DISPOSITION OF AQUIFERS IN INTERMONTANE BASINS OF NORTHERN NEVADA

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Résumé

Cette recherche à été entreprise afin de déterminer les relations qui pourraient être établies entre la distribution des nappes aquifères dans certains bassins intermontagneux et les caractéristiques physiographiques ou géologiques de ces bassins.

Les caractéristiques des nappes aquifères sont obtenues par l'analyse des registres des puisatiers et par l'analyse des essais de débits effectués par les puisatiers.

Quoique les registres des puisatiers soient peu estimés de la plupart des géologues, les résultats de cette investigation indiquent que quelques caractéristiques hydrogéologiques pertientes sont notées par la plupart des puisatiers. On a pu utiliser ces données pour établir les cartes «lithofacies» des nappes aquifères superficielles. Les données des essais de débits ont fourni assez de renseignements pour permettre une évaluation de «specific capacity» qui mette en position d'évaluer la perméabilité d'après la formule de non-équilibre de Theis. Une analyse statistique démontre l'existence d'un rapport significatif entre les «specific capacities» évaluées et la désignation lithologique des puisatiers.

On voit d'après les cartes «lithofacies» que les meilleurs nappes aquifères sont les gisements étendus de cailloutis associés aux tributaires principales de chaque vallée. On en vient à la conclusion suivante : le triage par le ruissellement a plus d'importance dans l'origine de ces nappes aquifères que le triage résultant de la sédimentation normale des éventails alluviaux.

Abstract

This study was undertaken in order to determine what relationships, if any, could be established between physiographic or geologic surface features and the distribution of aquifers in the subsurface in selected intermontane basins.

The geologic and hydrologic characteristics of the aquifers were obtained by analysis of the drillers' logs and reports of acceptance tests on water wells.

Although drillers' logs and reports are held in low esteem by most geologists, the results of this investigation show that certain pertinent hydrogeologic properties are recorded by most drillers. It was possible to utilize this data to construct lithofacies maps of the shallow aquifers. Further, the data from the crude production tests provided sufficient information for estimates of specific capacity which in turn allowed the calculation of transmissibilities and permeabilities from theoretical considerations. Statistical analyses reveal a meaningful relationship between the calculated specific capacities and the drillers' lithologic description.

The best aquifers are shown on the lithofacies maps to be the extensive gravel deposits associated with the major triburary or tributaries of each valley. The conclusion is that the action of sorting by stream flow is more important than the sorting which occurs as a result of normal alluvial fan deposition, in the origin of these aquifers.

1. Introduction

Northern Nevada is a small portion of the Great Basin of the Basin and Range Province. North trending mountain ranges which vary in size from 20 to 50 miles long and 5 to 10 miles wide separate alluvial valleys of approximately equal dimensions. The alluvial valleys are underlain by clastic sediments derived from adjacent highlands and are areas of potential ground-water development. Loeltz and Malmberg (1961) indicate that in the majority of these valleys less than 50 percent of the estimated "perennial yield" of ground water has been developed. In a semi-arid region such as

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northern Nevada this ground water represents a valuable natural resource that will be exploited sooner or later.

The importance of understanding the geology in order to meet the problems encountered in ground-water development is understood by everyone familiar with water resources studies. Geologists must describe the physical properties of the rocks that make up ground-water reservoir systems, and they must have a knowledge of the subsurface geology. In most instances sufficient funds are not available for an extensive test-drilling program and geologists must rely on information already available. In ground-water studies this is often limited to the logs and reports of water-well drillers.

Geologists often tend to discount the value of drillers' logs for stratigraphic information. However, examination of the logs and reports on file in the State Engineer's Office in Nevada indicated that it might be possible using methods patterned on the statistical procedures of Krumbein and his associates (Forgotson, 1960) to interpret the shallow subsurface geology of several valleys from this information.

2. DISTRIBUTION OF AQUIFERS

Highly productive aquifers are being developed in many valleys in northern Nevada. The pattern of development in each valley is usually determined by the suitability and availability of land for cultivation. Little consideration is given to the areal limits of aquifers and every well is both a test hole and, hopefully, a production well. An understanding of the geology of the valley-fill deposits should allow better success in selecting well locations. In the past it has been thought that the most pro-

TABLE 1

Geologic interpretation of the Drillers' Description 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 grains	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.

ductive aquifers were related to alluvial fan deposition and, owing to their complex depositional pattern, the distribution of aquifers was thought to be almost unpredictable. It seemed that if the available drillers' logs could be used for subsurface geologic studies, sufficient information would be available to map the disposition of the major aquifers in selected valleys. Location of the various valleys considered is shown on a map of Neveda (Figure 1).

The personal element involved in interpreting the lithologic descriptions used by drillers is an important source of error. A standard interpretation of each of the common driller's terms was established in an effort to try to reduce this error. The usual driller's terminology and the authors' interpretation are summarized in Table 1.

Most of the ground water produced in northern Nevada is used for irrigation. In this area wells which yield less than 750 gallons per minute are considered poor irrigation wells. Statistical analysis of the drillers' well logs and production test data indicate that deposits described by the drillers as "gravel" comprise the major aquifers.

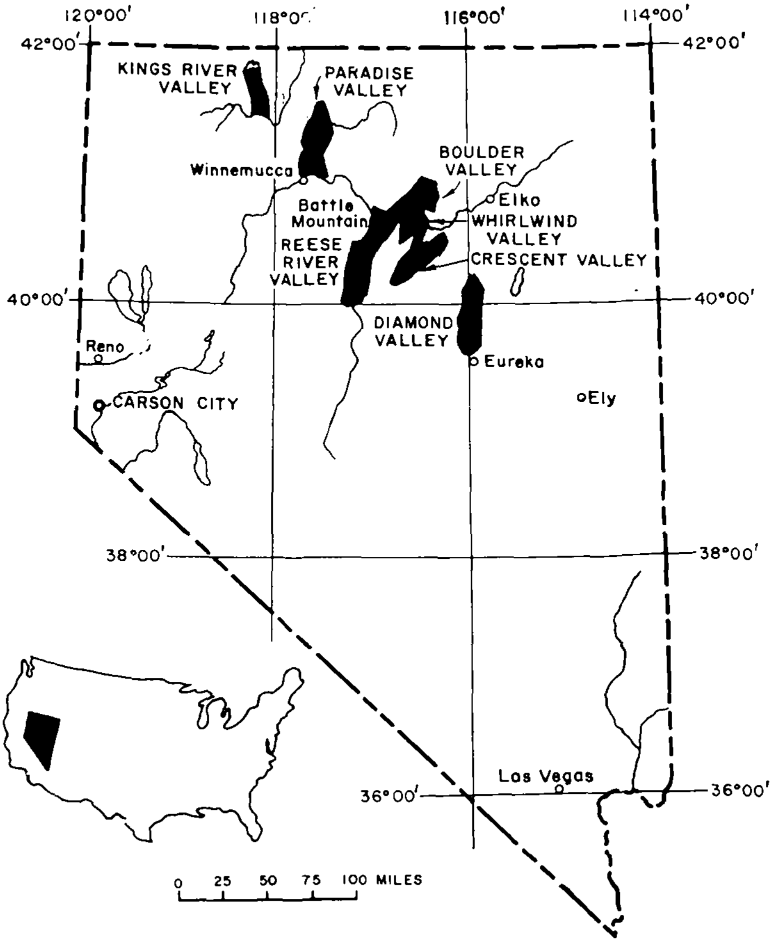

Fig. 1 — Map of Nevada Showing Location of the Various Valleys Discussed.

3. ASSOCIATION OF GRAVEL AQUIFERS WITH THE MAJOR STREAMS.

In valleys where there are sufficient data to allow mapping the disposition of gravel deposits, they appear to be closely related to the larger streams, especially where these streams are through-flowing. This suggests that the alluvial fan deposits in many instances are only a source of coarse granular material.

4. BOULDER VALLEY

Maxey and Shamberger (1961) pointed out that based on a 12-year average, 72,000 acre-feet of water are lost annually in the reach of the Humboldt River between Battle Mountain and the next gaging station approximately 50 miles upstream. This water appears to recharge groundwater reservoirs in the Boulder Valley vicinity (Fig. 1). It is believed to be discharged from the water table largely as evapotranspiration by phreatophytes. These data suggest that extensive, near-surface aquifers are hydrologically connected with the river along this reach.

An interpretation of the drillers' logs was made in an effort to determine the extent and location of these aquifers. For mapping purposes an arbitrarily defined rock unit, the so-called "slice" (Forgotson, 1960) was selected. In Boulder Valley and vicinity the two slices studied consist of the upper 50 and 100 feet of valley fill deposits. This method of arbitrarily defining the geologic unit to be investigated was used because the nature of the deposits as well as the data make correlation of shallow stratigraphic units very difficult, if not impossible. The method of using a slice is well suited to investigating variations in lithology of the shallow deposits in the valleys. Similar methods have been employed in lithofacies studies in petroleum investigations where stratigraphic correlations are difficult to make.

A "sand-shale" ratio map was drawn for the upper 100 feet of valley fill deposits in the Boulder Valley area (Fig. 2). The sand-shale ratio is defined as the ratio of the cumulative thickness of coarse clastic rock, boulders, gravel, and sand, to the fine clastic rock, silt, and clay (Krumbein and Sloss, 1953). Since the sediments in most of the valleys of northern Nevada are composed almost entirely of clastic rocks, all of the frequently encountered valley fill deposits are considered in computing the sand-shale ratio. Figure 3 is a map of the cumulative thickness of gravel, a gravel isolith, of the upper 100 feet of valley fill sediments. Figure 4 is a gravel isolith of the upper 50 feet of valley fill deposits for the same area.

All three maps present a consistent interpretation of the subsurface geology. Large near-surface gravel deposits are present in both Boulder Valley and Whirlwind Valley, the smaller 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 the Humboldt River. A smaller deposit in Boulder Valley is associated with Boulder Creek. Gravel deposits in Whirlwind Valley, shown best on the sand-shale ratio map (Fig. 2), are clearly associated with the Humboldt River.

The maps are limited to relatively shallow depths because available control is largely from shallow wells. A longitudinal cross-section along the Humboldt Valley from below Battle Mountain to Beowawe is shown in Figure 5. This cross-section is highly interpretative. It indicates, however, the extent of coarse clastic deposits in Boulder and Whirlwind Valleys. 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, evidence of an early Pleistocene or later Tertiary lake in this area.

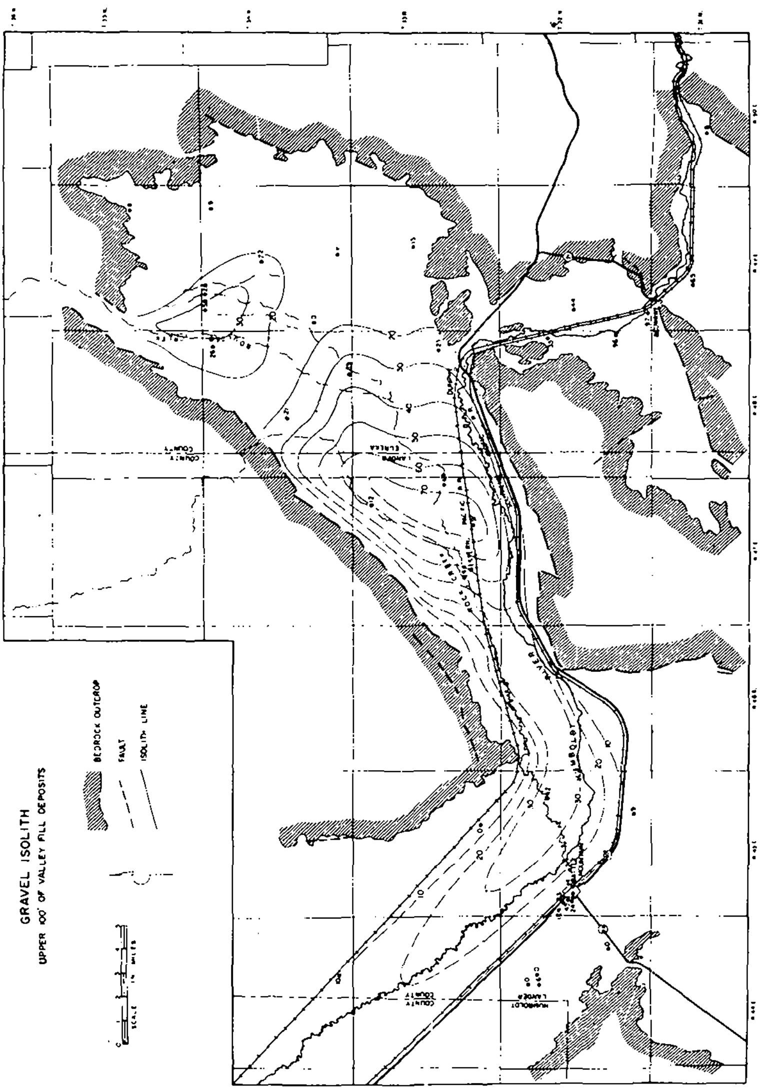

Fig. 2 — Sand-Shale Ratio Map of the Upper 100 Feet of Valley Fill Deposits in Boulder Valley and Vicinity.

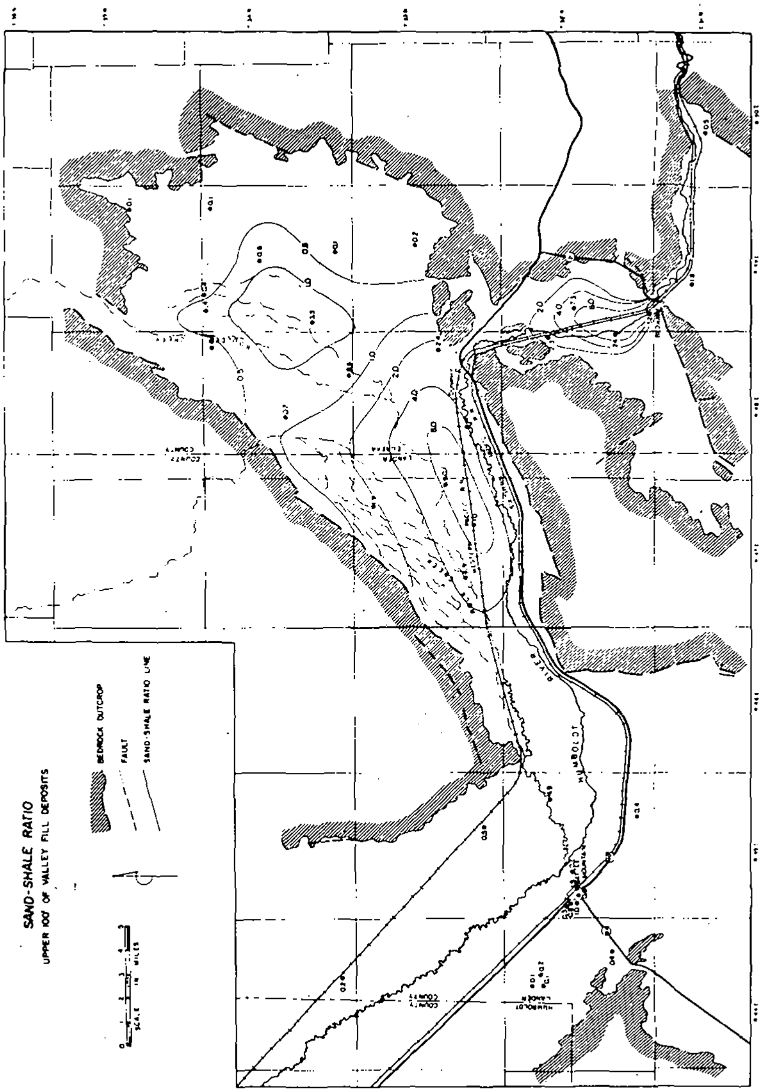

Fig. 3 — Gravel Isolith of the Upper 100 Feet of Valley Fill Deposits in Boulder Valley and Vicinity.

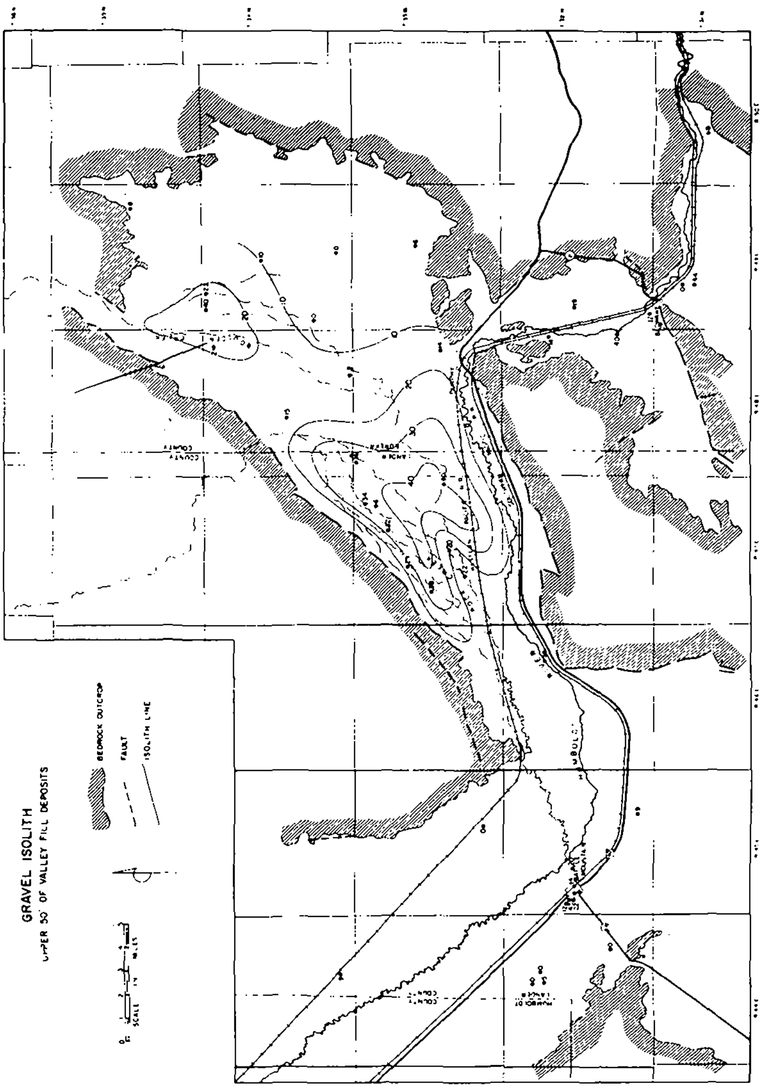

Fig. 4 — Gravel Isolith of the Upper 50 Feet of Valley Fill Deposits in Boulder Valley and Vicinity.

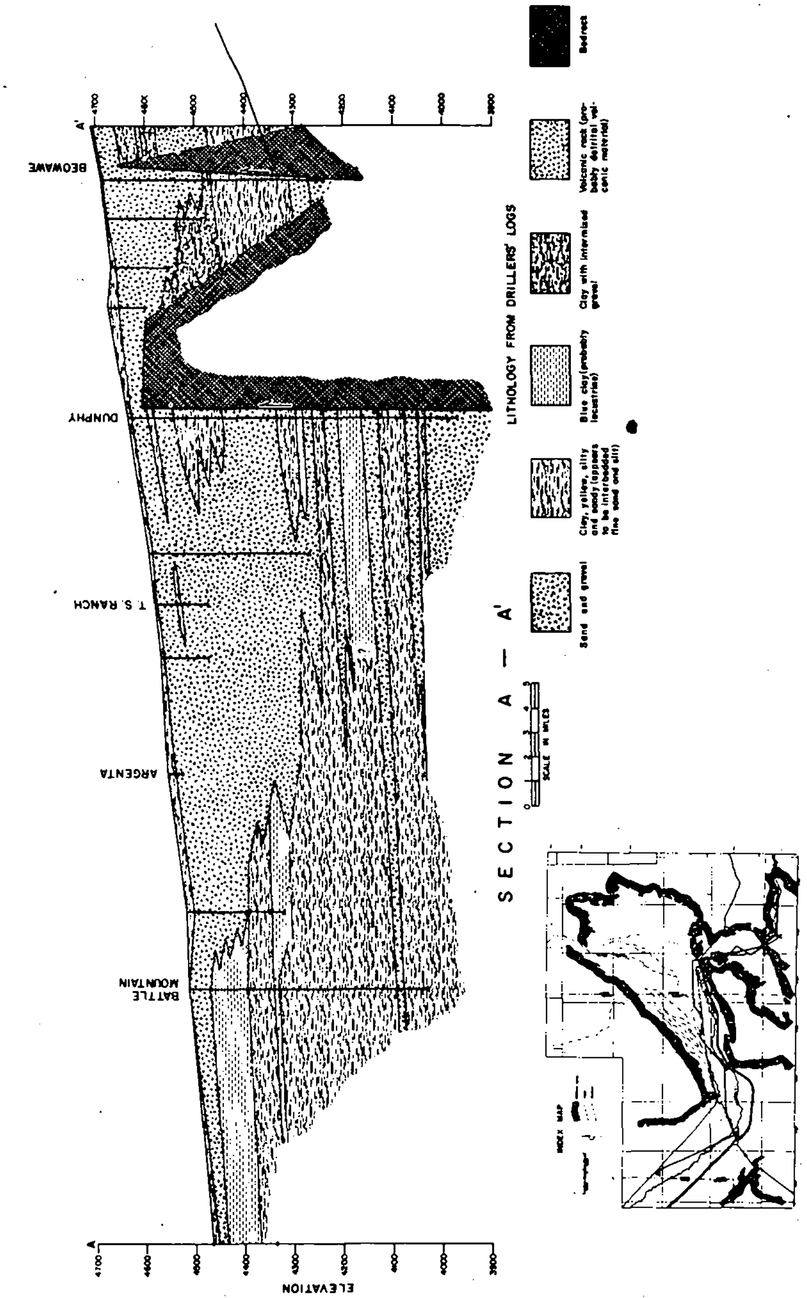

Fig. 5 — Cross-Section Along the Humboldt Valley from Below Battle Mountain to Beowawe.

5. OTHER VALLEYS OF NORTHERN NEVADA

A gravel isolith of the upper 100 feet of valley fill deposits in Paradise (Fig. 6) clearly illustrates a similar association of gravel deposits with major streams. The greatest thickness of gravel is just below the points at which Martin Creek and the Little Humboldt River enter the valley. Both are major streams with extensive drainage basins.

A similar gravel aquifer in the Reese River Valley (Fig. 1) 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 mountain range to the south. The deposition of gravel in Kings River Valley (Fig. 1) is very similar to that in Paradise Valley and Reese River Valley; elongate gravel deposits are associated with Kings River, a major through-flowing stream. Hawley (1962) finds a similar association of the "medial gravels" with the Humboldt River in the Winnemucca area (Fig. 1).

Maps showing the disposition of gravel aquifers in Crescent Valley and Diamond Valley (Fig. 7 and 8) also show a close association between the surface drainage features and the gravel isoliths. The relationship in Crescent Valley (Fig. 7) is not so clear as in the other valleys, possibly because the main stream which entered the valley from the south was much smaller than those which drained into the valleys mentioned above. Diamond Valley appears to have been a closed basin during the time of deposition of the shallow alluvial fill. The gravel appears to comprise a deltaic-like deposit at the mouth of the main stream into the valley (Fig. 8).

This series of maps indicates that the gravel aquifers are associated with the main streams of the intermontane basins. Two alternative interpretations for this association exist: either (1) that the main streams of the area reworked alluvial-fan deposits which were actively filling the valleys, and that the major aquifers are lag gravels; or (2) that the streams of the area actively transported and deposited the coarse sediments from some point upstream, in the uplands region. In either case the deposit probably originated during an earlier Pleistocene or late Tertiary pluvial climatic period.

There is evidence of earlier more humid climatic periods in the area. Late tertiary and Pleistocene lacustrine deposits are present throughout the Great Basin. Investigations by Van Houten (1956), Axelrod (1956) and Deffeyes (1958) indicate the presence of numerous Miocene-Pliocene lacustrine deposits. Axelrod from paleontologic studies of the flora suggests that the late Tertiary climate was subhumid with an annual rainfall of approximately 25 to 30 inches.

Investigations by King (1878), Russell (1885), Jones (1925), Antevs (1925), Morrison (1961) and others demonstrate the presence of large Quaternary lakes in this area. There is every indication that a sequence of Pleistocene and Recent lakes followed the sequence of Tertiary lakes. Synder and Langbein (1962) suggest that based upon hydrologic considerations an annual precipitation rate of 20 inches accompanies by an annual evaporation rate of 21 inches would be sufficient to restore a number of the Pleistocene lakes of the region.

According to classical concepts of sedimentation, three conditions are requisite for deposition of extensive stream-associated gravel deposits : (1) a major stream of sufficient volume must flow into the area of deposition, (2) a favorable site for deposition must exist, and (3) there must be a source of coarse clastic material. All three conditions appear to have existed in the past in the areas of northern Nevada.

6. AVERAGE PERMEABILITY OF THE STREAM-ASSOCIATED GRAVEL DEPOSITS.

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

If the specific capacity of a well is known from a production test, the coefficient of transmissibility can be interpreted from the theoretical relationship between specific capacity and transmissibility (Fig. 9). This theoretical relationship is based upon nonequilibrium pumping test theory, the so-called "Theis equation" (Theis, 1935;

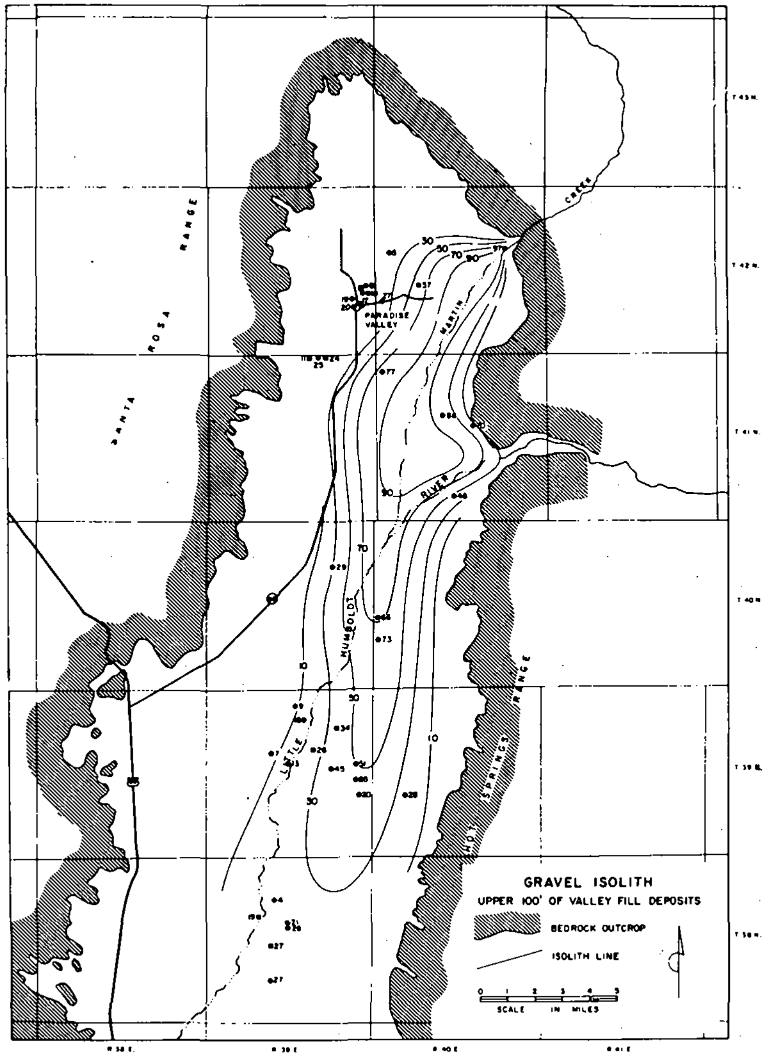

Fig. 6 — Gravel Isolith of the Upper 100 Feet of Valley Fill Deposits in Paradise Valley.

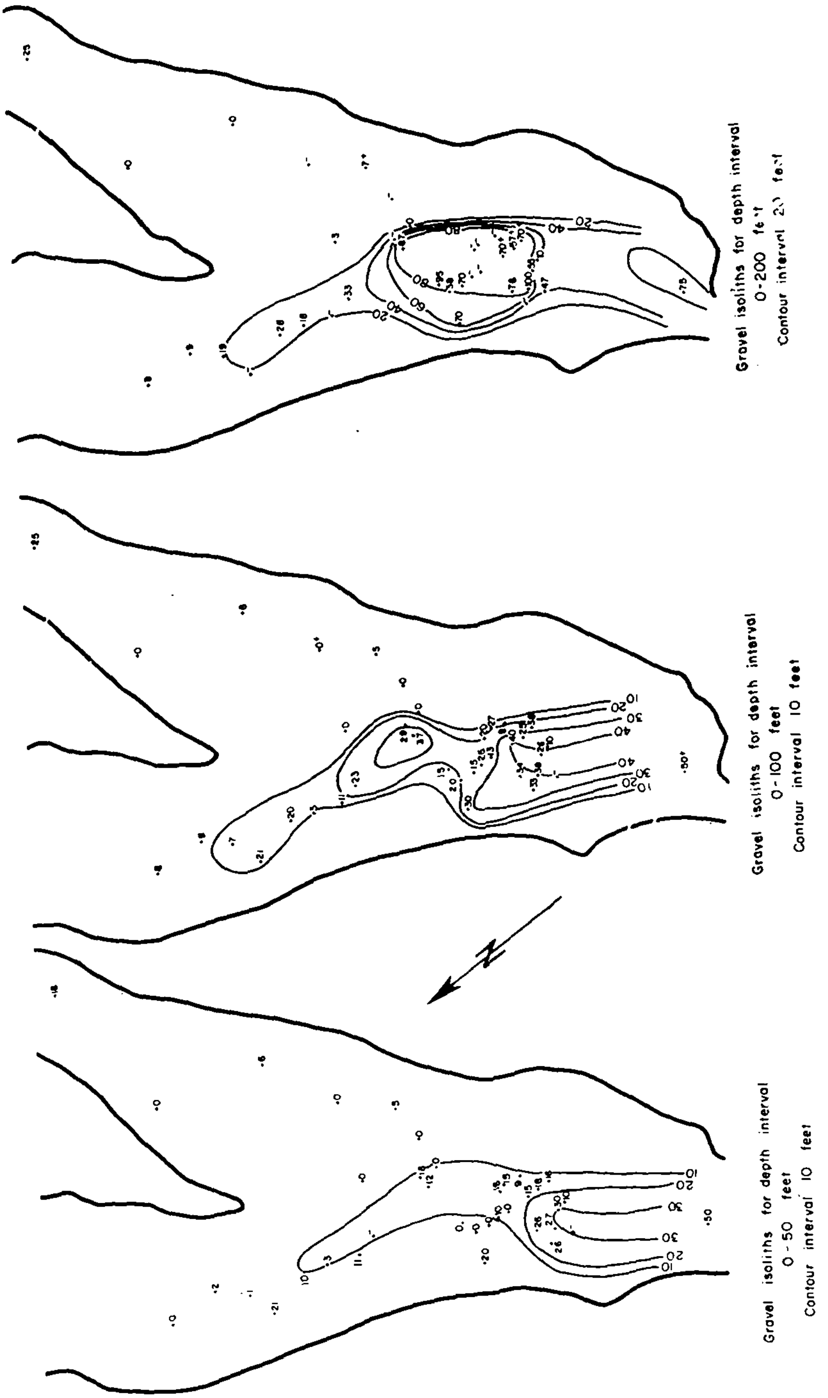

Fig. 7 — Gravel Isoliths of the Upper 200 Feet of Valley Fill Deposits in Crescent Valley.

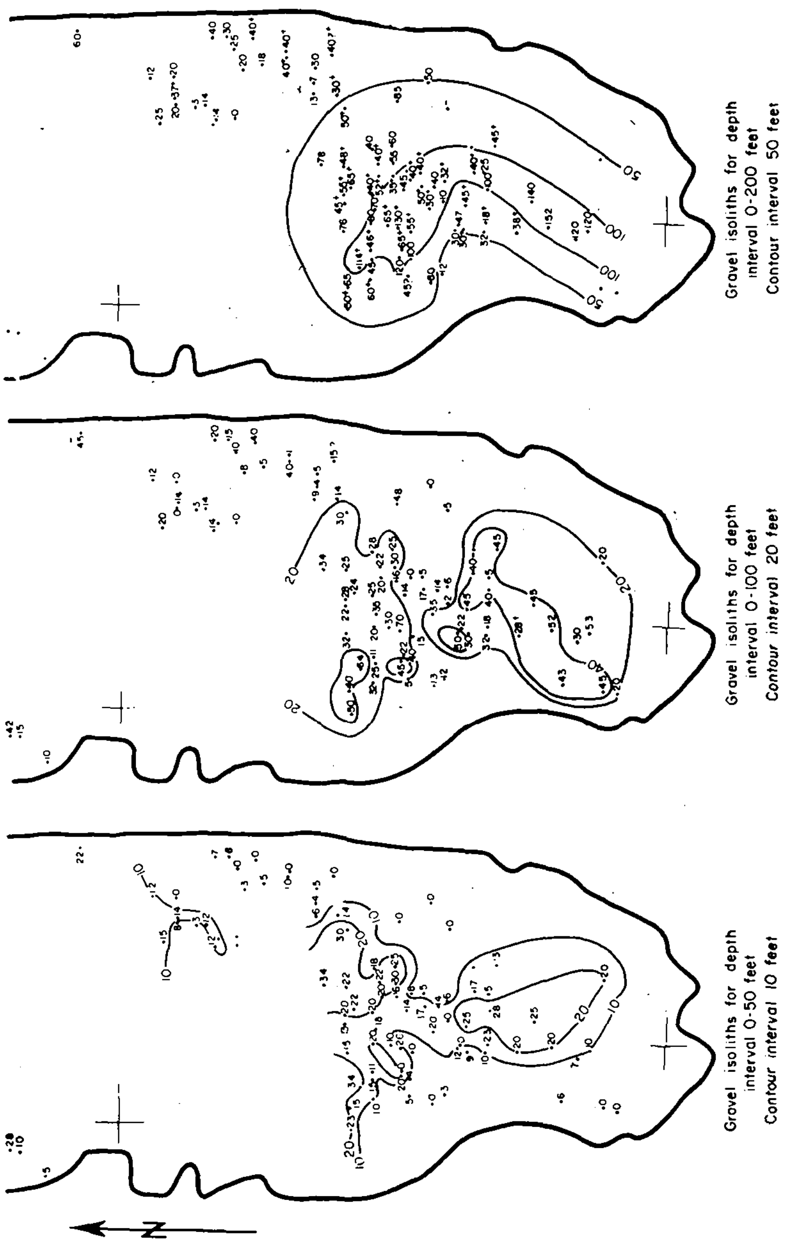

Fig. 8 — Gravel Isoliths of the Upper 200 feet of Valley Fill Deposits in Diamond Valley.

Walton and Csallany, 1962). 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) conducted a pumping test at Battle Mountain and determined that the storage coefficient was 0.0025. For a short-term pumping test in an aquifer which is neither truly water table or artesian, 1×10^{-2} seems to be a reasonable value for the storage coefficient. If the assumption is 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 drillers' log to obtain the coefficient of permeability of the gravel. Admittedly this procedure involves all the assumptions necessary to apply pumping-test theory as well as the, assumption that the gravel is the most significant aquifer unit in the well; however an index value in the right order of magnitude is obtained.

The errors involved are such that the coefficient of transmissibility interpreted from the specific capacity-transmissibility relationship (Fig. 9) would probably tend to be low. 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 partly compensated for if the well has a large effective radius. The effective well radius is probably greater for most of these wells than the 9-inch radius that was assumed in computing Fig. 9 because normal drilling and testing procedures cause well development.

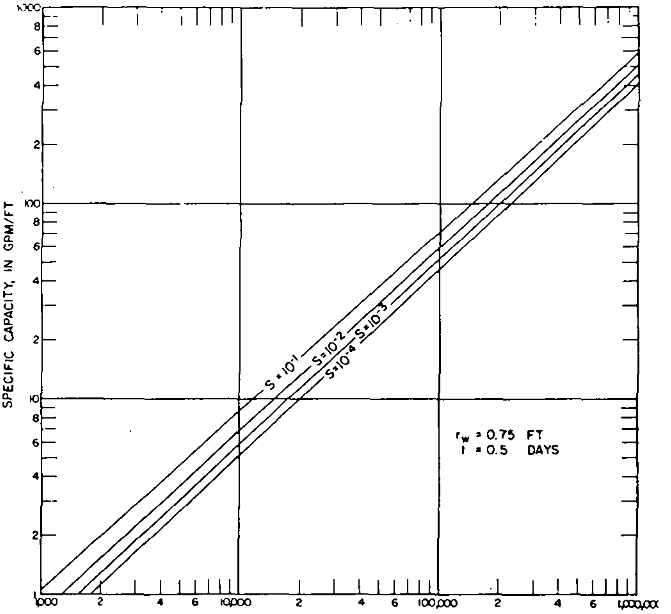

Fig. 9 — Theoretical Relationship Between Specific Capacity and Transmissibility.

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 aquifers. A tabulation of the data is presented in Table 2. The results are shown graphically in Fig. 10 with the log of the coefficient of permeability plotted against the percent of the number of wells on normal distribution paper. Except for one anomalous point, the data approximate a statistically log normal distribution. 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 gallons per minute per foot of drawdown is particularly outstanding. This well was drilled for irrigation in the middle Reese River Valley near the mouth of a tributary valley. As Table 2 indicates the theoretical value of the coefficient of transmissibility interpreted from the specific capacity is 410,000 gallons per day per foot of aquifer although it is reportedly producing from only 50 feet of gravel. The well appears to be anomalous, and therefore was not considered in drawing the line of best fit on Fig. 10.

TABLE 2

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	1120	Reese River Valley
65	110,000	88	1250	Reese River Valley
90	156,000	115	1360	Reese River Valley
46	76,000	49	1550	Reese River Valley
111	191,000	99	1930	Reese River Valley
225	410,000	50	8200	Reese River Valley

It is possible to predict coefficients of transmissibility by using the average coefficient of permeability data together with the gravel isoliths. The gravel thickness interpreted from the isolith map is multiplied by the average permeability to obtain the estimated transmissibility of the interval in question. This is, of course, only an average value; however, it affords a quantitative means of estimating the order of magnitude of the coefficient of transmissibility. This is of importance in evaluating areas of

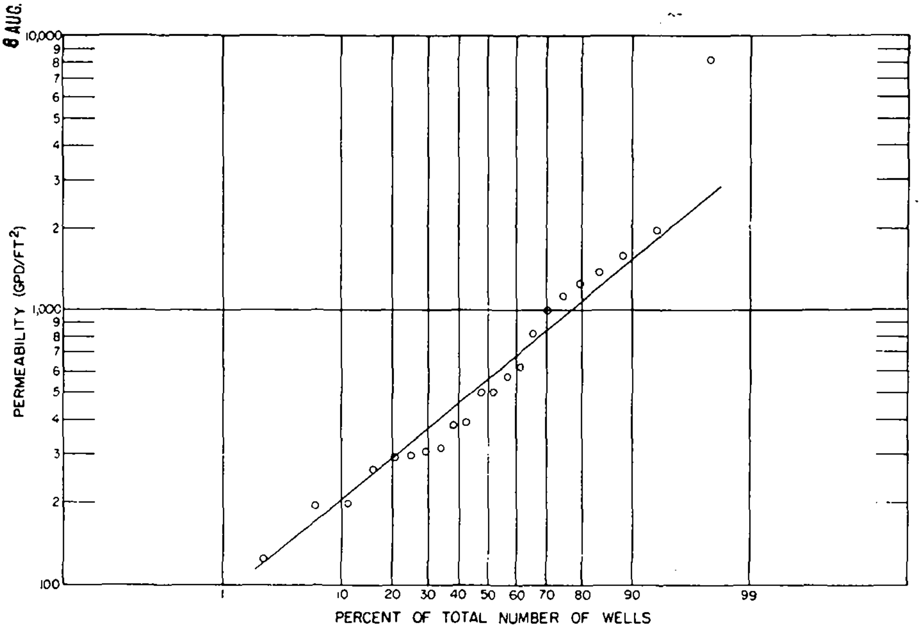

Fig. 10 — Graph of Permeability of Stream Associated Gravel Versus Percent of the Total Number of Wells.

proposed development. For example, the value of such an estimate is apparent in connection with a project under consideration in Boulder Valley using the groundwater reservoir conjunctively with the Humboldt River. The estimated transmissibility as interpreted from the average value and the isolith map 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.

7. Conclusions

Lithofacies maps were compiled from the drillers' logs for several valleys to investigate the distribution of the aquifers. Extensive gravel deposits are associated with the major streams, and were probably deposited during an earlier period of pluvial climate.

Three conditions are necessary fot the deposition of extensive gravel deposits : (1) a major stream of large volume must have been present, (2) there must have been a suitable area for deposition, and (3) there must be a favorable source of coarse clastic material. Exploration and development of the best aquifers should be guided by the relationship of the aquifers to the major drainage basins.

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

If analyzed properly, drillers' data are shown to be useful for interpreting the hydraulic characteristics of aquifers. Both the lithologic and hydrologic data appear to be consistent as well as reliable when interpreted by statistical methods.

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