bredehoeft. The study on which this report is based was made possible by appropriations made for the support of the Humboldt River Research Project and the Research Project on the Behavior of Underground Waters. The former project was authorized and funds first appropriated in 1959 while the latter was authorized and funded in 1961.

Dr. Bredehoeft carried on this work under the direct supervision of Dr. George B. Maxey, Research Professor of Hydrology and Geology of the Desert Research Institute of the University of Nevada. The outline of the study was developed by Dr. Maxey and approved by this office. Dr. Maxey conferred frequently with us on developments while the study was in progress.

The next bulletin in this series to be published will be a comprehensive review and evaluation of data from technical investigations relating to the hydraulic system in the Humboldt River Valley near Winnemucca. Reports on other phases of this broad project will be issued as those studies are completed.

In addition to the bulletin by Dr. Bredehoeft and the other bulletins which are to follow, a number of reports relating to the Humboldt River Research Project have been published in the Water Resources-Information Series of the Department of Conservation and Natural Resources and as professional papers. Also, a number of manuscripts of reports not yet published are on open file at the offices of the U.S. Geological Survey, 222 E. Washington Street, Carson City, Nevada, and the Department of Conservation and Natural Resources, State Office Building, Carson City, Nevada.

Respectfully submitted,

HUGH A. SHAMBERGER, *Director.*

FOREWORD

This is the third of a series of reports prepared by the Desert Research Institute for the State of Nevada. It makes public the results of a scientific reconnaissance conducted during the field season of 1961 and 1962 as a part of the Humboldt River Research Project and of the Desert Research Institute studies in ground water. The work was made possible by funds appropriated by the 1961 Nevada State Legislature for the Humboldt Project (Chapter 97, Stats., 1959 and 1961) and for research on ground-water problems in the State (Chapter 166, Stats., 1961).

The chapters on Geography and Geology provide a background for further proposed hydrologic work in the Humboldt Basin and support a forthcoming review of the hydrology now being prepared by the staff of the Institute. The final chapter, entitled *Ground-Water Geology* not only performs this function but demonstrates the value of existing well-records, primarily drillers' logs, in the location, delineation and analysis of aquifers in arid and semi-arid regions. This last chapter represents the initial step in a statewide study to demonstrate the value of and to utilize fully these valuable records in hydrogeologic studies. It is our hope that the many agencies, organizations, and individuals in Nevada who are so vitally interested in and dependent upon the State's water resources can profitably utilize the ideas, information, and methods set forth in this report.

GEORGE B. MAXEY,
*Research Professor of
Hydrology and Geology,
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University of Nevada.*

June 1, 1963

ABSTRACT

The purpose of this investigation is to describe the geology of the alluvial valleys of the Lower Humboldt River Basin as a framework for future hydrologic studies. This is the second phase in a continuing water resources study of the Humboldt River Basin.

The geology of the valley-fill deposits is presented on a 1/250,000 map. A detailed investigation of Hawley, Wilson and Cartwright in the Winnemucca region was used as a pilot study to guide work in remaining portions of the area. Farvolden, Cartwright and the author completed reconnaissance mapping of the remainder of the Lower Humboldt Basin. The mapping was done chiefly from the Army Map Service high level aerial photos following extensive field investigation.

Valley-fill deposits were subdivided into 13 units using the genesis of the deposits as a basis for subdivision. Stream, alluvial-fan, lacustrine, playa, eolian, and colluvial deposits comprise the bulk of the valley-fill sediments.

Later Tertiary and Quaternary sedimentation is controlled largely by two factors: (1) the tectonics and (2) climatic changes. Basin and Range block faulting, which started at least as early as the Oligocene and has continued to the present, primarily formed the basins of deposition. A number of climatic changes occurred during the late Tertiary and Quaternary and have influenced deposition. The Quaternary climate has varied between pluvial periods and periods of extreme aridity. The great bulk of Quaternary sediments were deposited during the more pluvial climatic periods.

An analysis of drillers' logs was made in an effort to interpret the subsurface geology and relate it to the surface geology. Two items of

reported information were most useful for interpretation: (1) hydrologic data from the results of acceptance production tests, and (2) the lithologic logs. Data from the crude production tests provided sufficient information for estimates of specific capacity which allowed the theoretical calculation of transmissibilities and permeabilities.

Statistical analyses reveal a meaningful relationship between the calculated specific capacities and the drillers' lithologic description. A graph of cumulative thickness of reported gravel versus specific capacity shows good correlation with the results expected from theory.

Permeability differs markedly between lacustrine deposits and fluvial deposits. As expected, the lacustrine deposits are much less permeable. The best aquifers were deposited in the fluvial environment.

Lithofacies maps were compiled from drillers' logs from several valleys to investigate the distribution of aquifers. Extensive aquifers occur associated with major stream courses. These sand and gravel deposits were laid down during an earlier period of pluvial climate. Three conditions are necessary for the deposition of the extensive sand and gravel deposits: (1) a major stream of large volume must have been present, (2) there must have been a favorable area for deposition, and (3) a rock type that will form gravel must occur in outcrop in the basin. The best aquifers can be explored for in the valleys on the basis of their relationship to the major drainage basins.

An average permeability for the most extensive aquifers, stream-associated sand and gravel deposits, was computed statistically from drillers' data. A median value of 500 gallons per day per square foot was determined using the specific capacity calculated from production test data.

INTRODUCTION

This work is part of an initial phase of a water resource investigation of the Lower Humboldt River Basin below Palisade, Nevada, supported by the Nevada Department of Conservation and Natural Resources under the direction of Assistant Director George Hardman. It is intended to outline the physical setting for further hydrologic studies in the Lower Basin.

Of principal interest is the geologic investigation of the alluvial valleys. These valleys are areas of present and potential ground-water development. Ground-water reservoirs present in these valleys, largely untapped at present, if properly developed may afford sizeable additional water supplies as well as a means of modulating the surface flow of streams such as Humboldt River.

Much of the geologic investigation of the valley is the work of a team of geologists from the University of Illinois under the direction of G. B. Maxey (Plate I*). Detailed mapping during the field seasons of 1959, 1960 and 1961 was carried out by Hawley, Wilson and Cartwright in the Winnemucca area. This detailed work was used as a pilot study to guide the remainder of the investigation. It was intended to map the major valleys of the Lower Basin on a reconnaissance basis and to compile the work on one map. Field investigations by Cartwright, Farvolden and the author during the 1961 field season were directed toward this end and were completed in 1962.

The Nevada Department of Conservation and Natural Resources, Hugh A. Shamberger, Director, and George Hardman, Assistant Director, financed a large part of this investigation. The author is indebted to Dr. G. B. Maxey of the Desert Research Institute of the University of Nevada for his support and guidance of the work. The writer is also indebted to Philip Cohen of the U. S. Geological Survey who gave advice particularly about the format of the map.

*Plate I is not included in this report. Copies of Plate I may be obtained from the Desert Research Institute at the price of \$1.

HYDROGEOLOGY OF LOWER HUMBOLDT RIVER BASIN, NEVADA

by

John D. Bredehoeft*
Desert Research Institute
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GEOGRAPHY

General Statement

The area is in north-central Nevada in the Basin and Range Physiographic Province and includes portions of Elko, Eureka, Lander, Humboldt, Pershing and a small part of Churchill Counties comprising about 9,000 square miles (Figure 1).

The population of this sparsely populated area, according to the 1960 Census, is approximately 9,350, a population density of approximately one person per square mile. Two-thirds of the people live in three major towns: Winnemucca, population 3,453; Lovelock, population 1,948; and Battle Mountain, population approximately 800.

Transcontinental U. S. Highway 40, the Southern Pacific Railroad and the Western Pacific Railroad traverse the Humboldt River Valley. Together with several state and county roads these provide excellent access to the area.

Topography

The area is in the Basin and Range province and is characterized by subparallel block-faulted mountain ranges separated by alluvial valleys of approximately equal size. The trend of the ranges and valleys varies from north-south to northeast-southwest. Both the ranges and valleys vary from about 10 to 12 miles in width and from 30 to 70 miles in length.

Valley elevations range from approximately 3,900 feet in the Humboldt Sink to 4,700 feet along Humboldt River in the vicinity of Crescent Valley and 5,000 feet to the south in Reese

River Valley. The mountain ranges generally rise from 2,000 to 4,000 feet above the valley floors. High points in the area are Star Peak in the West Humboldt Range, elevation 9,835; Granite Peak in the Santa Rosa Range, elevation 9,779; Sonoma Peak in the Sonoma Range, elevation 9,421; and Mount Lewis in the Shoshone Range, elevation 9,688.

Humboldt River flows from east to west through the area following, for the most part, a physiographic and geologic discontinuity. Many of the ranges both to the north and south terminate at the river, and many general structural trends apparently change at this point. Valleys south of the river abut against ranges to the north and vice versa. This physiographic break, perhaps the result of some transcurrent structural trend in the earth's crust, provides a topographic low in which the Humboldt River flows from east to west along much of its course at right angles to the general north-south trend of Basin and Range topography.

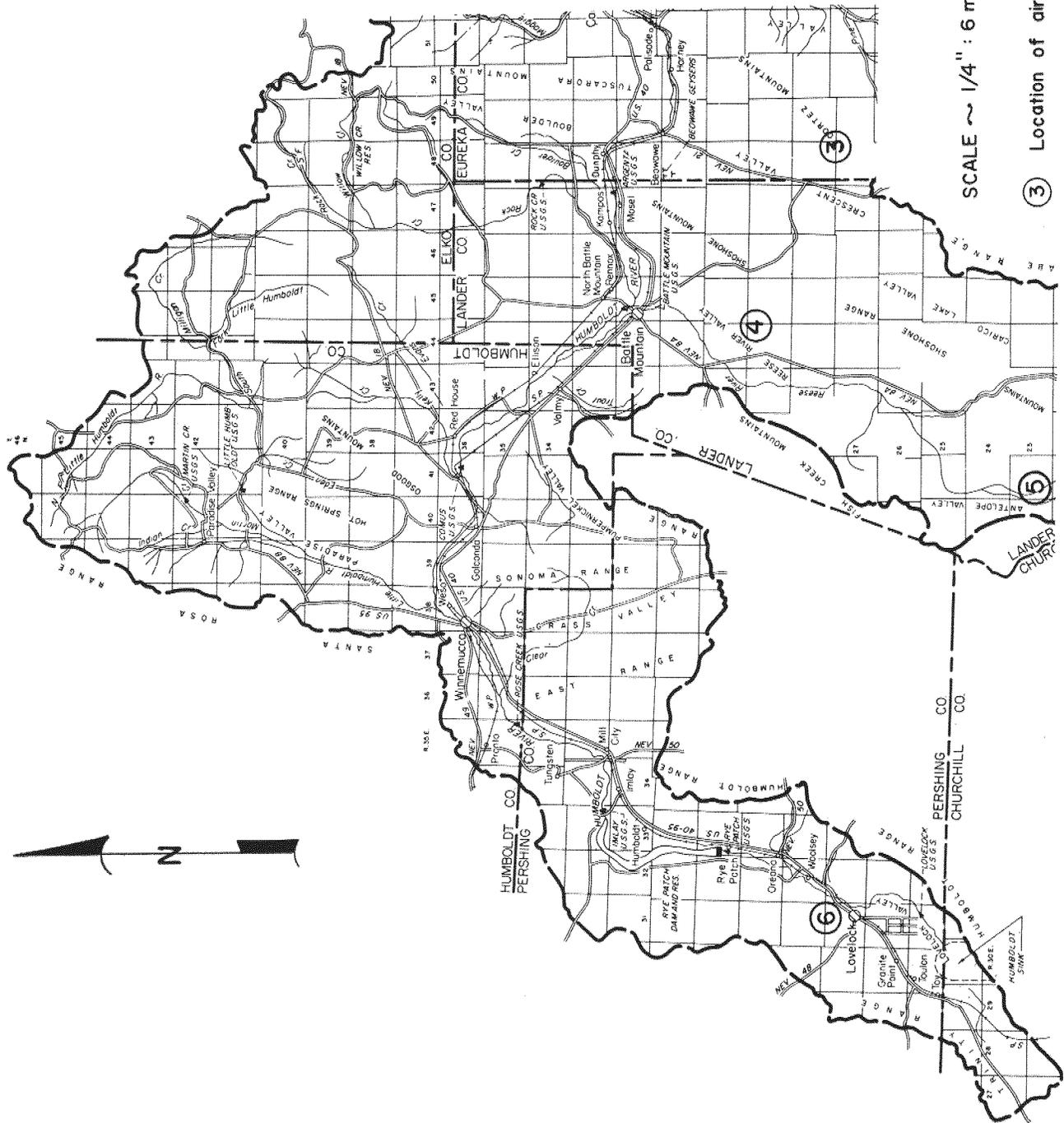
Climate

The climate is arid or semiarid, characterized by low precipitation and humidity and extreme diurnal variations of temperature.

Figure 2, modified from Hardman (1936), is a precipitation map for the area. Large differences in precipitation between the valleys and ranges are apparent. Much of the precipitation occurs as snowfall during the winter months.

*The report is based on a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree at the University of Illinois, Urbana.

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SCALE ~ 1/4" : 6 miles

③ Location of airphoto in figure 3.

Figure 1. Location map of the Lower Humboldt River Basin.

Summer precipitation usually occurs as localized showers, often as "cloudbursts."

Wide seasonal and daily variations of temperature occur. At Winnemucca the average daily temperature range is 25°F in January increasing to 35°F in July. The average temperature is 28°F in January and 72°F in July, with an annual average of 49°F. The minimum and maximum recorded temperature prior to 1941 was -36°F and 108°F respectively. The average growing season is approximately 120 days (U. S. Department of Agriculture, 1941, p. 979-988).

Rather high rates of evaporation occur. Weather Bureau records for the past 21 years at Rye Patch Reservoir indicate an average rate of evaporation of 49.2 inches of water annually from a standard class A pan (U. S. Weather Bureau, 1961, p. 153). This evaporation rate is verified by evaporation estimates based on the differences in inflow and outflow of Rye Patch Reservoir (Maxey and Shamberger, 1961).

Economy

The economy of the area is based primarily upon ranching, mining, and recreation.

Ranching operations are limited by the surface water available for irrigation. In most instances the size of a rancher's operation is dictated by the amount of winter feed he can produce. Irrigation of pasture land and hay fields is common practice throughout the Lower Humboldt Basin. Extensive areas of irrigation are developed along Humboldt River in the reach from Winnemucca to Beowawe, in the Lovelock area and in Paradise Valley.

Irrigation along Humboldt River and in Paradise Valley is by the flood method. In these areas available surface-water runoff is spread over the fields. Water supply is high during spring runoff and decreases to almost nothing later in the summer. Availability of water varies from year to year depending upon climatic factors.

Throughout much of the area little is done to modulate stream runoff. In several valleys ground water is being developed to supplement surface-water supplies.

Modern irrigation practice is highly developed in the Lovelock area. Here water is supplied from Rye Patch Reservoir on Humboldt River. A maximum of 30,000 acres of land planted almost entirely in alfalfa have been irrigated. In most years practically all Humboldt River water reaching Rye Patch Reservoir is used for irrigation in the Lovelock area; normally only return

flow from irrigation reaches the Humboldt Sink. Streamflow data from 1952 to 1960 suggest that only in one year in ten does a large quantity, perhaps as much as 300,000 acre-feet, of flood flow of Humboldt River actually reach the Humboldt Sink (Maxey and Shamberger, 1961).

Mining has been one of the principal industries of this area since the 1860's. The mines of the area have produced a variety of metals including gold, silver, copper, lead, zinc, iron, tungsten, manganese, antimony, nickel, cobalt and mercury. The Nevada Massachusetts Company tungsten mine in the Eugene Mountains near the Humboldt-Pershing County line, in the past one of the world's leading producers of tungsten, is currently closed down. Work is presently under way to reopen the Getchell mine and mill, one of the largest gold, silver and copper mines of the area. The Getchell is one of the newer mines, discovered in 1938 on the east side of the Osgood Mountains, northeast of Winnemucca.

Several large mines are currently active, the major mined products being iron ore, barite, diatomaceous earth and perlite. Iron mines in Eureka, Lander, Humboldt and Pershing Counties are shipping ore to Japan. Barite is produced from two mines in the Shoshone range. Diatomaceous earth and perlite are mined and processed in the Lovelock area.

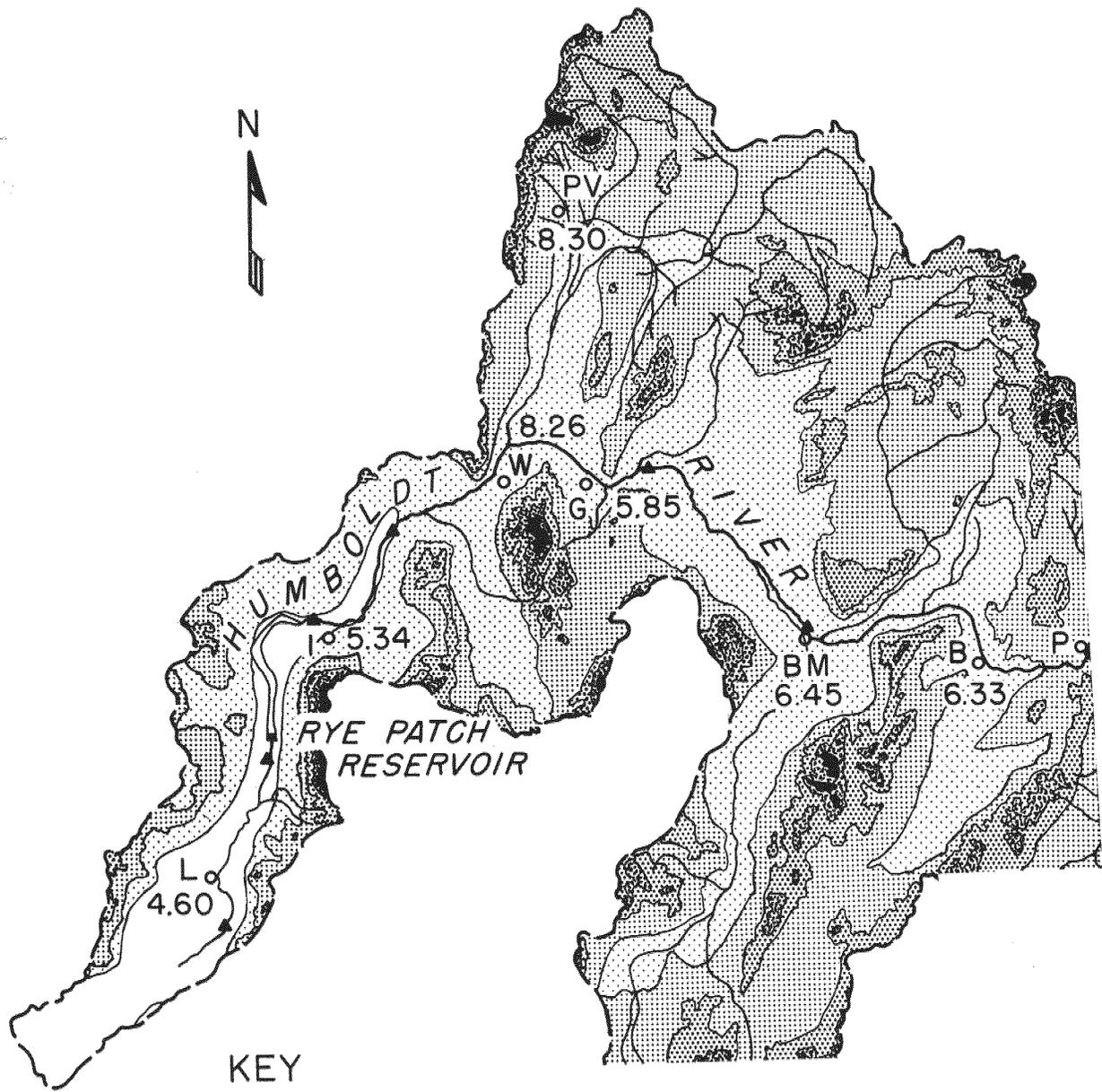
GEOLOGY

Introduction

Scope of the Geological Investigations

This investigation is restricted almost entirely to the valleys because they are the populated areas in the Great Basin in which need for water occurs. Valley fill deposits are in large part good aquifers; they provide an excellent facility to store and transmit water.

Many studies of water resources in the Great Basin are carried out with the basic assumption that mountain ranges act as permeability boundaries between ground-water basins and further that the effect of ground-water storage in the ranges is negligible. It is recognized that most of the water which recharges ground-water reservoirs in the valleys falls on the mountains as snow and runs off to the valleys in intermittent streams. Most recharge is believed to occur through the alluvial aprons adjoining the mountain fronts. Although the mountains are recognized as most important in the hydrologic cycle within the Great Basin, their effects, other than



KEY

PRECIPITATION IN INCHES

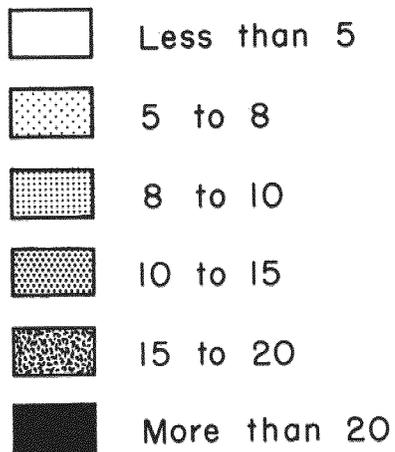


Figure 2.

as geohydrologic boundaries and recharge catchment areas, are considered negligible in most ground-water investigations.

Several investigators have pointed out the fallacy of this assumption for specific areas. This, however, still appears a reasonable basis on which to approach the ground-water problems of the Lower Humboldt Basin, at least until the data suggest that other consideration of mountain ranges is necessary.

For these reasons the emphasis in this investigation was placed on the alluvial valleys.

Method of Mapping

Much of the geology of the bedrock areas has been mapped (Plate I, Index of Bedrock Mapping). This index is incomplete; areas mapped in detail in Humboldt and Eureka Counties which were used in compiling the county geologic maps are not shown on the index map. All of this information was used freely in compiling and adapting the geology for this report. Unfortunately, many of the older topographic base maps on which much of the geology was done were inadequate. Discrepancies between the map in this report and previous maps can, in part, be attributed to inadequacy of the older base maps.

Much mapping was done using the Army Map Service high-level aerial photographs, with a scale of approximately one mile to the inch—about 1/60,000. Intensive field investigation of all the valleys outside the Winnemucca and Kelly Creek Valley area was undertaken by Farvolden and the writer, working together in the field. It was possible, following a close field check, to map the alluvial geology from the aerial photographs. This procedure was used for most mapping outside of the Winnemucca area. Except for Hawley's and Wilson's work in the Winnemucca region, mapping is of a reconnaissance nature.

The geology was compiled from 1/60,000 aerial photographs on 1/125,000 work maps, which were photographic enlargements of the Army Map Service one minute by two minute topographic maps. Topography on the 1/250,000 Army Map Service maps, contoured at a 200-foot interval, was found to be reasonably accurate in the field. The geology taken from the work sheets was reduced photographically and drafted on the present 1/250,000 map. Some modification was necessary to meet map registration requirements.

Previous Investigations

The Lower Humboldt Basin comprises such a large area that much of the geologic literature

bearing on the problems of the Great Basin is pertinent. Therefore, only the detailed mapping in the area and that work which is especially pertinent is indicated.

Some of the earliest explorers of the Great Basin traversed the Humboldt Valley. In 1833 Joseph Walker led an expedition to California by way of the Humboldt Valley. Topographic surveys by Beckwith, 1854, and Ingalls, 1855, contributed little to knowledge of the geology (Russell, 1885, p. 17). Simpson's expedition which crossed the Reese River in the vicinity of Austin in 1859 (Simpson, 1876, p. 78) included a geologist, H. Englemann, who reported his observations along the route.

The Geological Exploration of the Fortieth Parallel under the direction of Clarence King included almost the entire Lower Humboldt Basin. King (1878) assisted by such able geologists as S. F. Emmons and Arnold Hague (1877) mapped the region in the years 1867 to 1873. Although their interpretations have been modified by more recent work, much of their field description is excellent.

Russell (1885) contributed extensively to our knowledge of the Quaternary geology with his monograph on the geological history of Lake Lahontan.

Louderback (1904), mapping in the West Humboldt Range east of Lovelock, demonstrated that many of the ranges of the Basin and Range were fault blocks as suggested earlier by Gilbert.

Jones (1915), (1925) worked extensively in the Lahontan Basin in the vicinity of Lovelock suggesting modifications of Russell's ideas. Jones, De Berard and York did detailed mapping in this area; unfortunately their map was not published.

Most of the mining camps of the area have been mapped, at least in a reconnaissance manner. Much of this mapping, however, is of such a limited area and being mainly in the mountain ranges, was not particularly useful for this study.

The index of geologic mapping (Plate I) shows most of the detailed mapping. For simplicity only the county geologic maps for Humboldt and Eureka Counties are shown; more detailed mapping within these counties has been consolidated in the county maps. The following is a comprehensive list of detailed mapping and water resource investigations in chronologic order:

KING, CLARENCE, 1878, Geological exploration of the fortieth parallel.

RUSSELL, I. C., 1885, Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada.

LOUDERBACK, G. D., 1904, Basin and Range structure of the Humboldt region.

- LEE, W. T., STONE, R. W., GALE, H. S., et al., 1916, Guidebook of the Western United States, part 6, The Overland Route.
- WARING, G. A., 1918, Ground water in Reese River Basin and adjacent parts of Humboldt River Basin, Nevada.
- JENNY, C. P., 1935, Geology of the central Humboldt Range, Nevada.
- CAMERON, E. N., 1939, Geology and mineralization of northwestern Humboldt Range, Nevada.
- ROBINSON, T. W., and FREDERICKS, J. C., 1946, Ground water in Lovelock Valley, Nevada.
- HOBBS, S. W., 1948, Geology of the northern Osgood Mountains, Humboldt County.
- ROBINSON, T. W., LOELTZ, O. J. and PHOENIX, D. A., 1948, Ground water in Grass Valley and adjacent portions of the Humboldt River Valley, Pershing and Humboldt Counties, Nevada.
- LOELTZ, O. J., PHOENIX, C. A., ROBINSON, T. W., 1949, Ground water in Paradise Valley, Humboldt County, Nevada.
- COWAN, A. G., 1950, The geology of a portion of Crescent Valley and Hilltop quadrangles, Nevada.
- MULLER, S. W., FERGUSON, H. G., ROBERTS, R. J., 1951, Geology of the Mount Tobin quadrangle, Nevada.
- ROBERTS, R. J., 1951, Geology of the Antler Peak quadrangle, Nevada.
- FERGUSON, H. G., MULLER, S. W., ROBERTS, R. J., 1951, Geology of the Winnemucca quadrangle, Nevada.
-, 1951, Geology of the Mount Moses quadrangle, Nevada.
-, 1952, Geology of the Golconda quadrangle, Nevada.
- WALLACE, R. E., SILBERLING, N. J., IRWIN, W. P., TATLOCK, D. B., 1959, Preliminary geologic map of the Buffalo Mountain quadrangle, Nevada.
- COMPTON, R. R., 1960, Contact metamorphism in Santa Rosa Range, Nevada.
- MASURSKY, H., 1960, Welded tuffs in the northern Toiyabe Range, Nevada.
- LEHNER, R. E., TAGG, K. M., BELL, M. M., ROBERTS, R. J., 1961, Preliminary geologic map of Eureka County, Nevada.
- WILLDEN, R., 1961, Preliminary geologic map of Humboldt County, Nevada.
- MAXEY, G. B., and SHAMBERGER, HUGH A., 1961, The Humboldt River Research Project, Nevada.
- ZONES, C. P., 1961, Ground-water potentialities in the Crescent Valley, Eureka and Lander Counties, Nevada.
- WALLACE, R. E., TATLOCK, D. E., SILBERLING, N. J., IRWIN, W. P., 1962, Preliminary geologic map of the Unionville quadrangle, Nevada.
- SOUTHERN PACIFIC RAILROAD, Areal economic geology (unpublished).
- COHEN, PHILIP, 1962, A preliminary evaluation of the ground-water hydrology of the valley of the Humboldt River, near Winnemucca, Nevada, a summary.
- EAKIN, T. E., 1962, Ground-water appraisal of the Imlay area, Humboldt River Basin, Pershing County, Nevada.
- NEVADA DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES AND U. S. DEPARTMENT OF AGRICULTURE, 1962, Water and related land resources, Humboldt River Basin, Nevada, report number one, Little Humboldt sub-basin.

Geomorphology

Much geologic and stratigraphic interpretation is based upon analysis of land forms. This is especially true of the alluvial valleys where most of the geomorphic features are depositional features. By mapping these depositional features it is possible to interpret the stratigraphy of at least the upper part of the valley fill. In essence this was the procedure used in this report.

Inasmuch as much of the geologic interpretation is based upon understanding the geomorphology, it seems worthwhile to discuss and illustrate the land forms in considerable detail.

Most of the region can be conveniently subdivided into three geomorphic subdivisions: the mountain highland, the piedmont alluvial apron, and the valley lowland areas. Each of these will be discussed separately.

A number of aerial photographs are included to illustrate the different geomorphic features of the area (Figure 1).

The Mountain Ranges

The ranges of the region are characteristic Basin and Range fault-block mountains. Louderback's (1904) cross section of the West Humboldt Range, in the vicinity of Lovelock, has often been used as typical of the ranges of the region. Davis (1903) discussed both the Santa Rosa Range north of Winnemucca and the Shoshone Range east of Battle Mountain as typical fault-block ranges of the Great Basin.

Most of the ranges are in a youthful or mature stage of erosional development. The Cortez Range is one of the best examples of a mountain block which has been recently faulted (Figure 3). Here most of the criteria indicating an early stage of erosional development are met: the frontal fault plane of the range is evident, triangular facets truncate the spur ends, very steep v-shaped canyons are present, the alluvial slope is made up of fans beginning to coalesce.

The back slope or more gentle slope of the tilted fault blocks affords a much different setting from the steep or frontal faulted slope. The west side of Crescent Valley is formed by the back slope of the Shoshone Range. The core of the Shoshone Range is composed of Paleozoic sedimentary rocks and intrusive granite, is covered by gently dipping Tertiary basalt which forms the back slope of the tilted fault block. Differentiating between the Tertiary basalt and the older dissected alluvial apron deposits is particularly difficult. Gently dipping back slopes of tilted fault

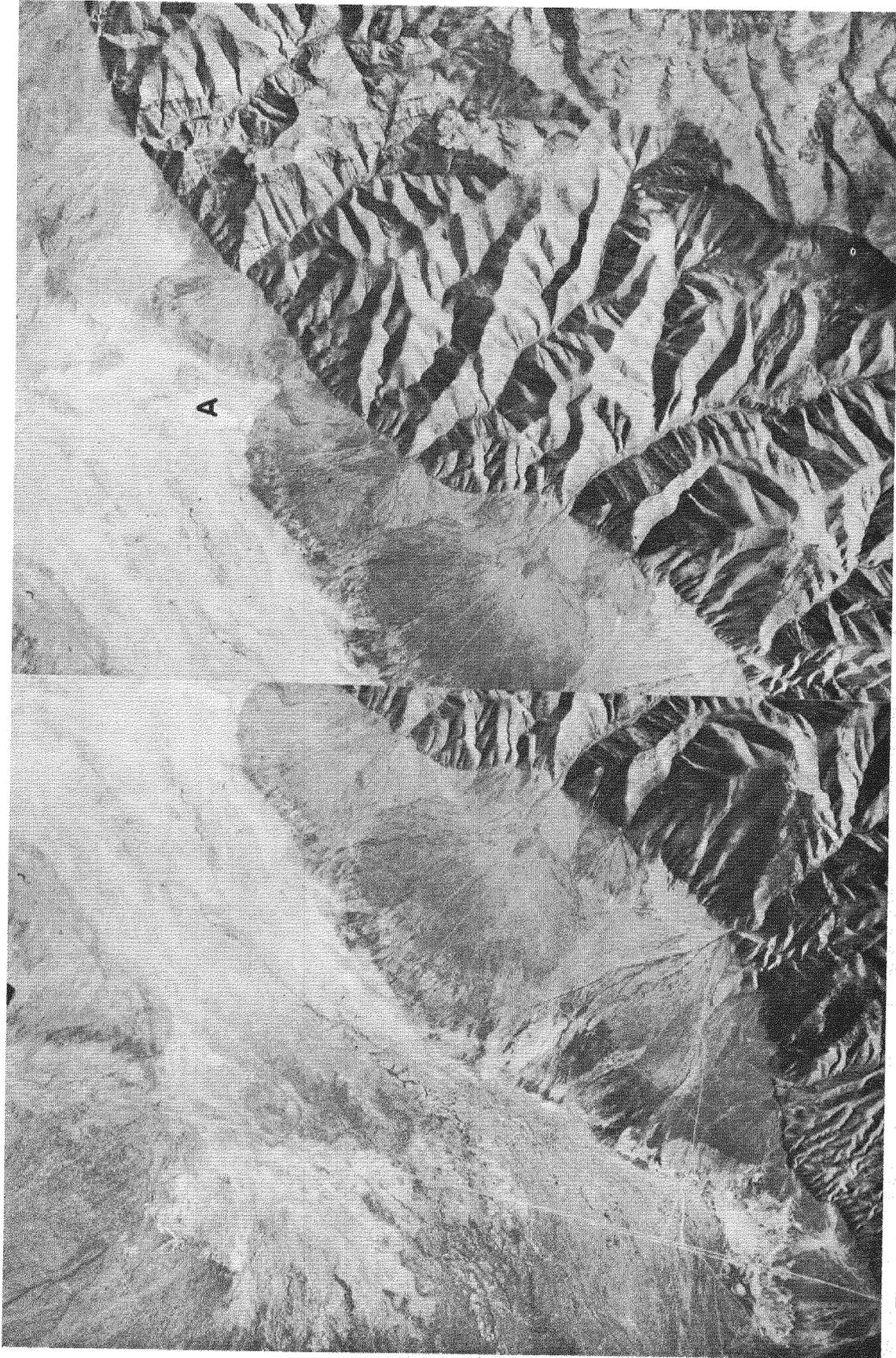


Figure 3. Aerial photographs (stereo pair) of the Cortez Range and Crescent Valley. Illustrates a block faulted mountain range in the early stages of erosional development—fault scarp with triangular facets, v-shaped canyons in the range, alluvial apron composed of coalescing alluvial-fans, playa in the valley (marked A). Scale: 1 inch equals 1.3 miles.

block presented a continual problem in reconnaissance mapping. Because of the gentle slope, the contact between the alluvial slope deposits and bedrock is difficult to define even when outcrops are closely examined in the field.

Not every faulted block is tilted as the example given above. Many blocks are faulted on both sides and more nearly resemble a horst. Davis (1903) called this type simply a lifted block. Erosion in a few of the ranges has advanced to a mature stage. The Antelope Range, a northern extension of the Trinity Range, situated on the west edge of the Humboldt River Basin at the Humboldt-Pershing County line, is an example. Erosion here has clearly advanced to the mature stage. There is only a relatively low ridge at the crest of the range; no evidence of a fault scarp remains. A pediment with scattered bedrock outcrops has developed on the east side of the range.

This area of mature erosional development is typical of much of the Trinity Range. The Trinity Range and other associated ranges along this structural trend appear to have undergone a longer period of structural stability accompanied by erosion than other ranges within the Lower Humboldt River Basin.

The Alluvial Apron

Coalescing alluvial-fans surround most of the mountain areas. A group of fan deposits which appear to be much older, Quaternary-Tertiary, are also recognized; these, however, generally are closely associated with mountain blocks. Because the ranges of the area are in relatively youthful stages of erosional development, extensive pediments are absent. Pediments, however, make up part of the piedmont slope in several valleys.

Two ages of recognizable alluvial-fans usually comprise the alluvial apron. The distinction between the Younger and Older alluvial-fan deposits is based on whether the present environment is predominantly one of erosion or deposition.

The Older fan deposits are being eroded and generally a dendritic drainage pattern is evident, either as an incipient or a well integrated system. The dissected pattern of the Older alluvial-fans is clearly shown in Figure 4. Commonly a well developed soil profile occurs near the surface of the Older fan deposits. Wilson (1963) has described this soil in considerable detail. He interprets it as a pre-Lahontan, early Pleistocene soil. At many localities this soil is covered by 9 to 18 inches of silt.

The various stages of dissection as well as the two ages of alluvial-fans are shown in Figure 4. In these photographs, dissected, coalescing Older fans comprise the upper slopes of the alluvial apron. Each of the larger intermittent streams issuing from the mountain front has a well-developed fan-head trench. Below the Older fans are areas of active deposition which make up the Younger alluvial-fan deposits.

As fan building progresses, shifts in areas of active deposition are integral parts of the process. Accompanying these shifts in the active depositional area is a change from a depositional environment to one of active erosion. Apparently as soon as deposition ceases in a particular area, erosion sets in. In the process of building the alluvial apron, the higher slopes, sites of earlier deposition, undergo progressively longer periods of erosion. This explains the various stages of erosional development typical of many of the alluvial aprons of the area. Because both erosion and deposition appear to be integral in the development of the alluvial apron, distinction of Older and Younger fan deposits is somewhat artificial. It is apparent from the aerial photographs that the contact between Older and Younger fans is often rather arbitrary.

The two ages of fan deposits imply only relative age, although the differentiation is carried throughout the area using the criteria described above. The pre-Lahontan soil which developed on the Older alluvial-fan deposits is present throughout most of the area. In the Lahontan Basin fan deposits can be related to the last stage of Lake Lahontan. Most younger fan deposits overlie lake features, and lake features overlie many Older alluvial-fan deposits.

Remnants of Quaternary-Tertiary alluvial fans are associated with the mountain ranges. A typical example of these features occurs on the west flank of the Humboldt Range near Imlay. A remnant of a Quaternary-Tertiary fan has been uplifted with the Humboldt structural block. Its lower slope is truncated by a fault clearly associated with the mountain front to the south. Distinctive, more or less parallel canyons are characteristic of the erosional pattern generally developed on these uplifted Quaternary-Tertiary fans throughout the area although the pattern is not often so pronounced as in this case.

Field (1933), in a geomorphic study of this particular area, concluded that a sequence of pre-Lahontan alluvial fans was faulted up with the mountain block and subsequently eroded. Remnants of the fan deposit remain; however, to the

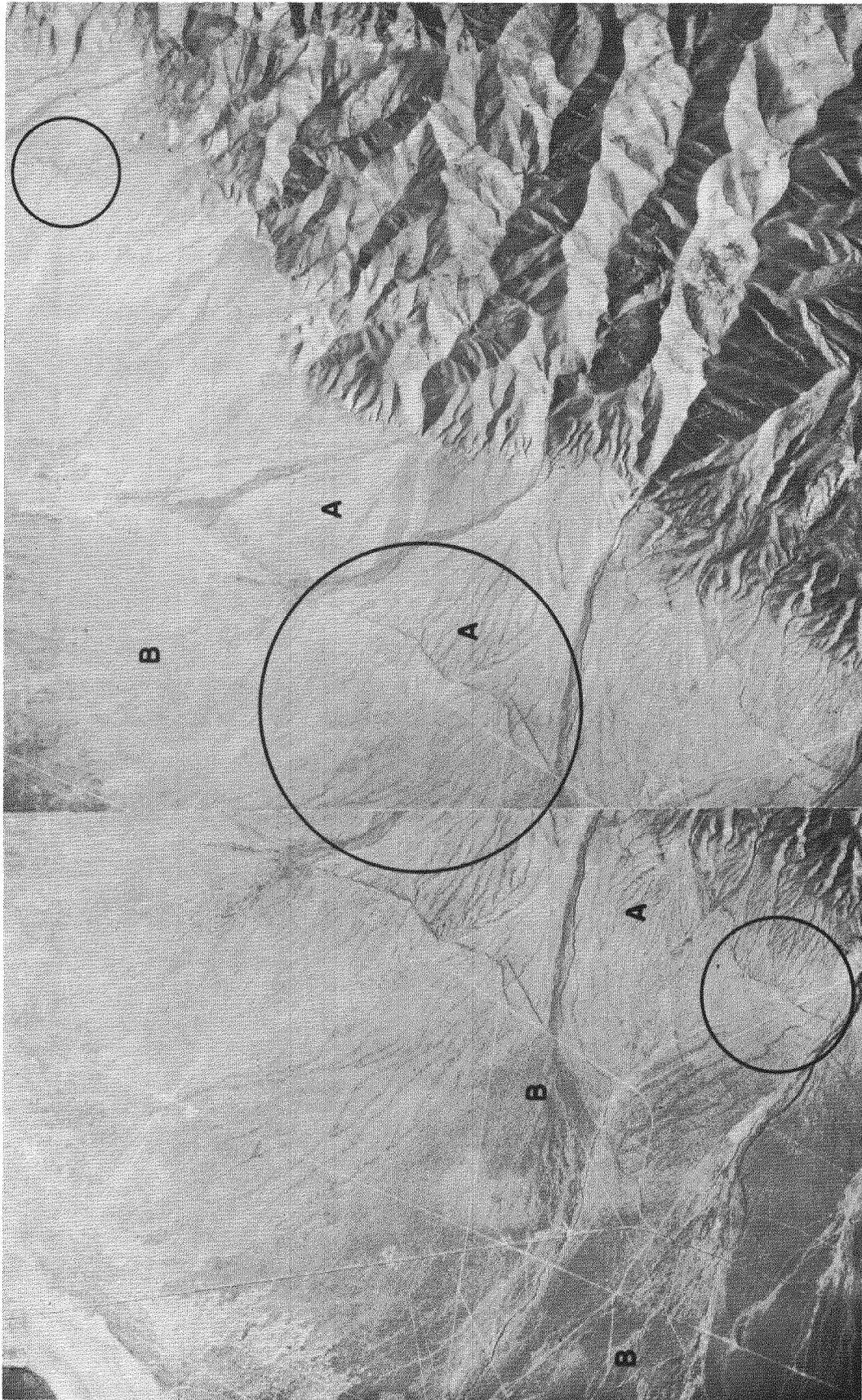


Figure 4. Aerial photographs (stereo pair) showing both the relationships between Older and Younger alluvial fan deposits and Recent fault scarps in the alluvial apron, Reese River Valley. The alluvial apron is composed of Older alluvial-fan deposits (marked A) and Younger alluvial-fan deposits (marked B) associated with well developed fanhead trenches. A series of scarp, the largest of which are indicated (circled), parallel the Shoshone Range mountain front to the east. To the north is an echelon series of scarps (small circle). Scale: 1 inch equals 1.5 miles.

south these have been stripped away exposing the bedrock surface which he interprets as a suballuvial bench. Other similar Quaternary-Tertiary fans occur near the East Range and the Sonoma Range.

In most of the area erosion has not progressed far enough to produce extensive pediments. Most of the ranges are in a relatively youthful stage of development, as mentioned above. However, an extensive pediment does occur in several valleys where Tertiary sediments underlie the piedmont slopes. In some areas this erosional surface truncates the bedding planes; in other instances, however, the erosional surface may nearly parallel the bedding. Pediments cut on Tertiary sediments occur in Antelope Valley, Carico Lake Valley, Crescent Valley and Kelly Creek Valley.

The erosional surface in Antelope Valley is illustrated with a stereo pair of aerial photographs in Figure 5. Here the pediment covered by only a thin veneer of alluvial deposits extends across the width of the valley. Several isolated hills in the valley remain above the erosional surface exposing Tertiary bedrock. Most outcrops show a gentle eastward dip indicating that the erosional surface truncates the bedding. Two relatively large intermittent streams cross the area; however, the alluvial deposits associated with these streams appear to be relatively thin.

An erosional stream pattern is not particularly well developed on the pediment in Antelope Valley. This is somewhat peculiar to Antelope Valley. In several other valleys where pediments of this sort occur a well-developed dendritic drainage pattern is incised in the erosional surface. The pattern of the drainage in these other areas suggests that the pediments are currently being dissected.

Slopes underlain by Tertiary sediments appear to be particularly favorable areas for pedimentation.

The Valley Lowland

The area below the piedmont slope in the typical closed valley of the Basin and Range is one of fine-grained sedimentation. Through drainage of Humboldt River has modified the typical pattern in a number of valleys of the Lower Humboldt Basin.

Alluvial deposits of the larger intermittent through-flowing streams cover extensive portions of a number of valley floors. These deposits fill a large part of Reese River Valley and at the junction of Reese River Valley and Antelope Valley the valley floor is composed almost entirely

of a stream alluvium. More extensive areas of similar sediments occur in Antelope Valley, Boulder Valley, Crescent Valley, and Kelly Creek Valley.

Humboldt River integrates the drainage from the various valleys. Above Comus the river occupies a relatively wide flood plain and the meander pattern of the river is well developed. Below Comus the character of the flood plain changes. In this area the river is entrenched in Lahontan sediments. Remnants of two stream terraces are present above the flood plain. In this reach the Humboldt appears to be down cutting at present, possibly in response to lowering of base level accompanying the desiccation of a recent lake in the Humboldt Sink.

Several of the valleys contain playas. The Humboldt Sink in the valley below Lovelock is a part of the old lake bottom of Lake Lahontan and is really a large playa. In most years practically all the Humboldt River water reaching Rye Patch Reservoir is used for irrigation in the Lovelock area and generally only return flow from irrigation reaches the Humboldt Sink.

One of the unusual features of the Humboldt Sink is the giant mudcracks. These cracks range from 10 to 24 inches wide and are five or more feet deep and are from approximately 100 yards to over a mile long. Good examples occur along the south side of the Sink, adjacent to the old immigrant trail shown on the Carson Sink 15' Quadrangle. Willden and Mabey (1961) describe similar features in the Black Rock Desert of Nevada. They attribute the cracks to desiccation accompanying a long-term climatic trend toward more arid conditions.

Playas also occur in Carico Lake Valley and Crescent Valley. Because of a very low gradient, through drainage occurs in Crescent Valley only in years of very high runoff. In other years drainage into the central valley floor area forms a playa. In Paradise Valley an ephemeral lake, named Gumboot Lake, occurs in years of high runoff because Little Humboldt River is partially dammed by sand dunes near its junction with Humboldt River.

Pleistocene Lake Lahontan occupied the Humboldt River Valley to a point just east of the Osgood Mountains. Below this point Lake Lahontan sediments cover a large part of the valley floor. The highest lake level was at about 4,380 feet above sea level, and many lacustrine landforms such as gravel bars and wave-cut terraces are present in the Lower Humboldt Basin below this elevation.

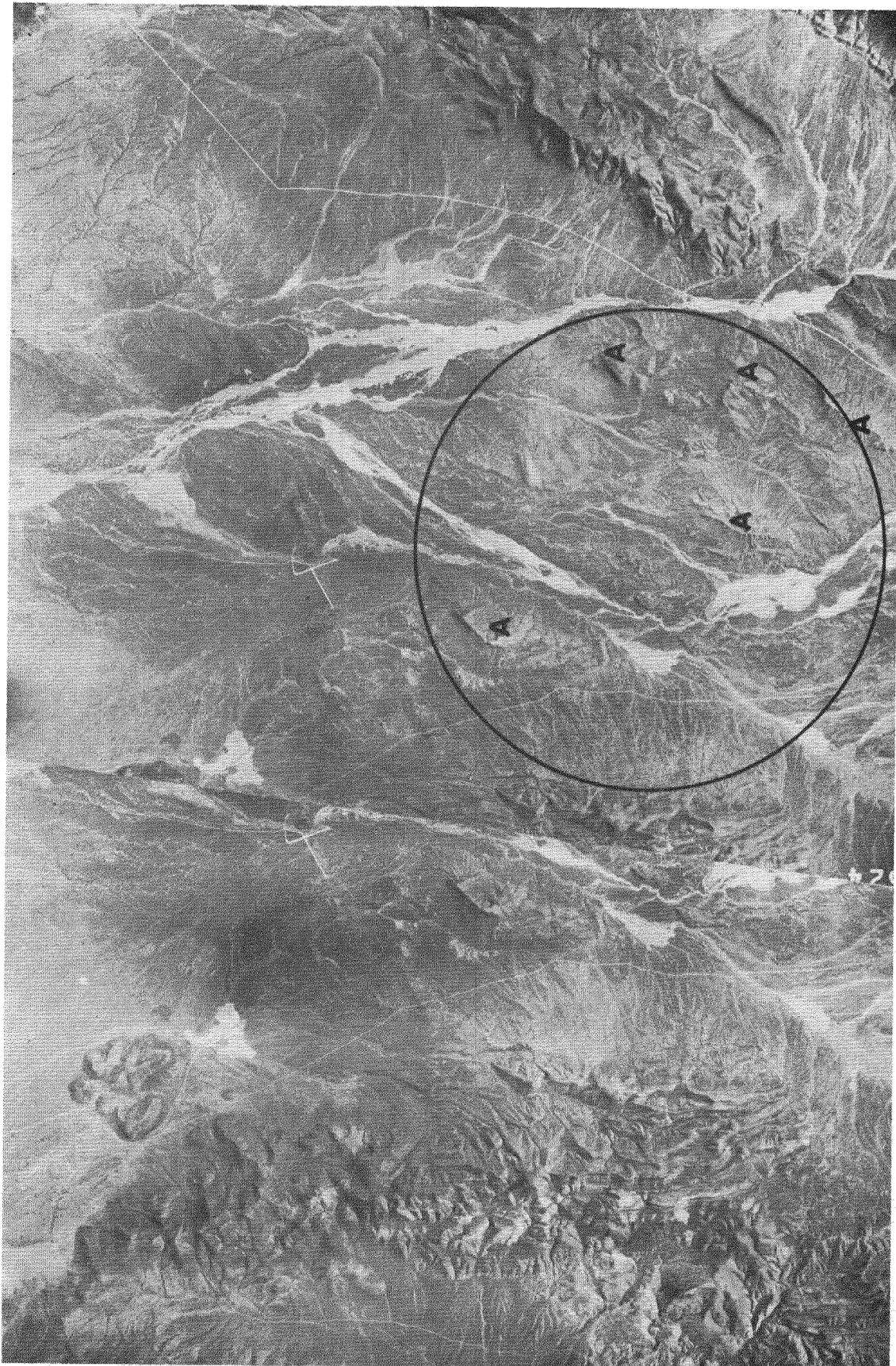


Figure 5. Aerial photographs (stereo pair) of a pediment on Tertiary sediments in Antelope Valley. The pediment (partially encircled) extends across the valley with scattered bedrock hills (marked A) rising above the erosion surface. Scale: 1 inch equals 1.4 miles.

In the vicinity of Lovelock a wide series of wave-cut terraces is present on the east slope of the Trinity Range (Figure 6). Here Younger alluvial-fans are deposited on top of the wave-cut terrace. An island with encircling strand lines is present just west of Lovelock. Two areas of sand dunes are shown in the photographs: one several miles north of town along the fringe of the farmed area, the other just east of town.

The incised Humboldt River floodplain and a part of the Lovelock irrigation area are also shown in Figure 6.

The different shorelines of Lake Lahontan are marked by different kinds of tufa deposits characteristic of various stages of Lake Lahontan. Russell (1885, p. 188) classified these into three types: lithoid tufa, thinolitic tufa and dendritic tufa. Russell and later Morrison (1961) were able to correlate the lake sediments and shoreline features of Lake Lahontan stages using the tufa as a guide. Jones (1915) pointed out that, except for the thinolitic tufa which is a chemical precipitate, the tufas were deposited by varieties of blue-green algae. Much of the tufa was deposited as algal domes. Along some shorelines in the Lovelock area the tufa domes are 10 to 25 feet high. Just west of the Humboldt Sink, in an area where the lake environment was particularly favorable, algal domes spaced from 10 to 100 yards apart occur for several miles along a shallow lake terrace. In other areas near Lovelock tufa encrusts sea cliffs and other bedrock promontories with as much as 10 to 15 feet of calcareous deposits.

In the Winnemucca area Lake Lahontan was shallow. The lacustrine features, although present, are inconspicuous.

Another large lake or series of lakes occupied the basin east of the Osgood Mountains. Lacustrine deposits are present in Kelly Creek Valley. King (1878, p. 529) recorded on a map the presence of a lake of the glacial period in Kelly Creek Valley. Russell (1885, p. 1), however, on a similar map did not acknowledge the presence of a Quaternary Lake in this area. Only meager geomorphic evidence of a lake has been observed here. Very few probable shoreline features, many of which are of questionable origin, occur. The extensive and essentially featureless valley floor of much of Kelly Creek and Reese River Valleys is suggestive of a lake plain. From the well logs it appears that lacustrine sediments are present in the subsurface over a wide area. At Battle Mountain the drillers' logs record a thick sequence of clays that are probably of lacustrine origin, at relatively shallow depths.

Stratigraphic evidence suggests that this lake in Kelly Creek and Reese River Valleys was older than the last high stage of Lake Lahontan. Two possible explanations may be suggested for the lack of physiographic features, particularly the shoreline features, associated with the lake: either the landforms have been destroyed or covered because of the age of the lake, or the lake was very shallow and did not develop good lacustrine landforms.

Sand dunes occur in a number of the valleys. They are particularly abundant in the Humboldt Valley below Winnemucca and in the lower parts of Paradise Valley. Both longitudinal and transverse dunes are present; however, the longitudinal forms predominate in much of the area. In this area prevailing westerly winds have blown sand into Paradise Valley through a low pass between Winnemucca Mountain and the Santa Rosa Range to the north. As mentioned above, these dunes have at times dammed the Little Humboldt to produce ephemeral Gumboot Lake in Paradise Valley.

Stratigraphy

Paleozoic, Mesozoic, and Tertiary Rocks

Paleozoic Rocks

The area is on the hinge line between the Paleozoic and early Mesozoic eugeosyncline and miogeosyncline of the Cordilleran Trough. Roberts, Hotz, Gilluly and Ferguson (1958) summarize the Paleozoic stratigraphy. A marked change in both lithology and thickness of the rocks occurs between the eugeosynclinal facies and the miogeosynclinal facies. The rocks of the eugeosynclinal assemblage are comprised of approximately 20 to 40 percent shale, 10 to 30 percent quartzite, up to 30 percent chert and up to 30 percent volcanic and pyroclastic rocks. In the Sonoma Range the Mississippian and older rocks are estimated to be more than 50,000 feet thick (Roberts, et al., 1958, p. 2816). The Paleozoic section in the Eureka area to the southeast is considered typical of the Cordilleran miogeosynclinal assemblage of rocks. This sequence, approximately 15,000 feet thick, is composed of 60 percent limestone, 30 percent dolomite, 8 percent shale and 2 percent quartzite. The transitional assemblage (in the Osgood Mountains) recognized by Hotz and Willden (1955), is characterized by a combination of clastic, volcanic and carbonate rocks; less than 40 percent of the sequence is carbonate rock.

An orogenic disturbance occurred in this area in the Late Devonian or early Mississippian. Nolan (1928, p. 158) postulated that a geanticline

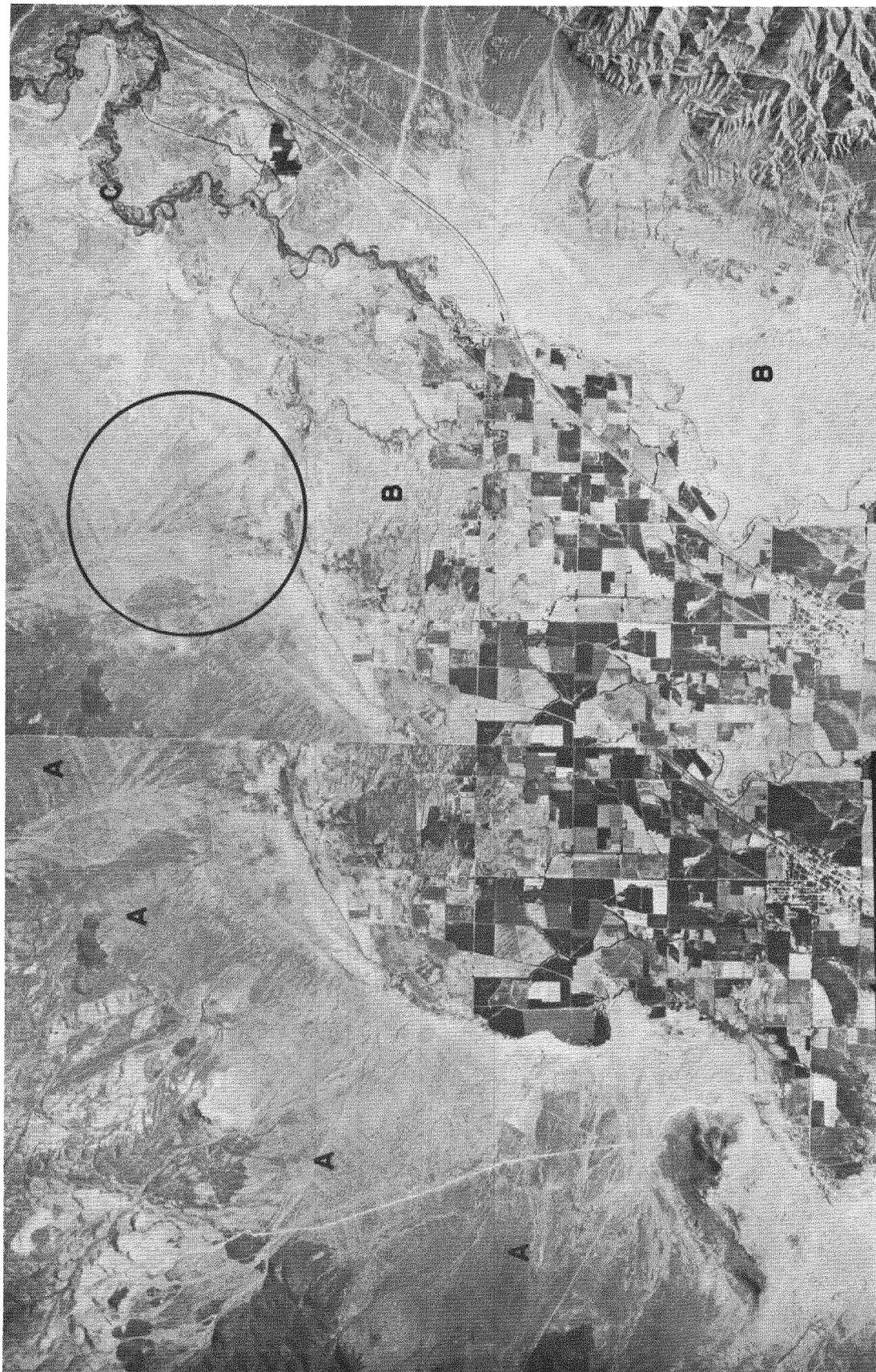


Figure 6. Aerial photographs (stereo pair) of the Humboldt Valley in the vicinity of Lovelock. Illustrates some Lake Lahontan features. A wide series of wave-cut terraces (marked A) is present on the east slope of the Trinity Range. Younger alluvial-fan deposits overlie the Lahontan features; one of the Younger alluvial-fans is circled. The incised floodplain (marked C) of the Humboldt River in this area is apparent northeast of Lovelock. Two areas of sand dunes (marked B) are shown: one just south of the circled area, and another east of Lovelock. Scale: 1 inch equals 1.5 miles.

divided the Cordilleran Trough during the late Paleozoic. Roberts, et al., (1958) point out that more recent work indicates this was a major orogenic belt to which they give the name Antler Orogenic belt. This orogeny culminated in a complex thrust belt in which the clastic and volcanic rocks of the eugeosyncline were thrust over the carbonate sequence of rock of the miogeosyncline.

Late Paleozoic and Mesozoic rocks in the area show the effects of continued tectonism. A sequence of coarse clastic rocks was deposited both east and west of the Antler Orogenic belt. Roberts, et al., (1958, p. 2838) call this sequence of chiefly clastic deposits the overlap assemblage. To the east these deposits interfinger with the predominately carbonate rocks of late Paleozoic age. To the west the eugeosyncline persisted in the late Paleozoic; the lithologic assemblage continued to be one of interbedded marine volcanic, pyroclastic and clastic rocks.

Mesozoic Sedimentary Rocks

Thick sequences of Mesozoic sedimentary and metamorphic rocks make up large parts of several ranges in the western part of the Lower Humboldt Basin. Two facies of Triassic rocks originally deposited at a considerable distance from one another have been subsequently thrust into juxtaposition by faulting of presumed Jurassic age. The original geographic distribution of these rocks is in doubt as the direction of thrusting has not been definitely established (Ferguson, et al., 1951a). The lower plate is composed principally of shallow water marine deposits with about equal percentages of carbonate and clastic rocks. The upper plate is composed of deeper water marine deposits, laid down in an environment farther from shore, made up of a greater percentage of carbonate than clastic rocks. The entire sequence is complexly deformed by Jurassic thrusting and later block faulting.

Mesozoic, Tertiary and Quaternary Intrusive and Volcanic Rocks

The later Mesozoic and Tertiary rocks of the area are principally igneous intrusive and volcanic rocks. Table 1 shows the various lithologic units recognized in five areas where detailed mapping has been done. To generalize, granitic intrusive rocks of probable Jurassic or Cretaceous age were followed by a sequence of volcanic rocks ranging from Cretaceous to Quaternary.

Throughout the area scattered sedimentary rocks, predominantly conglomerate, are tentatively dated as Jurassic and Cretaceous. Apparently these were deposited in isolated basins within the developing orogenic belt.

Tertiary Sedimentary Rocks

Large parts of several valleys as well as portions of a number of mountain ranges are composed of Tertiary sedimentary rocks. The Tertiary sediments were deposited in isolated intermontane basins formed as a result of the Basin and Range block faulting. Block faulting, which was initiated in the early Tertiary, has continued active in this area to the present. Late Tertiary faulting has broken up the earlier basins of deposition elevating some areas of Tertiary rocks with the present mountain blocks and leaving other areas in the valleys.

The rocks are predominately interbedded lacustrine sediments, alluvial deposits and volcanics. Since the basins of deposition were originally isolated and subsequently disturbed tectonically, correlation of rock units over wide areas is difficult. In the past the sequence of late Tertiary sediments have been loosely referred to the Humboldt Group or Formation in northeastern Nevada and to the Truckee Group or Formation in western Nevada. Van Houten (1956) points out the stratigraphic difficulties involved in such an approach. Recent workers have tended to describe rocks and work out their local age relationships without assigning formation or group names. An exception to this approach is the work of Regnier (1957) in Pine Valley east of the Cortez Range. On the basis of detailed mapping he subdivided the extensive Tertiary sediments of that valley into five formations. Van Houten (1956) suggests that regionally the Tertiary stratigraphy can be divided into a lower Cenozoic sequence of sedimentary deposits, a volcanic sequence that is probably Oligocene to Miocene, and an upper "vitric tuff" unit which is late Miocene to early Pliocene.

Deffeyes (1959) studied in detail the Tertiary sediments in the vicinity of the middle Reese River Valley. He measured sections in two areas in the Reese River Valley (T. 24 N., R. 43 E. and T. 27 N., R. 44 E.), one area in Jersey Valley just west of the Fish Creek Mountains (T. 27 N., R. 40 E.), and one area in the Fish Creek Mountains (T. 28 N., R. 41 E.). These measured sections are considered typical of late Tertiary sediments in this area. Vertebrate fossils indicate that the deposits in Jersey Valley as well as those in the Reese River Valley are late Miocene to mid-Pliocene. The sequence reaches a maximum thickness of 3,000 feet and is composed predominantly of gray-brown to brown mudstone and siltstone interbedded with coarse sandstone, conglomerate, limestone, and altered and unaltered tuff. Most

	MOUNT MOSES QUADRANGLE Ferguson, Muller & Roberts (1951)	WINNEMUCCA QUADRANGLE Ferguson, Muller & Roberts (1951)	GOLCONDA QUADRANGLE Ferguson, Muller & Roberts (1952)	BUFFALO MOUNTAIN QUADRANGLE Wallace, Silberling, Irwin & Tarlock (1959)	OSGOOD MOUNTAIN QUADRANGLE Hotz & Willden (1961)
QUATERNARY	RECENT	alluvium	alluvium	alluvium	alluvium
	PLEISTOCENE	older gravels	older gravels	Lake Lahontan deposits	
TERTIARY	PLIOCENE	basalt	older gravels	basalt flows	older gravels
		?	basalt	?	?
	MIOCENE	sedimentary rocks	sedimentary rocks	basalt flows	basalt flows basalt intrusives gravels, silt & ash rhyolite & dacite volcanics
CRETACEOUS	lavas	rhyolite flows & tuffs andesite & andesite breccia	rhyolite flows & tuffs	rhyolite & dacite volcanics	
	?	rhyolite porphyry dikes	?	diabase dikes	
JURASSIC	granitic intrusives	granitic intrusives	granitic intrusives	granite	dacite porphyry
	?	?	?	rhyolite porphyry aplite monzonite diorite	granodiorite ? intrusive basalt

Table 1. Chart showing the various Jurassic, Cretaceous, Tertiary and Quaternary lithologic units recognized in five areas of detailed mapping.

of the sediments were deposited in a lacustrine environment; however, it was not possible to estimate the extent of the basin of deposition from the outcrops examined.

Axelrod (1956) did detailed stratigraphic work on the Mio-Pliocene sediments in the vicinity of Desert Peak in the Hot Springs Range (T. 22 N., R. 27 E.). In this area the aggregate stratigraphic thickness of Mio-Pliocene rocks dated on the basis of vertebrate fossils is in excess of 7,000 feet. The deposits are composed of interbedded basalt, volcanic tuff, siliceous shale and fewer beds of sandstone, conglomerate, diatomite and some limestone, laid down in a local lake basin. The fossil flora indicate that the climate during the period of deposition was subhumid with an annual rainfall of 25 to 30 inches, a mild summer and winter climate and a long growing season of approximately 260 days. The late Tertiary sediments in this area are cut by numerous faults, are folded and are overlain by Quaternary volcanics.

Similar deposits of Tertiary rocks underlie extensive areas in Kelly Creek Valley, Reese River Valley, Antelope Valley, Crescent Valley and Carico Lake Valley.

The fine-grained sediments which make up the bulk of the Tertiary deposits are generally not well suited for good ground-water aquifers. Several wells, however, produce sizeable quantities of ground water from sediments that appear to be of Tertiary age. One example is the well which supplied the Getchell Mine (sec. 6, T. 38 N. R. 43 E.) with approximately 1,000 gallons per minute. This well was capable of producing over 1,000 gpm (gallons per minute) from "cemented gravel and rock streaks" and "rock and streaks of loose gravel" overlain by ". . . streaks of shale . . . dry hard clay . . . cemented gravel and shale," according to the drillers' report.

The problem of attempting to work out the ground-water potential of the Tertiary sediments is particularly difficult because of inadequate stratigraphic information. It is extremely difficult to recognize Tertiary sediments in the subsurface from the drillers' logs. Further investigation of the Tertiary stratigraphy of the Great Basin is needed. The results of such investigations, particularly subsurface studies, should be useful in future ground-water studies.

Late Tertiary and Quaternary Valley-Fill Deposits

These geologic deposits comprise the units in which the major ground-water reservoirs are to be found. The bulk of this material appears to

have been deposited during the early Pleistocene but some of it is probably of Pliocene age. In many instances it is only possible to suggest relative age for many of these deposits. For this reason they are considered together.

Bedrock Topography

Later Tertiary and Quaternary sediments were deposited in the valleys on a complex but largely unknown bedrock surface. With one or two exceptions the deeper water wells in the area are less than 800 feet deep, and only a relatively few wells are drilled to depths of over 300 feet. None of these reach pre-Tertiary rocks. Two of the deeper wells of the area are: (1) a water well drilled in Paradise Valley in 1889 to a depth of slightly over 800 feet without encountering Paleozoic, Mesozoic, or Early Tertiary bedrock (Loeltz, et al., 1949, p. 57); and (2) the deeper of several oil tests drilled in the vicinity of Battle Mountain, for which records are available, to a total depth of 912 feet also without encountering Paleozoic, Mesozoic or early Tertiary bedrock (Lintz, 1957, p. 42). As stated above, it is difficult to distinguish between the late Tertiary sediments and the Quaternary deposits from well data even with microscopic studies of the samples.

Geophysical studies throughout the Great Basin indicate that some thicknesses of Tertiary and Quaternary valley fill deposits may be on the order of 8,000 feet and perhaps even greater. In general the valleys are considered as complexly faulted grabens filled with Tertiary and Quaternary lacustrine and alluvial deposits interbedded with volcanic tuff and flow rock. Perhaps 500 to 1,000 feet of this material in the thicker sections is Pleistocene and Recent.

Quaternary-Tertiary Alluvial-Fan Deposits

The oldest valley-fill sediments mapped in the area are those comprising the Quaternary-Tertiary alluvial-fans. These deposits are intimately associated with the mountain ranges. In almost every instance the deposits mapped appear to be truncated along their lower edge by a frontal fault of one of the mountain ranges, and uplifted with the mountain block.

Several lines of evidence suggest that these deposits are older than the remaining valley-fill deposits: (1) the apparent displacement by faulting of these deposits is greater than with any of the other valley-fill deposits, suggesting a longer period of tectonic activity; (2) the deposits are generally deeply entrenched by erosion, perhaps indicating a longer period of erosion; (3) the

deposits appear to contain more large boulders than any of the younger deposits, which may indicate different climatic conditions during the time of deposition; and (4) the surface of these deposits appears to be associated with erosion surfaces in the mountain ranges which are postulated as older. None of these lines of evidence is incontrovertible but the weight of evidence suggests an older, possibly Quaternary-Tertiary, age.

The Quaternary-Tertiary fans are composed of poorly sorted pebbles, cobbles and boulders in a sand and silt matrix. Some of the boulders are in excess of 10 feet in diameter. The deposits are coarser in some areas than in others. Along the West Humboldt Range they do not contain as many cobbles and boulders as those in the Sonoma Range and the Shoshone Range. A caliche zone as much as 30 inches thick is present on these deposits along the Sonoma Range (Wilson, 1963); however, no clayey soil horizon has been observed.

Tertiary-Quaternary alluvial-fan deposits occur in a small area along the west flank of the Shoshone Range, in a much larger area along the west flank of the East Range where they are mapped as "older gravels" by Ferguson, et al. (1951a), and in more limited areas along the west flank of the Humboldt Range.

These deposits, where present, occur high above the valley floor and are trenched by the present drainage. They may be important avenues of ground-water recharge in some valleys; however, because of their topographic position near the mountain front, they are not important sites for well development.

Lake Deposits in the Kelly Creek Valley

Lacustrine clays and silts crop out in Kelly Creek Valley but only isolated and poorly defined shoreline features are found. A terrace and a gravel bar, both associated with an isolated hill of Paleozoic rocks (T. 34 N., R. 42 E.), are interpreted as a wave-cut terrace and a lacustrine bar respectively. It seems probable that the lake was shallow and did not develop prominent shoreline physiographic features. The lack of prominent shoreline physiographic features may also suggest long periods of erosion and deposition in which the shoreline features were destroyed.

Both stratigraphic and geomorphic evidence suggest that the lacustrine deposits in Kelly Creek Valley are older than Lake Lahontan. Kelly Creek Valley is topographically above the highest known level of Lake Lahontan. At Battle Mountain lacustrine deposits, perhaps equivalent with those seen

in outcrop are overlain by 50 to 100 feet of stream alluvium (Figure 27).

In the outcrop the deposits consist of thin beds of unconsolidated gray-brown clayey silt and silty clay with some interbedded thin beds of fine sand. Phoenix (1949) described the samples from a well drilled by the U. S. Geological Survey as follows:

* * * greenish-gray clay, which is blue when wet, and is probably of lacustrine origin.

This unit is readily distinguishable in drillers' logs in the Battle Mountain area where it is commonly described as blue shale or blue clay.

These deposits are known to crop out only in Kelly Creek Valley, where they were mapped by Cartwright (Plate I). Hydrologically, the sediments are relatively impermeable and can be considered aquitards.

Older Valley Alluvium

Three deposits of Older Valley alluvium occur in the central area of Boulder Valley as low hills slightly above Recent stream alluvium which more or less surrounds them. The surface of these deposits is dissected by incipient dendritic drainage which, together with their elevated topographic position, suggests that they are older than the Recent stream alluvium. The origin of these unique deposits is in doubt. Similar deposits occur in only the three isolated areas in Boulder Valley.

Where exposed, these deposits are composed principally of interbedded, relatively thin beds of clayey silt, silt, and fine sand. Drillers' logs, however, indicate that these deposits contain relatively large amounts of sand and gravel interbedded with the beds of fine sand and silt at relatively shallow depths. Several good irrigation wells have been drilled in these deposits in the northern part of Boulder Valley.

Older Alluvial-Fan Deposits

Most of the ranges of the area are surrounded by a piedmont alluvial apron composed primarily of coalescing deposits of Older and Younger alluvial-fans. The Older alluvial-fan deposits are considered pre-Lake Lahontan in age. Dissection of the surface of the deposits indicates that they are older than the more recent undissected alluvial-fan deposits. The surface of these deposits is often covered by a layer of silt as much as 18 inches thick. Below the silt a soil profile consisting of a well developed B horizon of blocky,

reddish-brown silty clay is exposed in many gravel pits throughout the area. Wilson (1963) describes this soil in detail in the Winnemucca area; both Wilson (1963) and Hawley (1962) indicate that this is a pre-Lahontan early Pleistocene soil.

Both mudflow and stream deposits make up the alluvial-fan deposits of the area. Typically, the sediments are comprised of thick beds of coarse gravel with intermixed cobbles and boulders in a matrix of fine to coarse sand. The coarse gravel appears to result from stream deposition on the alluvial fans. Interbedded with the gravel are layers of silt with intermixed gravel to boulder sized material which appear to be mudflow deposits.

Deposition on the fans appears to have resulted from periodic mudflows interspersed in periods of predominately stream deposition. During periods of stream deposition mudflow material was reworked while new material was also being deposited. In this area, stream deposits predominate over mudflow deposits. Most of the deposition in the Older alluvial-fans probably occurred in earlier periods of more pluvial climate.

Alluvial aprons composed principally of Older alluvial-fan deposits occur along the west side of Crescent Valley, on the east side of Boulder Valley, in the Reese River Valley, along the west side of Kelly Creek Valley, along the east side of Grass Valley, in Paradise Valley and along the east side of the Humboldt Valley from Rose Creek to Lovelock.

The Older alluvial-fan deposits are important hydrologically as areas of ground-water recharge. Areas near the toes of the fan deposits are also important areas of well development. The Older alluvial-fan deposits generally contain reasonably good aquifers.

Lake Lahontan Deposits

Lake Lahontan deposits occupy the Lower Humboldt Basin below the narrows in the Osgood Mountains. King (1878, p. 528) recognized that an extensive Quaternary Lake occupied a large area of Nevada but included most of the Lake Lahontan sediments in the Humboldt Valley in the Pliocene Humboldt Group. Russell (1885) demonstrated that most of what King had included in the Pliocene in the Humboldt Valley below Winnemucca are actually deposits of Lake Lahontan.

Russell (1885) was the first to investigate the history and stratigraphy of Lake Lahontan in detail. He pointed out that there were two major rises of the lake separated by a period of dessica-

tion. Russell related the major fluctuations of the lake to Wisconsin ice advances in the Sierra. Jones (1925) suggested that the lake history involved only one cycle of inundation which occurred within the last 2,000 years. Recent work by Antevs (1945) and Morrison (1961), however, supports Russell's earlier conclusions.

Both the early and later Lahontan lakes rose to very nearly the same elevation. Russell (1885) suggested that the later lake was 10 to 30 feet deeper than its predecessor. Morrison (1961) has reversed this concept suggesting that the earlier lake was the deeper of the two. Russell, Antevs and Morrison conclude that each of the major lake stages was accompanied by a number of fluctuations in lake level.

Russell (1885) divided the Lahontan sediments into three divisions which he called the "lower lacustral clays," the "medial gravels" and the "upper lacustral clays." These units are exposed in the canyon of the Humboldt River north of Lovelock. Antevs (1925, p. 80 and 82) and Hawley (1962) have remeasured a number of these sections in detail. Their work indicates that Russell's "upper lacustral" clay unit probably includes all the Lake Lahontan deposits in this area. However, a threefold division of the stratigraphy is recognized within Russell's "upper lacustral" clay unit. Morrison's and Hawley's work substantiate Russell's concept that the Lahontan sediments were deposited during two major inundations separated by a period of desiccation.

Inasmuch as Hawley (1962) discusses the Lake Lahontan sediments in detail, only a brief resume is presented here.

The lower lacustrine deposits are composed of interbedded fine sand and silt with local deposits of coarse sand and gravel. Overlying this is a well sorted sand and gravel deposit of alluvial and lacustrine origin which in the Winnemucca area has a maximum thickness of 150 feet. The thickness of these sand and gravel deposits differs greatly from one area to another. The sand and gravel is overlain by thinly bedded lacustrine clays and silty clays which grade shoreward into silt and sandy silt. Beach and bar deposits composed of well sorted, well rounded, cross-bedded gravel occur usually near the old shoreline.

The Lahontan "medial gravel" deposit is a major aquifer particularly in the Winnemucca area. Most of the bar and beach gravel deposits are situated about the fringe of Lake Lahontan generally topographically above the valley floor. They are not considered major aquifers because

of their topographic position above the valley floor and limited areal extent in most instances.

Tufa deposits occur both interbedded with the sediments and exposed at the surface. Morrison (1961) has refined the correlation of tufa deposits with various lake sediments. In places tufa deposits spread laterally to the extent that deposits of individual colonies interfered with one another forming a pavement over a surface of lacustrine sediments. In other areas tufa completely encrusts bedrock promontories, particularly in areas near the surface of the lake. Tufa domes as much as 20 feet high and from 10 to 15 feet in diameter dot some of the wave-cut terraces for miles adjacent to the Trinity Range east of the Humboldt Sink.

Younger Alluvial-Fan Deposits

Younger alluvial-fan deposits comprise a large part of the alluvial aprons throughout most of the area. These deposits are easily differentiated on air photos as areas of recent fan deposition (Figures 3 and 4). The upper layers of these fans are Recent in age and deposition is still active. In the Lahontan basin Younger alluvial-fans overlie Lahontan sediments (Figure 6).

Evidence of recent fan-building was provided in 1961 when runoff following summer storms deposited new material on innumerable fans throughout the area. The frequency of such occurrences is perhaps one year in every fifty years.

Deposits of the Younger alluvial-fans are similar to deposits of the Older alluvial-fans. They are comprised of coarse sand and gravel deposits with some cobbles and boulders interbedded with deposits of poorly sorted silt, sand, gravel and boulders. The mudflows of 1961 contained boulders as large as 12 feet in diameter which were deposited several miles from the mountain front. The sediments become progressively finer away from the mountain fronts. Fine sand and silt sized material is generally deposited well out in the valleys.

Alluvial aprons composed in large part of Younger alluvial-fan deposits occur in several valleys. One of the most striking areas of Recent alluvial-fan deposits occurs along the Cortez Range where alluvial fans are just beginning to coalesce into an alluvial apron (Figures 3 and 4). Other extensive areas of Younger alluvial-fan deposits occur in Reese River Valley and in Grass Valley.

The Younger and Older alluvial-fan deposits comprise major areas of ground-water recharge to many of the valley aquifers. Highly productive

wells are often drilled near the toe of alluvial-fan deposits. Alluvial-fan deposits, however, are not as good aquifers as some of the stream associated gravel deposits.

Young Valley Alluvium

The occurrence of the Younger Valley alluvium is similar to that of the Older Valley alluvium except that the surface is relatively undissected, which suggests that these sediments, at least near the surface, are relatively recent.

The sediments are composed of beds of clayey silt and silty clay interbedded with beds of intermixed silt and gravel and beds of sand and gravel. Except for clay beds the sediments resembled alluvial-fan material. The origin of the Younger valley alluvium is in doubt but may be similar to that of the fluvial deposits described below. At most localities they occur in more or less isolated areas in the valley lowland.

Younger valley alluvium occurs in Boulder Valley, Kelly Creek Valley and Antelope Valley. Good irrigation wells have been drilled in these deposits in Antelope Valley. Hydrologically, they appear to be best grouped with alluvial-fan deposits.

Fluvial Deposits

Stream deposits comprise a large percentage of a number of valleys. Humboldt River deposits are differentiated from the other stream deposits on the map.

The pattern of Humboldt River changes from widely anastomosing in the valley above Winnemucca to narrow entrenchment below Winnemucca. Hawley (1962) discusses the Humboldt flood plain deposits in detail. Above Winnemucca the river is very near grade at present. However, the braided appearance of the flood plain in Kelly Creek Valley, Boulder Valley and Whirlwind Valley suggests aggradation by the river at some fairly recent time. Below Winnemucca down-cutting by the Humboldt River has predominated since the last extensive inundation of Lake Lahontan.

Above Winnemucca Humboldt flood plain deposits are composed largely of well sorted sand and gravel interbedded with some fine sand and silt. The deposits range up to several hundred feet in thickness. The thickness of the deposits reflects in part the topography of the valleys during deposition, which in turn is related to the tectonic histories of the various valleys. The bulk of the thick sand and gravel deposits is perhaps Pleistocene, related to earlier periods of pluvial climate.

Below Winnemucca the Humboldt River deposits in most areas are only a relatively thin veneer of interbedded pebble gravel, sand, silt, silty clay and organic material over Lake Lahontan sediments.

The other stream deposits of the area cover extensive areas in nearly all the valleys east of the Osgood Mountains. The deposits are easily recognized in air photos by the braided stream pattern. Although the sediments on the surface are Recent, the major part of these deposits were probably laid down during a Pleistocene, pluvial, climatic cycle.

The stream alluvium is composed of beds of silt and fine sand interbedded with beds of coarse sand and gravel. Extensive deposits of sand and gravel occur in the subsurface.

The best aquifers of the area occur in deposits associated with major streams. Extensive aquifers are found in fluvial deposits in Paradise Valley, Reese River Valley, Boulder Valley, Whirlwind Valley and in the Humboldt Valley in the vicinity of Winnemucca.

Subaerial Deposits

Colluvium and sand dune deposits are classed together as subaerial deposits.

Colluvium is present in several small areas where bedrock is relatively near the surface overlain by unconsolidated colluvial material. It is composed of a very poorly sorted mixture of silt, fine to coarse sand, angular pebbles, cobbles and boulders. Only minor transportation of the material has taken place. A large landslide along the fault bordering the south side of Whirlwind Valley is included with the colluvial deposits on the map.

Small areas of colluvium exist in Whirlwind Valley, Boulder Valley, Reese River Valley and the Winnemucca area. These deposits are relatively unimportant for the production or recharge of ground water. They do, however, reflect areas of bedrock near the surface and suggest geohydrologic boundaries.

Extensive sand dune areas are present, for the most part associated with the Lahontan Lake Basin. Most of the eolian deposits are at least partially stabilized by vegetation. The bulk of eolian deposition appears to have taken place during a period of very arid climate following deposition of the uppermost Lahontan Lake sediments. Morrison (1961) correlates this period of eolian activity with the Altithermal age of Antevs (1945).

The dunes are composed of fine to medium

grained, well sorted sand. The source of the sand is the upper Lake Lahontan sediments. In some areas sand dunes are intimately associated with deflated areas in Lahontan sediments. Only the most prominent dune areas were included on the map, and almost without exception these areas are within the immediate Lahontan Lake basin.

Dune sand forms a relatively thin veneer over the underlying deposits. In most areas the dunes are of little importance as far as ground water is concerned. In a more humid climate sand dunes might be areas of ground-water recharge; however, here, where most of the recharge comes from the streams during periods of spring runoff and where for all practical purposes no recharge comes from direct precipitation on the valley floors, sand dunes are areas of negligible recharge.

A layer of silt blankets most of the older deposits of the area except where it has been removed by recent erosion. The presence of the silt almost everywhere is striking. It appears to be a loess deposit also associated with Altithermal eolian activity. The deposits are composed of yellow silt ranging to as much as 24 inches thick and containing scattered pebbles. These deposits are subject to redistribution both by wind and stream action almost continuously.

Playas

Playas are present in several of the valleys in which storm and spring runoff accumulates and stands until it evaporates.

The playa deposits are composed of thin beds of fine silty sand, silt, and clayey silt interbedded with minor evaporite deposits. Near the fringes of the playa the deposits interfinger with coarser alluvial fan and stream sediments. Playa deposits exist in Carico Lake Valley, in Crescent Valley, in the Humboldt Sink, and in Paradise Valley where the sediments of ephemeral Gumboot Lake were grouped with the playa deposits. In Paradise Valley only thin playa deposits overlie the Lake Lahontan sediments. In the Humboldt Sink thin playa deposits overlie Recent lake sediments.

The Humboldt Sink, now a playa, has been the site of several large Recent lakes. It was the site of the Humboldt Lake in the last century (King, 1878; Russell, 1885). However, in this century, particularly since the development of irrigation in the Lovelock area, Humboldt Lake has become intermittent. Morrison (1961) mapped a sequence of deposits representing four Recent lakes in the Fallon area. The earliest of these had two fluctuations with shorelines at elevations of 3,950 feet and 3,930 feet respectively. Shorelines occur in

the Humboldt Sink at approximately the 3,950 foot elevation; however, correlation with the lakes of the Fallon area is questionable. The large Lake Lahontan bar which extends across the Humboldt Valley from the Trinity Range to the West Humboldt Range below the Humboldt Sink may have effectively dammed the Humboldt Valley from a lake in the Fallon area.

King (1878, p. 503) reports that a small playa area in Crescent Valley produced very pure sodium chloride which was used to chloridize silver ore from local mines. King's description is ambiguous, but the area appears to have been near Hot Springs Point (sec. 12, T. 29 N., R. 48 E.).

Hydrologically, the fine grained playa sediments are considered aquitards. Wells which yield moderate quantities can sometimes be drilled near the fringes of the playas where coarser alluvial deposits interfinger with the playa sediments. Sufficient coarse-grained material is interbedded in the playa deposits so that small domestic wells can be developed even in the central playa areas.

Late Tertiary and Quaternary Geological History

The late Tertiary and Quaternary history of this area of the Great Basin is characterized by continued block faulting, volcanism and changes in climate from extreme aridity to subhumid conditions. Sedimentation in the valleys is controlled to a large extent by the block faulting and the climate.

Mio-Pliocene History

During Mio-Pliocene time, a period during which a subhumid climate prevailed, sediments were deposited in many local lacustrine basins. Axelrod (1956) concludes from detailed studies of Mio-Pliocene flora from scattered localities in this part of the Great Basin that the region consisted of a plateau, in which the valleys were approximately 2,000 feet in elevation, separated by relatively low volcanic mountains. The fossil flora assemblages indicate an annual rainfall of approximately 25 to 30 inches, mild summer and winter temperatures, and a growing season of approximately 260 days. He suggests that the Sierra Nevada, with its summit during Mio-Pliocene time at an elevation of approximately 3,000 feet, did not greatly affect the climate of central Nevada at this time. Sedimentation occurred in local lake basins. Deffeyes (1958) also suggests that the Mio-Pliocene sediments in the vicinity of the middle Reese River Valley were deposited in a lacustrine basin which probably encompassed areas of several of the present valleys and ranges.

The local basins of deposition are the result of active tectonics during the Mio-Pliocene. Axelrod suggested that the local basins were caused by active volcanoes in the area. Deffeyes in a more plausible explanation suggested that the local basins and ranges were due to the block faulting.

Nolan (1942) reviews the evidence as to the age of the block faulting and concludes that it began at least as early as the early Oligocene and has continued to the present. There is evidence in this area of Nevada of block faulting of at least Miocene age. Regnier (1960, p. 1205) concluded that the Tertiary sediments of Pine Valley (east of the Cortez Range just outside the mapped area, Plate I) show definite evidence of Miocene block faulting. Detailed studies in the southern Cortez Range (T. 26 N., R. 47 E.) by Masursky (1960, p. 261) has suggested that a sequence of welded tuffs tentatively dated as Oligocene were deposited in a fault controlled east-west trending linear trough. Later block faulting with a measured minimum throw of 8,500 feet which is probably Pliocene or Pleistocene in age has cut this early trend nearly at right angles. Both Axelrod (1956) and Deffeyes (1959) indicate that Mio-Pliocene sediments are disturbed by the block faulting.

The Tertiary basins of deposition in many cases do not correspond with the present topography. Van Houten (1956, p. 2823) stated:

At least locally the present structural pattern of ranges and basins differed from that which prevailed during Cenozoic time.

Deffeyes suggests that the basin of Mio-Pliocene deposition in which the sediments he investigated were deposited probably extended over an area which now includes several ranges and valleys. Numerous areas of late Tertiary sediments and volcanics occur in the present mountain blocks.

Quaternary History

Quaternary time was a period of continued tectonism accompanied by alternating periods of pluvial and arid climate. Present evidence suggests that at least one pluvial cycle and one period of aridity preceded Lake Lahontan. Kelly Creek Valley lake deposits represent a pre-Lahontan lake. Morrison (1961, p. 113) also states that there is evidence of a Pleistocene lake preceding Lake Lahontan in the Fallon area. In the Fallon area the pre-Lahontan lacustrine sediments are overlain by subaerial deposits on which a soil is developed.

The Lake Lahontan stratigraphy suggests two pluvial cycles, with numerous fluctuations in the lake level, separated by a period of aridity. The changes in climate during the pluvial period are not as great as it might seem at first. Snyder and Langbein (1962) suggest that based upon hydrologic considerations that an annual rate of precipitation of 20 inches and an annual evaporation rate of 31 inches would be sufficient to restore the Pleistocene lake in Spring Valley. Their work indicates that similar changes in climate would restore Lake Lahontan as well as Lake Bonneville.

Recent time is marked by a period of extreme aridity during Altithermal time (Antevs, 1945) followed by several minor pluvial periods separated by periods of semiarid climate. Altithermal time was a period of great eolian activity. During this time most of the sand dunes were initially developed within the Lahontan Lake basin while a blanket of loess was deposited elsewhere.

The great bulk of the Quaternary valley fill sediments appear to have been deposited during Pleistocene pluvial climatic periods. A very large percentage of the deposits appear to be pre-Lahontan in age. The soil developed on the Older Alluvial-Fan deposits which is interpreted to be pre-Lahontan in age (Wilson, 1963) suggests that much of the alluvial apron deposits are pre-Lahontan in age. The lake deposits in Kelly Creek are covered by only relatively thin deposits of sediments which also suggest that a large percentage of the valley-fill deposits are pre-Lahontan in age.

There is substantial evidence of recent faulting in the area. In historical times several severe earthquakes have had their epicenters along a linear belt which extends to the south from Grass Valley (Table 2). As the table indicates two of these earthquakes caused fault scarps which extend along the ranges for distances in excess of 20 miles. Scarps associated with the 1915 Pleasant Valley quake extend along the Sonoma and Mt. Tobin Ranges for a distance of 22 miles; the scarps produced by the 1954 quake extend along both the east and west side of Dixie Valley for a distance of 60 miles.

TABLE 2
Major Earthquakes Along the Pleasant Valley-Dixie
Valley-Fairview Peak Structural Trend

Date	Location	Surface faulting
1915	Pleasant Valley	5-15 feet
1916	Dixie Valley	
1932	Cedar Mountain	
1934	Excelsior Mountain	
1954	Dixie Valley	12 feet (maximum)
1954	Fallon-Stillwater Range	

Fault scarps are preserved in alluvium in a number of valleys. Some of the most prominent of these scarps are in Reese River Valley (Figure 4). The larger scarps have a surface offset of approximately 25 feet. A series of smaller scarps parallel the Shoshone Mountain front. A seismic refraction investigation across the larger scarps indicates that the depth to bedrock is approximately 200 feet. Further to the south in the valley this fault trend can be traced into a series of faults which offsets the Paleozoic and Tertiary bedrock (Plate I, T. 28 N., R. 44 E.).

The pattern of faulting illustrated in Figure 4 is typical of the faults in a number of valleys. A series of faulted steps, with the downthrown block on the valley side of the faults, parallel the mountain front in a number of localities.

The more active areas of recent faulting, as indicated by recent fault scarps, appear to be: (1) along the east flank of the Sheep Creek Range; (2) along the north rim of the Shoshone Range; (3) along the west flank of the Shoshone Range; (4) along the west flank of the Sonoma Range; and (5) along the west side of the Humboldt Range.

Summary of the Quaternary Geological History

Late Tertiary and Quaternary Geological History is summarized as follows:

1. Block faulting was continuous from at least as early as Oligocene time to the Recent.

2. Local lacustrine basins received later Tertiary sediments. The later Tertiary climate was subhumid with 25 to 30 inches of rainfall annually, 260 day growing season and mild temperatures.

3. Intermittent basaltic and rhyolitic volcanic activity occurred throughout late Tertiary and early Quaternary time.

4. Early Pleistocene periods of pluvial climate produced extensive lakes and caused deposition of thick alluvial deposits in many valleys.

5. A pre-Lahontan interval with an arid or semi-arid climate was accompanied by deposition of subaerial deposits.

6. A late Pleistocene pluvial period produced the earliest Lake Lahontan inundation. The accompanying climatic conditions may have included about 20 inches of rainfall and 31 inches of evaporation annually.

7. A mid-Lahontan period of aridity completely desiccated the lake and produced extensive eolian deposits.

8. A second Lahontan inundation with numerous fluctuations of lake level occurred. The climate was probably similar to the early pluvial Lahontan period.

9. A period of extreme aridity during Altithermal time followed the last inundation of Lake Lahontan. This period of aridity produced extensive eolian deposits.

10. During Recent time minor pluvial periods have been interspersed with periods of semi-arid climate.

11. Block faulting has been continuous up to the present. Many of the Mio-Pliocene and early Quaternary depositional basins have been destroyed by the block faulting. Recent fault scarps occur in the valley-fill deposits.

GROUND-WATER GEOLOGY

Introduction

Alluvial valleys of the Lower Humboldt River Basin are areas of potential ground-water development. Loeltz and Malmberg (1961) indicate that development of ground water in every valley of the area except Grass Valley is less than 50 percent of the estimated amount available. In Grass Valley development approaches 50 percent of the available supply. These estimates are based upon calculations of average annual recharge of ground water, not upon what could be pumped from storage and not replenished.

Crescent Valley can be used as an example to illustrate the quantity of ground water potentially available for development. The average annual recharge of ground water in the valley is estimated by Zones (1961) to be 14,000 acre feet, which is approximately 4.6 billion gallons annually or 12.5 million gallons per day. Perhaps one-half the total annual recharge of approximately 6 million gallons per day could be economically developed. This is sufficient to support a city of 17,000 if the per capita use of water were the same as Reno, Nevada—350 gallons per day. In 1956 only 2,300 acre-feet of water, approximately 30 percent of the potentially available ground water in Crescent Valley were being used for irrigation.

The large ground-water reservoirs along Humboldt River afford the possibility of modulating the flow of the river by developing surface water and ground water conjunctively.

Maxey and Shamberger (1961) indicated two possible ground-water reservoirs in the Humboldt Valley where large scale conjunctive use projects

might be feasible. One of these is in the Winnemucca area, the other is in Boulder Valley. They estimated that under certain conditions 400,000 acre-feet of ground-water storage might be available within the aquifer in the Winnemucca area and approximately 230,000 acre-feet of storage might be available in the aquifer in the Boulder Valley area. Hawley (1962) has described in detail the aquifer in the Winnemucca area; aquifers in the vicinity of Boulder Valley are described in this report.

The importance of understanding ground-water geology in order to meet the immediate problems of the development of ground water in the valleys as well as in making feasibility and design studies of the proposed conjunctive use projects is evident. However, these are only two of the more immediate problems. Other problems of more long range interest such as the suitability of areas for waste disposal in arid intermontane basins, location of the best areas of recharge to the aquifers, and determination of the pattern of ground-water flow in the valleys all require knowledge of the ground-water geology.

The problem for the geologist is to be able to describe physical properties of the rock from available geologic information. Ground-water geology requires an understanding of subsurface geology, but in most instances it is too costly to do extensive test drilling particularly in project feasibility studies. For this reason geologists are forced to rely on information already available, which in ground-water work is usually limited to the reports and logs of water-well drillers.

Geologists have in the past tended to discount the value of drillers' logs. Taken individually these logs are admittedly generalized, and often impossible to interpret. However, taken collectively the mass of information may be useful. A number of the new methods in geology, particularly the lithofacies mapping techniques which employ a statistical approach, should allow much better analysis of the drillers' data.

Subsurface Geology

A cursory examination of drillers' logs on file indicated that it might be possible to interpret this information using methods patterned on the statistical procedures of Krumbein and his associates (Forgotson, 1960). The methods developed here should prove useful in future studies of a wider scope.

It was hoped that analysis of well logs might at least suggest: (1) how useful the geologic

information contained in the drillers' logs is in interpreting the subsurface geology; (2) how the surface geology is related to the subsurface geology; and (3) what is the distribution of the best aquifers in the area.

Personal Factor in the Interpretation

A personal element is present in interpreting the data, particularly the very brief lithologic description used by the drillers. To illustrate this point, the driller's description "sand and gravel" is interpreted to mean units of principally sand interbedded with units of principally gravel. Gravel is assigned to only 50 percent of the interval logged as "sand and gravel." Another trained geologist might interpret this description differently. Most geologists would agree that it is almost impossible to define explicitly their methods of interpreting driller's remarks. In practice this means that in using such abbreviated geologic data one man, or team of men working jointly, must carry the interpretation completely through for the results to be consistent. Even so, two geologists working on the area with similar methods will probably arrive at similar results. The author's interpretations of the drillers' lithologic descriptions are summarized in Table 3.

TABLE 3
Geologic Interpretation of the Drillers' Descriptions of Sediments

Driller's description	Geologic interpretation	Percent gravel*
Gravel.....	Gravel.....	100
Cement gravel.....	Gravel, pebble sized grains predominate.....	100
Sand and gravel.....	Interbedded beds of medium to coarse grained sand with beds of gravel.....	50
Gravel and clay..... (gravelly clay)	Pebbles and larger clastic material in a matrix of fine sand and silt; interbedded with some beds of gravel. (Probably mudflow deposits with some interbedded stream sediments).....	0-25
Sand.....	Sand, medium to coarse grained.....	0
Sandy clay.....	Interbedded, clay, silt and fine to medium grained sand.....	0
Silt clay.....	Silt with minor amounts of clay.....	0
Yellow clay.....	Interbedded clay, silt and fine grained sand (possibly, at least in part lacustrine).....	0
Blue clay.....	Clay, blue, thinly bedded (probably lacustrine).....	0
Lava rock.....	Either volcanic flows or volcanic detrital material.....	?

*Gravel is used to describe a clastic deposit in which the median grain size is 2 mm. or larger with a matrix of predominantly medium to coarse grained sand.

Information Available from Drillers' Logs

Among the standard items reported on the driller's log in Nevada are: a brief lithologic log; an indication of which units are aquifers; the depth of the first water-bearing unit; the static water level in the hole during and after drilling; a brief description of the casing including the depth of perforations; and a report of a production test if one was made. From this data two facts, the brief lithologic log and the hydrologic data available from production tests, appear to be significant in interpreting the ground-water geology.

The specific capacity of a well is a useful hydrologic index of well performance. Specific capacity is defined as the ratio of the pumping rate to the drawdown in the well. It is expressed in gallons per minute per foot of drawdown (gpm/ft).

If the assumption is made that for most wells which produce at relatively high rates the greatest percentage of the water is transmitted by gravel in the aquifer, it is reasonable to expect that a relationship should exist between the cumulative thickness of gravel penetrated by a well and the specific capacity of the well. Figure 7 is a graph of the cumulative gravel thickness versus specific capacity plotted on log paper for all the wells in the Lower Humboldt Basin for which specific capacities could be obtained. A least squares straight line was fitted to the points. The two parallel dashed lines are the limits of one standard error of estimate (Arkin and Colton, 1956, p. 76), a measure of the variation about the line of best fit. As expected, a wide scatter of points occurs on the graph. However, the line of best fit closely approximates the expected theoretical relationship as shown below. Considering the vagaries of various driller's lithologic descriptions, the actual differences in the lithologic character of the aquifers, the differences in pumping periods, the differences in well diameter and well efficiency of individual wells, it is striking that any relationship exists.

Theoretical Consideration of Specific Capacity

Ground-water hydrologists usually describe mathematically the flow of ground water to a pumping well by the so-called "Theis equation."

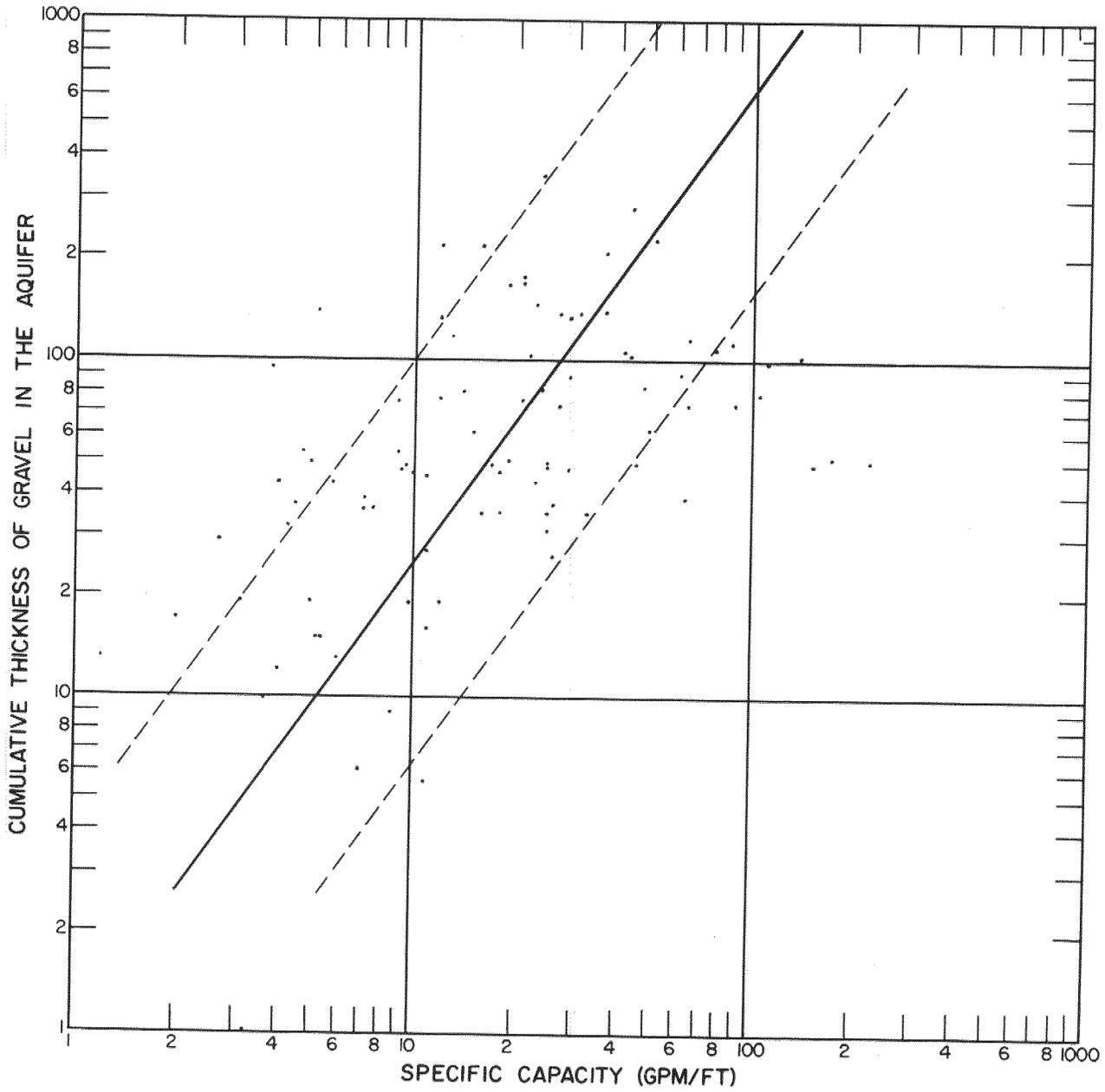


Figure 7. Graph of the cumulative thickness of gravel versus specific capacity.

Theis (1941) suggested the following form of the equation for problems of specific capacity:

$$\frac{Q}{s} = \frac{T}{264 \log \frac{Tt}{1.87 r_w^2 S} - 65.5} \quad (1)$$

where:

- Q = pumping rate, in gallons per minute
- s = drawdown of the well, in feet
- T = coefficient of transmissibility, in gallons per day per foot of aquifer
- t = pumping period, in days
- r_w = "effective" well radius, in feet
- S = storage coefficient, a dimensionless coefficient

$$\frac{Q}{s} = \text{specific capacity, in gallons per minute per foot of drawdown}$$

Theis (1938) defined the coefficient of transmissibility as follows:

The transmissibility is expressed quantitatively by a coefficient of transmissibility defined as the number of gallons of water which will move in one day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity. It is the average coefficient of permeability, . . . , multiplied by the thickness of the aquifer in feet.

Theis (1938) in the same article defined the coefficient of storage as follows:

* * * coefficient of storage, defined as the volume of water measured in cubic feet, released from storage in each column of the aquifer having a base 1 foot square and a height equal to the thickness of the aquifer, when the water table or other piezometric surface is lowered 1 foot.

The specific capacity obviously varies with variations in transmissibility, storage coefficient, pumping period, and effective well diameter. If the coefficient of transmissibility and the storage coefficient are known, the variations in specific capacity with variations in well diameter and pumping period can be computed from equation 1. These variations are shown graphically in Figure 8 for an aquifer with a coefficient of transmissibility of 25,000 gpd/ft and a storage coefficient of 1×10^{-2} ; these are reasonable values for the aquifers of this area. This method of presentation was suggested by Walton and Csallany (1962). After pumping has continued for approximately 8 hours, further variation in the specific capacity due to continued production is small. Changes in well radius from 8 to 12 inches, the usual range of casing size used in the Lower Humboldt Basin, do not affect specific capacity greatly.

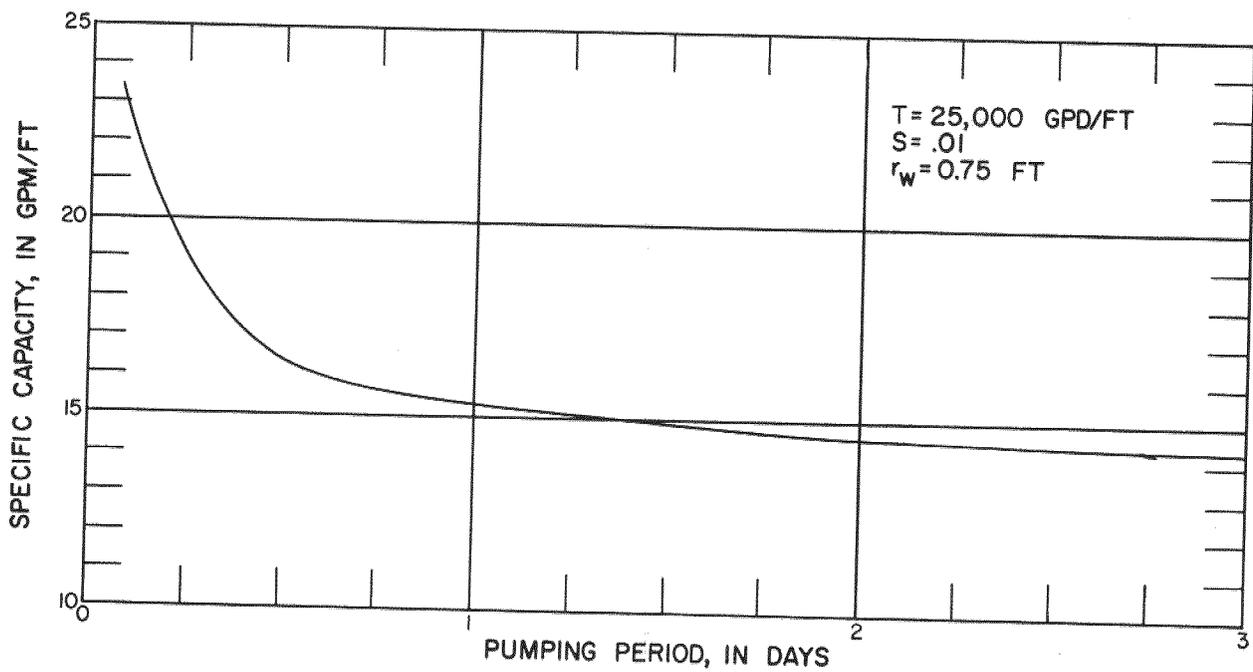
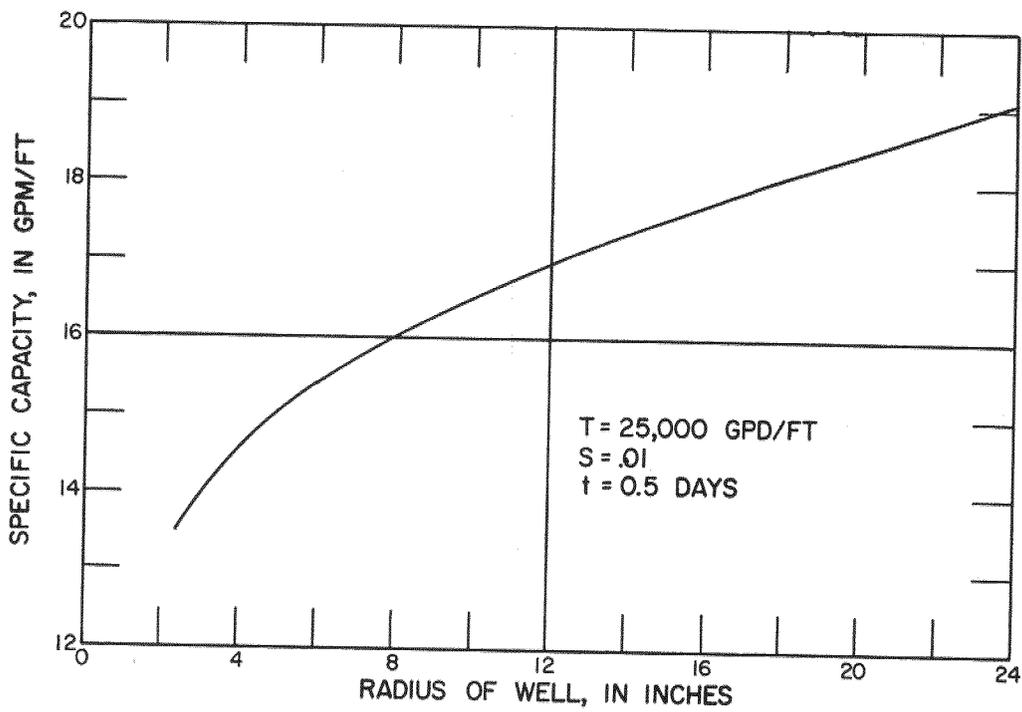


Figure 8. Graphs showing the variation of the specific capacity with the changes in well radius and with changes in the pumping period.

The "effective" well radius is not the same as the radius of the casing. It depends, to some extent, on well development. Commonly the well development in unconsolidated deposits extends the effective well radius beyond the radius of the casing. Development has the same effect as placing a gravel pack around the casing. There is no valid way of estimating these effects without controlled pumping tests.

The theoretical relationship between transmis-

sibility and specific capacity for a well with a radius of 9 inches and a pumping period of 12 hours is shown in Figure 9. From the drillers' data these values appear reasonable; 9 inches is a reasonable average for the larger wells of the area and most acceptance tests are carried out for about 12 hours. Several lines representing various coefficients of storage are shown on the graph. The relationship is one of a straight line on logarithmic graph paper.

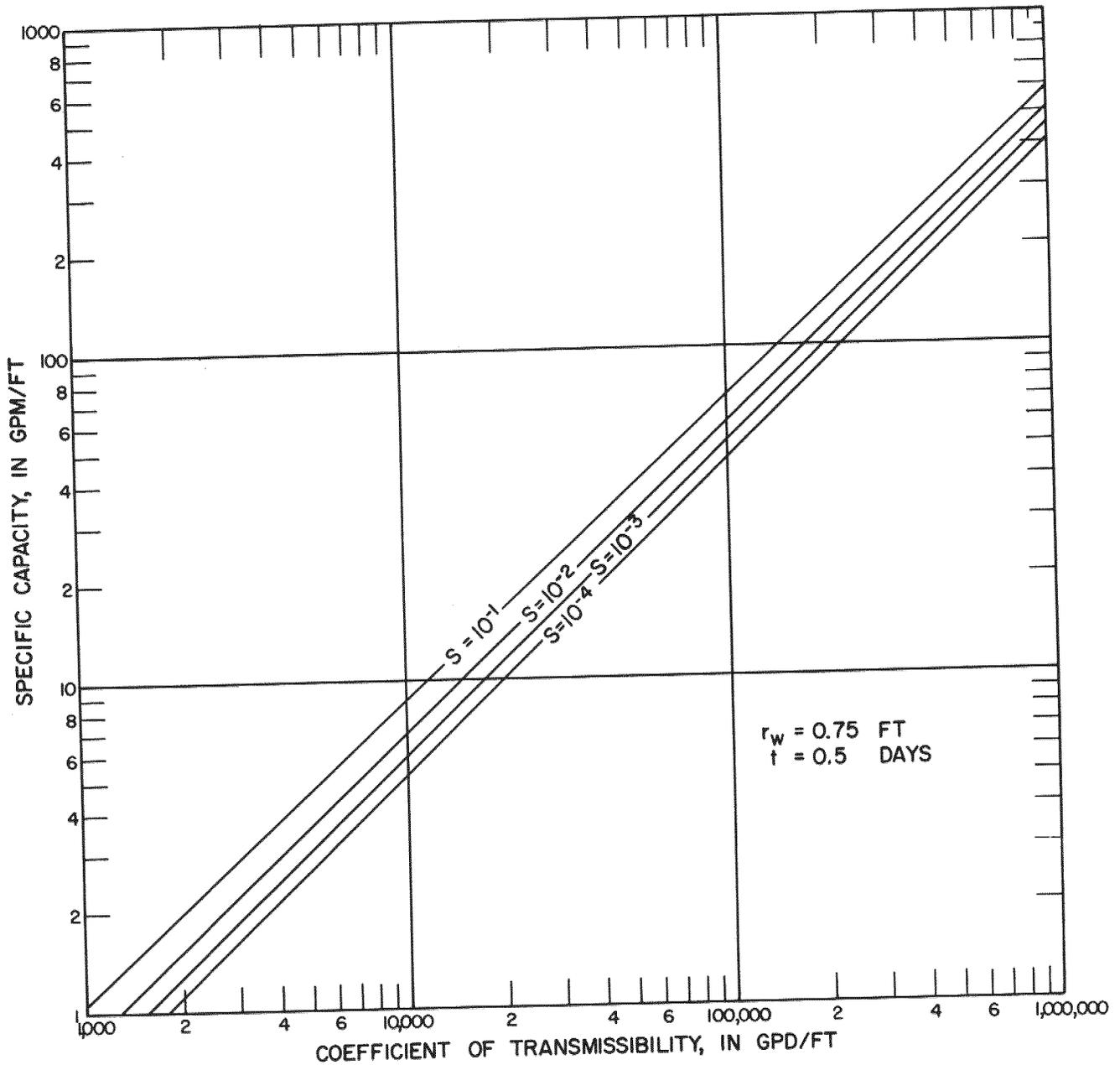


Figure 9. Theoretical relationship between specific capacity and transmissibility. Several lines are drawn representing various coefficients of storage.

All of these theoretical considerations are based upon a well that is 100 percent efficient, i.e., no well loss. However, losses in head within the well occur due primarily to the turbulent water flow. Well losses produce a greater drawdown in a pumping well than the Theis equation describes, lowering the specific capacity of the well. In Figure 9 a lower specific capacity indicates a lower transmissibility. Well losses which are uncorrected tend to indicate a lower transmissibility than is actually present.

Even with the inherent difficulties, the line of best fit relationship of cumulative gravel thickness to the specific capacity, Figure 7, fits quite well with the theoretical relationship of specific capacity to transmissibility. The original assumption that the transmissibility of the aquifer is represented by the cumulative thickness of a gravel agrees with the theoretical considerations if one accepts the wide scatter of points. Even the slope of the observed linear relationship, Figure 7, roughly approximates the slope of theoretical relationship, Figure 9, when the abscissa and the ordinate values are placed in the same relative positions. The wide scatter of points is to be expected considering the differences in the various geologic deposits as well as the fact that no corrections were made for well loss, effective well radius, or pumping period. This suggests that what drillers call gravel on the logs does in fact define the aquifers lithologically. This also indicates that various drillers' lithologic descriptions are similar enough to one another to be geologically meaningful.

Comparison of the Ground-Water Potential of the Different Geologic Units

It is possible to use available specific capacity data to compare the capacity of various types of geologic deposits to transmit water.

One of the obvious difficulties with such a comparison is that specific capacity depends upon the coefficient of transmissibility, as shown above, which in turn varies with the thickness of the aquifer. The coefficient of transmissibility is considered equal to the thickness of permeable material multiplied by its coefficient of permeability, or mathematically:

$$T = pm \quad (2)$$

- T = coefficient of transmissibility, usually expressed in gallons per day per foot of aquifer
 p = coefficient of permeability, usually expressed in gallons per day per square foot
 m = thickness of material being considered, usually expressed in feet.

It is immediately obvious that a direct comparison between the specific capacity of a 1,000-foot well with a 100 foot well is of no value if one is interested in a measure of the apparent permeability of the material.

To make a comparison possible, the specific capacities were corrected to a common base, that of a well penetrating 100 feet of saturated sediments. This correction was made as a simple ratio. The specific capacity was divided by the thickness of saturated material penetrated by the well and multiplied by 100 feet; or mathematically:

$$\frac{\text{specific capacity} \times 100 \text{ feet}}{\text{thickness of saturated deposits penetrated}}$$

This results in an apparent specific capacity corrected for 100 feet of penetration of saturated material which is a gross index of the capacity of the geologic deposit in which the well was drilled to transmit water.

Inspection of the form of the Theis equation previously used (1) indicates that the correction suggested above based on a simple ratio is not theoretically sound. The simplest check is to observe that specific capacities corrected by the above method do not give the same apparent permeability as the original specific capacity (Figure 9). However, because the method is simple and the errors involved are small, it seems reasonable to use this procedure to correct the data to a common base.

To state the significance of the corrected specific capacity in another manner, it reflects the apparent cumulative thickness of permeable material in 100 feet of saturated deposits. If the assumption is made that the permeable material is mostly gravel, then the corrected specific capacity reflects the apparent cumulative gravel thickness in 100 feet of saturated material at the well.

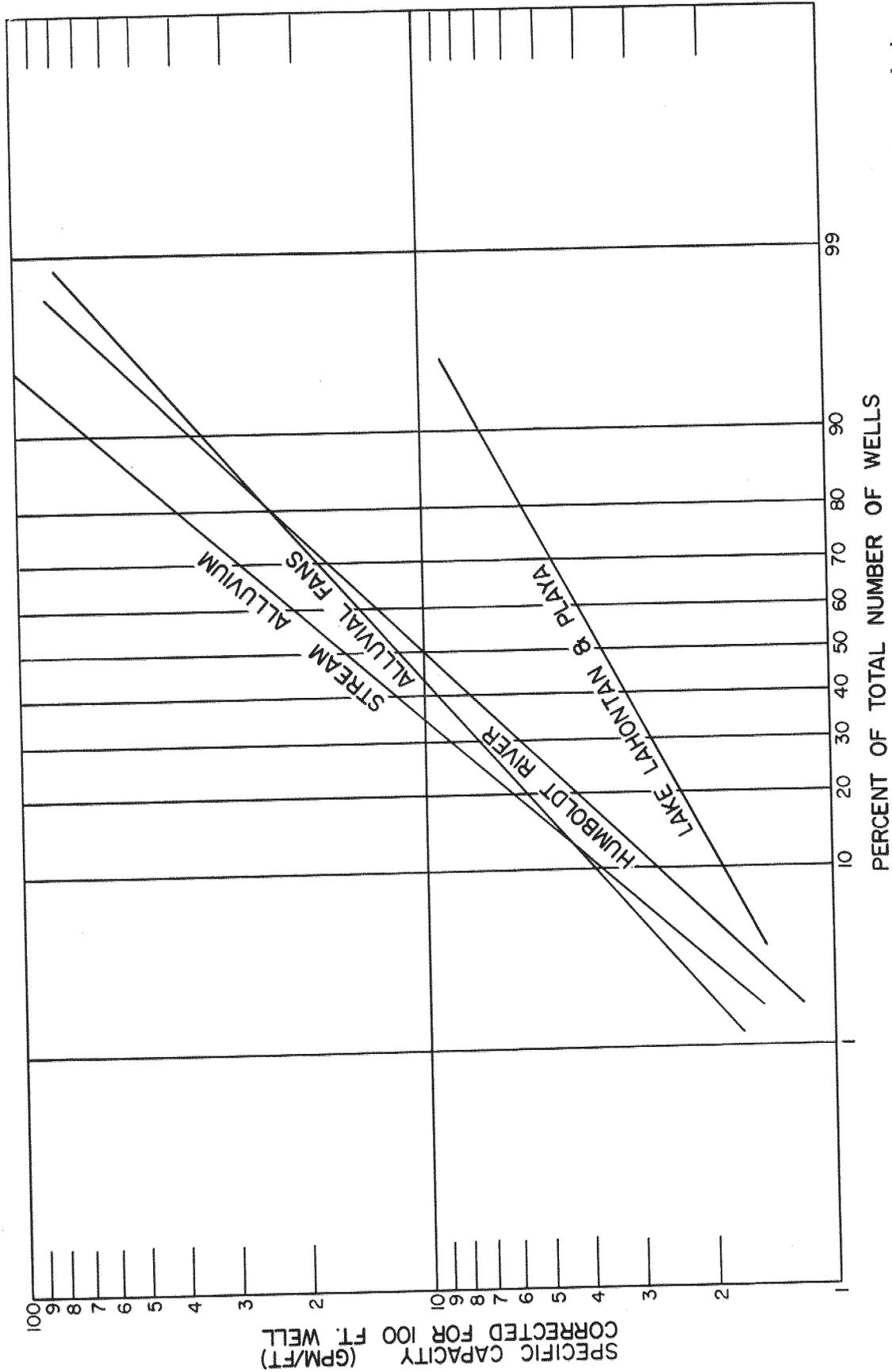


Figure 10. Graph of specific capacity corrected for 100 feet of aquifer penetration versus percent of the total number of wells within a geologic unit. The graph is plotted on log normal distribution paper.

A statistical comparison of the corrected specific data should indicate which geologic deposits contain a higher frequency of more permeable material. Two assumptions are necessary to make this comparison; (1) that the geologic unit mapped at the surface is representative of the subsurface; and (2) that within any particular geologic unit the occurrence of aquifer material more or less approaches a normal statistical distribution. There are obvious exceptions to the first assumption; for example, in the Winnemucca area thin Lake Lahontan sediments overlie alluvial-fan deposits. However, by proper geologic interpretation the obvious exceptions were excluded from consideration.

Wells for which specific capacities can be computed, corrected for 100 feet of penetration, were placed in categories according to the geologic unit mapped at the surface at the well site.

The corrected specific capacity versus percent of the total number of wells within a particular geologic unit is plotted on log normal distribution paper in Figure 10. The points within geologic units fall reasonably close to a straight line indicating that the assumption of a log normal distribution is reasonable. Walton (1961, personal communication) used a somewhat similar analysis in northern Illinois. Production test data are available for a combined total of approximately 70 wells drilled in the alluvial-fan deposits, the Humboldt River alluvium and other stream alluvium. Only 10 wells with sufficient data to calculate specific capacities were drilled in Lake Lahontan and playa deposits together.

Figure 10 indicates that there is a significant difference in the gross ability to transmit water of the deposits of two geologic environments; (1) Lacustrine deposits of the Pleistocene lakes and the playas; and (2) fluvial deposits of the alluvial fans and the streams. There appears to be little, if any, significant differences between alluvial-fan deposits, Humboldt River deposits and other stream alluvium.

Perhaps the explanation for the fact that the apparent permeability of alluvial-fan deposits is similar to the apparent permeability of the stream deposits is that the processes of deposition are similar. In this area of the Great Basin there appears to be considerable stream action on the alluvial-fans. Mudflows probably occur periodically, however, between mudflows, streams on the fans sort and redeposit the mudflow material and deposit large quantities of new material. This seems to have been particularly true during an earlier pluvial climatic period when much of the present valley fill was deposited.

Distribution of Aquifers

Particularly good aquifers are being developed in several areas within the Lower Humboldt Basin, notably along the Humboldt Valley in the vicinity of Winnemucca, in Paradise Valley, in the middle Reese River Valley and in Boulder Valley.

Maxey and Shamberger (1961) pointed out that, based on a 12-year average, 72,000 acre-feet of water is lost annually in the reach of the Humboldt River between Battle Mountain and the next gauging station upstream at Palisade just east of the mapped area. This water appears to be lost as recharge to ground-water reservoirs in the Boulder Valley vicinity. It is believed to be discharged from water table largely as evapotranspiration by phreatophytes. If this is true, these data suggest that extensive near-surface aquifers in the area are hydrologically connected to the river.

An interpretation of the drillers' logs was made in an effort to further define aquifers in the vicinity of Boulder Valley. Two slices were considered, the upper 100 feet and the upper 50 feet of valley fill deposits. Figure 11 is a sand-shale ratio map of the upper 100 feet of valley fill deposits in the Boulder Valley region and Figure 12 is a map of the cumulative thickness of gravel, a gravel isolith, within the same unit. Figure 13 is a gravel isolith of the upper 50 feet of valley fill deposits for the same area.

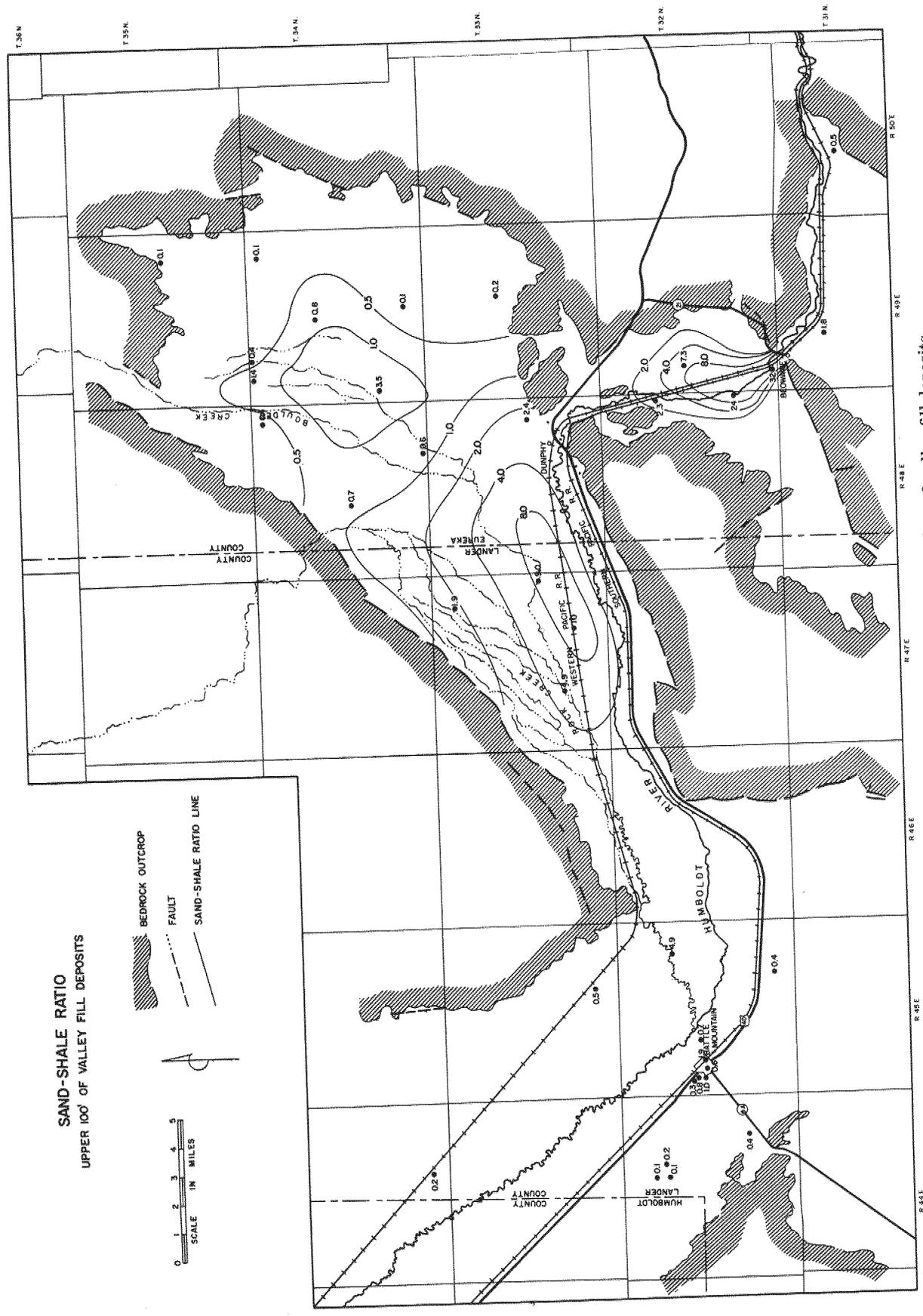


Figure 11. Sand-shale ratio map of the upper 100 feet of valley fill deposits.

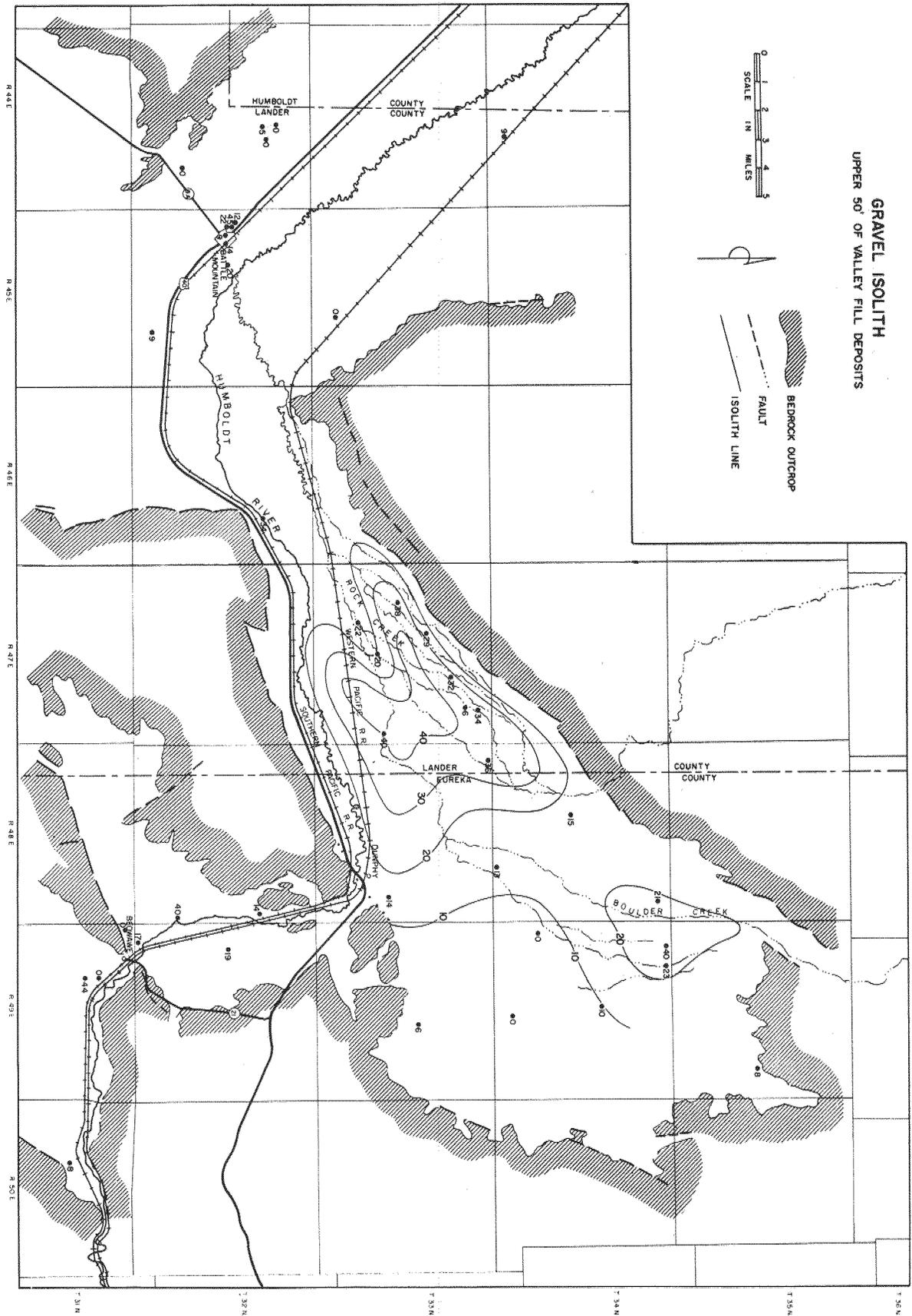


Figure 13. Gravel isolith of the upper 50 feet of valley fill deposits.

All three maps present a consistent interpretation of the subsurface geology. Large near-surface gravel deposits are present in both Boulder Valley and smaller Whirlwind Valley to the southeast. There appear to be two major associations for the gravels in Boulder Valley; (1) associated with Rock Creek; and (2) associated with Humboldt River itself. A smaller deposit in Boulder Valley is associated with Boulder Creek. Gravel deposits in Whirlwind Valley shown best on the sand-shale ratio map, Figure 11, are also clearly associated with Humboldt River.

This series of maps indicates that the gravel deposits are associated with the major streams of the area. The maps are limited to relatively shallow depths because available control is largely from shallow wells. Each of the three streams mentioned above has a large drainage basin. Two alternative interpretations for this association exist; (1) that the major streams of the area reworked alluvial-fan deposits which were actively filling the valleys; (2) that the streams of the area were actively transporting and depositing coarser sand and gravel material. In either case the deposit likely originated during an earlier pluvial climatic period.

Three conditions appear to be requisite for the deposition of extensive stream associated gravel deposits: (1) a major stream of sufficient volume flowing through the area of deposition, (2) a basin favorable for deposition, and (3) a source of gravel. This is in accordance with the classic concepts of sedimentation which require sufficient energy to move material as well as a favorable site for deposition.

A longitudinal cross-section along the Humboldt Valley from below Battle Mountain to Beowawe is shown in Figure 14. This cross-section is highly interpretive. It indicates, however, the extent of the gravel deposits in Boulder and Whirlwind Valleys and suggests the general shape of the valleys

including the faults. Thick clay deposits including a distinctive blue clay unit reported on many of the logs are present at shallow depths in the vicinity of Battle Mountain. Similar deposits occur at greater depths near Dunphy. These appear to be lacustrine deposits, further evidence of an early Pleistocene or later Tertiary lake in this area.

A gravel isolith of the upper 100 feet of valley fill deposits in Paradise Valley (Figure 15) clearly illustrates the association of gravel deposits with major streams. The greatest thickness of gravel is just below the points at which Martin Creek and Little Humboldt River enter the valley. Both of these are permanent streams with extensive drainage basins.

A similar gravel aquifer in the Reese River Valley is currently being developed for irrigation. This extensive aquifer occurs in the open part of the middle valley below the mouth of the Reese River canyon through the Shoshone Range. Hawley (1962) finds a similar association of the "medial gravels" with Humboldt River in the Winnemucca area.

Zones (1961) used a sand percentage map in Crescent Valley to indicate areas of favorable aquifer development. In a second map he classified areas in the valley according to the size of wells which might reasonably be expected. This is the only published paper in which an attempt was made to use a lithofacies mapping technique in a ground-water study in Nevada. This work indicates that good aquifers in the valley are near the toe of the alluvial-fan deposits. Zones suggests that only in a small area of the valley will wells yield over 1,000 gallons per minute. On the whole, gravel deposits associated with alluvial fans appear to be more limited in areal extent and do not possess the same potential for large scale developments as the more extensive deposits associated with major streams.

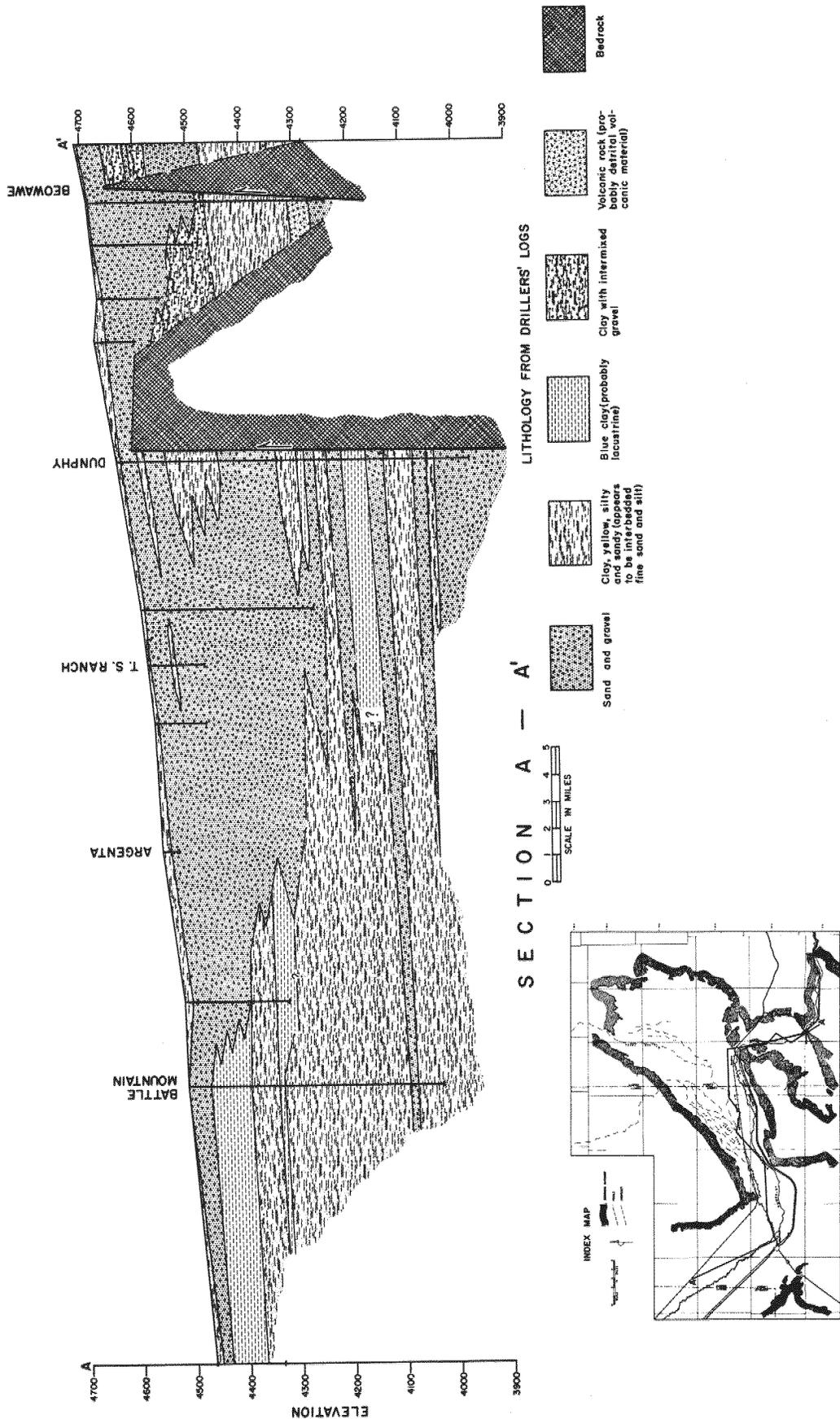


Figure 14. Cross-section along the Humboldt Valley from below Battle Mountain to Beowawe.

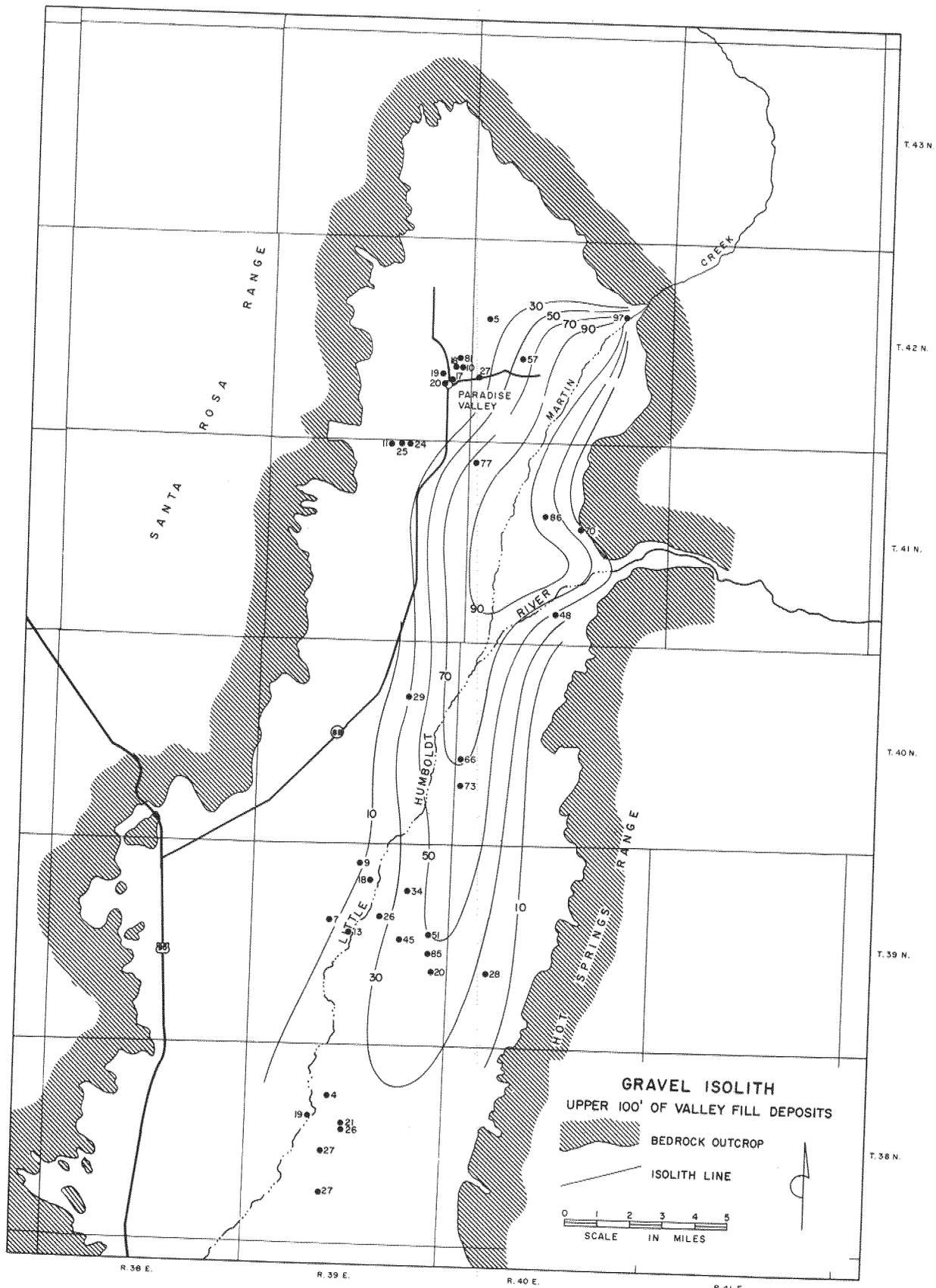


Figure 15. Gravel isolith of the upper 100 feet of valley fill deposits in Paradise Valley.

Average Permeability of the Stream- Associated Gravel Deposits

It is possible to work out an average permeability as well as to indicate the expected variation in permeability for similar deposits of stream associated gravels.

If specific capacity is known from a production test, transmissibility can be interpreted from the theoretical relationship between specific capacity and transmissibility (Figure 9). Some estimate of the value of the storage coefficient must be made; but a mistake in choosing the wrong storage coefficient value does not cause a large error in the value of the coefficient of transmissibility. Loeltz (1953) in a pumping test at Battle Mountain found the storage coefficient to be 0.0025 which suggests that the water is not fully confined. For our purposes here 1×10^{-2} may be a reasonable storage coefficient. If the assumption is again made that most of the water in a well producing at a high rate comes from gravel, the coefficient of transmissibility calculated from the specific capacity can be divided by the cumulative gravel thickness interpreted from the driller's log to obtain the coefficient of permeability of the gravel (refer to Formula 2, above). Admittedly, this procedure involves all the errors previously discussed as well as the assumption the gravel is the significant aquifer unit in the well, but an index value in the right order of magnitude is obtained.

The errors involved are such that the coefficient of transmissibility interpreted from the Theis equation (1), shown graphically in Figure 9, would probably tend to be low. As previously

mentioned, well losses tend to lower the specific capacity values. This, in turn, results in lower coefficient of transmissibility values derived by theoretical calculations if the proper corrections are not made. Low values may be partially offset if the well has a large effective radius. The effective well radius is probably greater for most of these wells than the 9 inches assumed to compute Figure 9, because normal drilling and testing procedures cause development of the well.

The procedure outlined above was used to analyze the 22 most productive wells in Boulder Valley, Whirlwind Valley, Paradise Valley and Reese River Valley which produce from stream associated gravel deposits. A tabulation of the data is presented in Table 4. The results are shown graphically in Figure 16, with the log of the coefficient of permeability plotted against the percent of the number of wells on normal distribution paper. The median permeability value is approximately 500 gallons per day per square foot for these gravel deposits.

One of these wells with a specific capacity of 225 gpm/ft is particularly outstanding. This well was drilled for irrigation in the middle Reese River Valley near the mouth of Antelope Valley. As Table 4 indicates, this well has a theoretically interpreted coefficient of transmissibility of 410,000 gpd/ft although it is reportedly producing from only 50 feet of gravel. The well appears anomalous and therefore was not considered in drawing the line of best fit on Figure 16.

It is possible to estimate coefficients of transmissibility by first estimating gravel thickness from the isolith and multiplying this value by the average permeability. This is, of course, only an

TABLE 4
Permeability Data for the Most Productive Wells Drilled in the Stream Associated Gravel Deposits

Specific capacity (gpm/ft)	Transmissibility (gpd/ft)	Cumulative thickness of gravel in aquifer (ft)	Permeability (gpd/ft ²)	Area
24	38,000	310	123	Paradise Valley
19	30,000	156	192	Whirlwind Valley
16	25,000	127	197	Whirlwind Valley
33	54,000	205	263	Boulder Valley
23	36,200	125	290	Paradise Valley
44	73,000	249	293	Paradise Valley
14	21,500	71	303	Paradise Valley
7.7	11,300	36	314	Reese River Valley
22	34,500	91	374	Paradise Valley
31	50,000	128	391	Paradise Valley
24	38,000	76	500	Paradise Valley
17	26,300	52	506	Paradise Valley
17	26,300	46	571	Paradise Valley
27	43,000	69	623	Paradise Valley
25	40,000	49	816	Paradise Valley
29	46,300	47	985	Paradise Valley
26	41,500	37	1,120	Reese River Valley
65	110,000	88	1,250	Reese River Valley
90	156,000	115	1,360	Reese River Valley
46	76,000	49	1,550	Reese River Valley
111	191,000	99	1,930	Reese River Valley
225	410,000	50	8,200	Reese River Valley

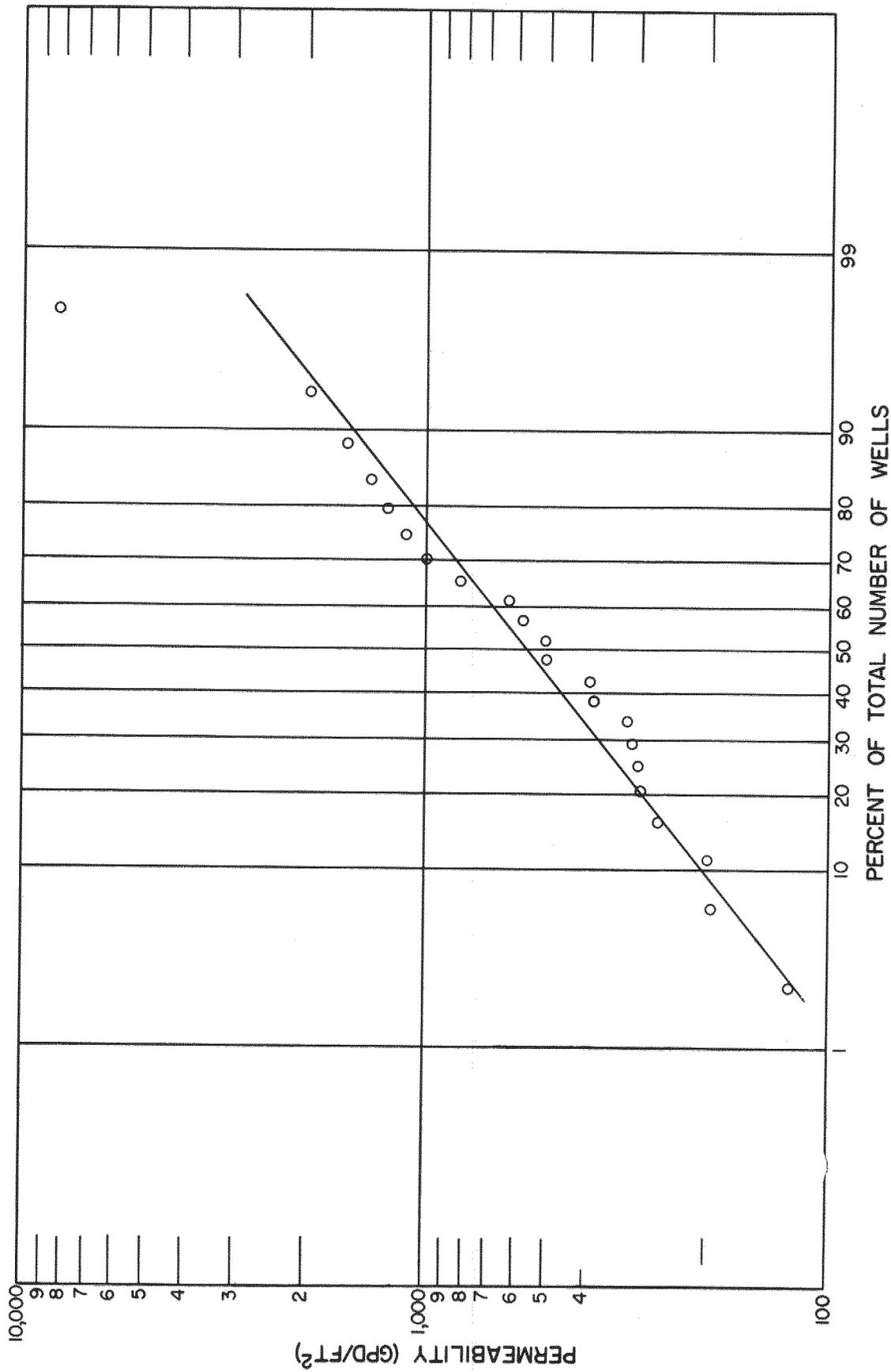


Figure 16. Graph of the permeability of stream associated gravel versus the percent of the total number of wells plotted on log normal distribution paper.

average value; however, it affords a quantitative means of at least estimating the order of magnitude of the coefficient of transmissibility. This is of importance in areas of proposed development. For example, the value of such an estimate in connection with the conjunctive use project under consideration in Boulder Valley is apparent. The gravel isoliths can be used with the median value of the coefficient of permeability as an index of the transmissibility of the shallow aquifer. This knowledge should be especially useful as a guide for feasibility considerations of the number of wells necessary, the most favorable recharge areas, etc. These transmissibility estimates should also be of particular value as a guide to future test drilling for such a project.

SUMMARY AND CONCLUSIONS

The purpose of this investigation is to describe the geology of the alluvial valleys of the Lower Humboldt River Basin as a framework for future hydrologic studies. This is the second phase in a continuing hydrologic study of the Humboldt River Basin.

The geology of the valley-fill deposits is presented on a 1/250,000 map. The detailed investigation of Hawley, Wilson and Cartwright in the Winnemucca region was used as a pilot study to guide work in remaining portions of the area. Farvolden, Cartwright and the author completed reconnaissance mapping of the remainder of the Lower Humboldt Basin (Plate I). The mapping was done largely from the Army Map Service high-level aerial photos following extensive field investigation. The original geologic mapping was done at a scale of 1/125,000 on enlarged Army Map Service topographic base maps and then reduced to the present 1/250,000 map.

The valley-fill deposits were subdivided into 13 units using the genesis of the deposits as a basis for subdivision. Stream deposits, alluvial-fan deposits, lacustrine deposits, playa deposits, eolian deposits, and colluvial deposits comprise the bulk of the valley-fill sediments.

Late Tertiary and Quaternary sedimentation is controlled largely by two factors; (1) tectonics and (2) climatic changes. Basin and Range faulting in the area started at least as early as the Oligocene and has continued to the present. In several valleys numerous fault scarps are preserved in the alluvium indicating the very recent age of the faulting. This block faulting has controlled the basins of deposition.

A number of climatic changes have occurred

in this area during the late Tertiary and Quaternary which influence the deposition. The Mio-Pliocene climate was subhumid, 25 to 30 inches of annual rainfall. The Quaternary climate has varied between pluvial periods and periods of extreme aridity. The great bulk of the Quaternary sediments were deposited during pluvial climatic periods. Current investigations suggest that the Pliocene pluvial periods had an annual precipitation of approximately 20 inches accompanied by a reduced rate of evaporation.

An analysis of the driller's logs was made in an effort to relate the subsurface geology to the surface geology. Interpretation is based both on hydrologic and geologic data available from the logs. Two items of reported information proved most useful; (1) hydrologic data from the results of acceptance production tests, and (2) lithologic logs reported by the drillers.

Results of the well log analysis indicate that deposits which drillers describe as gravel comprise the aquifer material. A graph of cumulative thickness of gravel versus specific capacity shows good correlation with the results expected from theory.

There is a marked difference in permeability between lacustrine deposits and fluvial deposits. As expected the lacustrine deposits are much less permeable. The best aquifers were deposited in association with the fluvial environment.

Lithofacies maps were compiled from the drillers' logs for several valleys to investigate the distribution of the aquifers. The most extensive aquifers occur associated with the major streams. These sediments were deposited during an earlier period of pluvial climate.

Three conditions are necessary for the deposition of extensive gravel deposits; (1) a major stream of large volume must have been present, (2) there must have been a favorable area for deposition, and (3) suitable rocks for gravel must have been available. The best aquifers can be explored for on the basis of their relationship to the major drainage basins.

An average permeability for the most extensive aquifers, the stream associated gravel deposits, was computed statistically from the drillers' data. A median value of 500 gallons per day per square foot was determined using the calculated specific capacity of the 22 best wells in these deposits.

Drillers' data is shown to be useful if analyzed properly. Both the lithologic and hydrologic data appears to be consistent as well as reliable when interpreted by statistical methods.

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