SUBSURFACE STRATIGRAPHY AND HYDROLOGY OF THE RILLITO CREEK-TANQUE VERDE WASH AREA, TUCSON, ARIZONA

by

Robert Streitz

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1962

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in The University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in their judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Robert Streitz

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

John W. Harshbarger
J. W. HARSHBARGER
Professor of Geology

May 3, 1962
Date

SUBSURFACE STRATIGRAPHY AND HYDROLOGY
OF THE RILLITO CREEK-TANQUE VERDE
WASH AREA, TUCSON, ARIZONA

by

Robert Streitz

ABSTRACT

The Rillito Creek-Tanque Verde Wash area is divided into two physiographic and hydrologic areas by Rillito Creek. The northern or Catalina Foothills area is a dissected pediment composed of Pliocene(?) red beds which are relatively impermeable. South of Rillito Creek is an area of moderately permeable valley-fill deposits of Tertiary-Quaternary(?) age.

These valley-fill deposits contain the major water supply for the City of Tucson. Because of the depletion of this reservoir, interest in its geologic and hydrologic nature is demanding more attention.

It was found that generalized stratigraphic sections may be made from water-well drillers' logs by grouping logs of somewhat similar appearance into composite logs from which correlations may be made. Well cuttings, when secured and handled carefully, provide

much more useful data than well logs alone. Samples of this type give an indication of the porosity, permeability, petrology, and depositional environment of the sedimentary units represented.

The thickness of the valley-fill sediments is as yet undetermined; the specific yield of the area is not known and can only be estimated with the incomplete data. The fine-grained character of the subsurface sediments and the large demand for water somewhat account for the rapidly declining water table.

Surface runoff accounts for a large percentage of the total amount of water leaving the Tucson basin. Because of evaporation, a large part of this surface water is lost from any beneficial use. The future water-supply problem may be somewhat alleviated if this runoff water is injected into the subsurface reservoir as artificial recharge.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF PLATES

Plate | Page

INTRODUCTION

Statement of Problem

The investigation was instigated to determine the use of water-well drillers' logs in the stratigraphic examination of valley-fill deposits. Such a study was deemed of great importance because of the large quantity of raw data available—drillers' logs—and the absence of detailed information of the local stratigraphic conditions.

A better understanding of the local subsurface stratigraphy, and its influence on the movement of ground water would be of great importance in gaining more efficient use of the water-supply reservoir for the City of Tucson.

The purpose of this study, then, is to describe the subsurface stratigraphy of part of the Tucson basin, using drillers' logs and well cuttings, and correlate this information with the observed ground-water reservoir characteristics.

Location and Physical Setting

The area under discussion lies within the Basin and Range province of southern Arizona and includes most of the eastern half of the City of Tucson (population 255,000). This area (Fig. 1) is in the

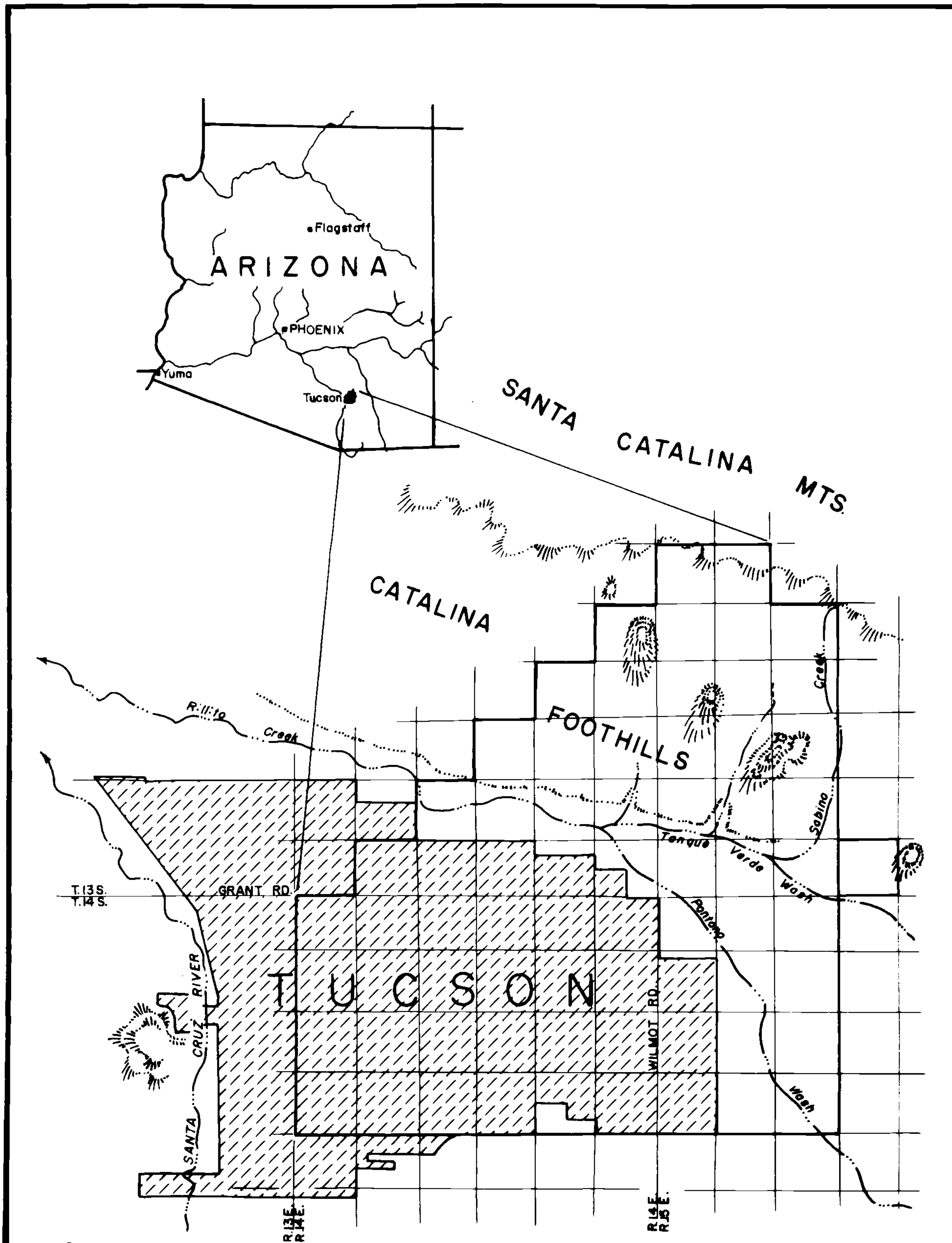


Figure 1. Index map of the Rillito Creek-Tanque Verde Wash area.

north-central part of the Tucson basin, and ranges in altitude from 2,400 feet to 3,200 feet above mean sea level.

The legal land description of the area covers secs. 12-14, 22-28, 32-36, T. 13 S., R. 14 E.; secs. 5-9, 16-21, 28-34, T. 13 S., R. 15 E.; secs. 1-24, T. 14 S., R. 14 E.; and secs. 4-9, 16-21, 29, 30, T. 14 S., R. 15 E.

The two main topographic divisions of the area are (1) the sharply dissected Catalina Foothills pediment to the north, and (2) the broad alluvial fan (distributary system) of Pantano Wash to the south. The north bank of Rillito Creek separates these two divisions. The surface slope, in the basin center, is about 25 feet per mile to the west and northwest. The Catalina Foothills surface generally slopes about 100 feet per mile to the southwest.

Economic Significance

The future demands for water in the Southwest, and Tucson in particular, will increase manyfold because of the exploding population in this region and the additional requirements for industry and recreation.

At the present time, water for industry and municipal use is supplied entirely from subsurface alluvial aquifers. The alluvial reservoir which lies directly beneath the City of Tucson is being depleted rapidly and there has been very little replenishment in recent years.

The lack of information concerning the nature of the material constituting this reservoir has, in the past, retarded efficient development and has led to misconceptions about the local hydrologic system. Kidwai (1957) made a local study of the stratigraphic make-up of the valley and compared earlier theories of the subsurface conditions with more modern concepts.

In future years, additional water could be captured by the City of Tucson through a system of artificial recharge of water now being wasted by surface runoff and evaporation. It will be possible to extend the life of the present reservoir system and maintain pumping levels of shallow depths with the adoption of such conservation practices.

Previous Work

Hydrologic investigations similar to this study, in part, were carried out by G. E. P. Smith (1910, 1938) and Schwalen and Shaw (1957). Kidwai (1957) described the valley-fill as an "alluvial complex." Subsurface units were correlated in a general way, with surface outcrops in the Tucson Mountains by Coulson (1950). The Catalina Foothills area was studied by Blissenbach (1951) and Voelger (1953). Turner described hydrologic conditions of the Tucson area (1943, 1947). Subsurface geology of the area immediately northwest and joining the area of this study was described by Maddox (1960).

In June of 1959 the Rillito Creek Hydrologic Research

Committee of the University of Arizona and the U. S. Geological Survey, published a comprehensive report entitled Capturing Additional Water in the Tucson Area.

Acknowledgments

The writer hereby wishes to express his gratitude to Dr. J. W. Harshbarger whose suggestions were of great help in organizing this study. Many thanks are also in order to Dr. J. F. Lance, Professor H. C. Schwalen, and Mr. Richard Shaw whose patience and assistance are greatly appreciated. The numerous helpful suggestions made by members of the Geology Department and personal friends are also herewith acknowledged. Financial aid by the U. S. Geological Survey enabled the writer to give additional time to the completion of this study, and I am sincerely grateful for this assistance.

REGIONAL GEOHYDROLOGY

General Geology

The rocks found in the Tucson basin, 30 miles long and 15 miles wide, may be divided in general into four types: (1) granite, gneiss and schist, and well-indurated pre-Tertiary sediments; (2) Tertiary sediments and volcanics; (3) Tertiary-Quaternary valley-fill; and (4) Recent fluviatile deposits.

The folded and foliated banded gneiss, schist, and granitic intrusive rocks occur to the north and east of the basin. They make up the bulk of the Santa Catalina and Rincon Mountains. On the lower slopes of these ranges are outcrops of faulted Tertiary strata. These sedimentary units are commonly referred to as the Rillito Formation (Voelger, 1953) in the Catalina Foothills area, the Pantano beds (Brennen, 1957) in the Cienega Gap and Rincon areas, and the Mineta beds (Chew, 1952) on the eastern slope of the Santa Catalina Mountains. These rocks outcrop over a large area in the Cienega Creek region to the east of the basin and everywhere exhibit much faulting and tilting.

To the southeast and south lie the Santa Rita Mountains composed of intrusive and extrusive igneous rocks, Paleozoic and Mesozoic sediments, and Tertiary sediments at lower elevations. Southwest of the Santa Cruz River, classic pediment surfaces are cut on intrusive and extrusive igneous rocks and Cretaceous sediments. Outcrops forming the very rugged skyline west of the basin are rhyolite plugs, volcanic flows, and Cretaceous limestone and arkose.

To the west and northwest of the Tucson basin lie the Tucson Mountains, a low range consisting mostly of Permian limestone; Cretaceous limestone, arkose, and "red beds;" Tertiary intrusive and extrusive igneous rocks and an alluvial chaos. Quaternary gravels are found in the Tucson Mountains as well as covering most of the pediments.

The Tucson basin is filled with Tertiary and Quaternary alluvial materials, including possibly lake beds similar to those found in adjoining valleys.

Tertiary stratigraphy. --Tertiary strata in the Tucson basin are represented by non-marine clastic units ranging from claystone to very coarse conglomerate. They commonly are dark red or brown in color, and frequently referred to as "Pantano beds." These units were named by Brennen in 1957 when he mapped them in the Cienega Creek area. Voelger (1953) made a detailed study of similar units north of Rillito Creek; these units he called the Rillito Formation. In his study, Voelger was able to identify three separate members of the Rillito Formation and the Recent alluvium on the basis of pebble counts. These members, together with their constituent percentages, are given below:

	Percent
Recent Alluvium	
Gneiss	75
Schist	19
Quartz	5
Upper Rillito	
Gneiss	28
Schist	21
Quartz	14
Volcanics	32
Granite	5
Middle Rillito	
Gneiss	21
Schist	21
Quartz	15
Volcanics	27
Granite	10
Limestone	6
Lower Rillito	
Gneiss	0
Schist	24
Quartz	28
Volcanics	20
Granite	39
Limestone	6

Brennen (1957) estimated the total thickness of the Pantano beds to be at least 8,000 feet in the Benson Pass area. Tectonic activity subsequent to induration of the Pantano beds has resulted in block faulting, with the intervening blocks tilted at high angles. Thrusting has also added to the complexity of these beds, in that the gneiss and Paleozoic limestone have been thrust on top of them in one place and they have been thrust over gneiss in another (Moore, *et al.*, 1932).

From Voelger's work (1953) and field observations in the Santa Catalina and Rincon Foothills it may be concluded that the lower member of the Rillito Formation was deposited in an environment somewhat different from the one that exists in the area today.

Lying above the Tertiary units and between the present stream channels are the Tucson basin deposits or older alluvium. This sequence of sand, silt, gravel, and clay is described by Kidwai (1957) as an "alluvial complex." From field examinations it is considered to have been derived from the adjoining mountain masses. This material is generally believed to have been deposited in an alluvial flood plain, and the silt and clay representing periods of relative quiescence.

The more permeable units in the Tucson basin are the present-day stream channel deposits, or Inner Valley fill. This unit of sand and gravel, and minor amounts of clay, ranges in thickness from a few feet to 100 feet or more. Because these units receive natural recharge during periods of runoff, they are the most efficient aquifers in the area and have been used for many years with relatively good success.

General Hydrology

Generally two rainy seasons occur in the Tucson area annually—one in mid-summer and the other in mid-winter. Typical of most arid and semiarid regions, the precipitation intensity varies widely from year to year, and from area to area.

The summer thundershower activity, though intense, is usually sporadic in areal coverage and intermittent in duration. Nonetheless, it accounts for more than 50 percent of the total annual precipitation. This summer-shower activity is caused by local turbulence and moist air moving in from the southeast (Gulf of Mexico) and the southwest.

The mid-winter storms, which may persist for several days and are more general in areal coverage, usually arise in the Pacific Ocean area and approach the Tucson area from the northwest, west, or southwest.

The average annual rainfall ranges from about 10 inches at the lower elevations of the Tucson basin to about 34 inches in the upper reaches of the Santa Catalina Mountains. Schwalen (1942) estimates the total annual precipitation in the catchment area, some 2,240 square miles, to be on the order of 1,800,000 acre-feet.

The major drainage system in the Tucson basin is the Santa Cruz River and its tributaries. This river begins in the San Raphael Valley and flows south into Mexico for 35 miles and re-enters the United States at Nogales, from where it flows north-northwest through Tucson to join the Gila River 10 miles southwest of Phoenix. Rillito Creek-Tanque Verde Wash and Pantano Wash drain the eastern and northern sides of the basin and comprise the only other important stream systems in the area.

There is intermittent streamflow in these drainages following prolonged periods of precipitation and after thunderstorms causing flash floods. The average annual discharge of the Santa Cruz River at Tucson as measured from 1906 to 1954 is 15, 560 acre-feet, while the average annual discharge of Rillito Creek as measured at U. S. Highway 80 from 1909 to 1954 is 12, 950 acre-feet (Schwalen and Shaw, 1957).

The chief cause of water loss from the Tucson basin is by evapotranspiration. The annual potential evaporation rate for the City of Tucson is approximately 90 inches, or about 10 times the rainfall. The greatest rate of evaporation occurs in June, whereas the rate is at its lowest point in January and February. Agricultural endeavors represent the largest consumption of water, using a minimum of 3.0 acre-feet per year per irrigated acre.

It was estimated (Schwalen and Shaw, 1957) that in 1956, 210, 000 people in the Tucson area used 41, 000 acre-feet for domestic purposes, or approximately 175 gallons per capita per day.

Ground-water withdrawal pattern. --Water-table maps depicting the withdrawal pattern of the Tucson basin have been compiled annually for many years by the Agricultural Engineering Department of the University of Arizona. These maps, with the exception of the very earliest, show a general depression centered about the center of the city and extending from Jaynes on the north to the southern limits of the city on the south. This depression is surrounded on three sides by a steepening of the free-water surface and is caused by (1) local permeability variations, (2) increased pumping rates, and (3) the lack of appreciable recharge.

The lack of contour lines (Fig. 2) in the Catalina Foothills area denotes the absence of a single continuous free-water surface and/or a paucity of well data. In either case, the impermeable nature of these sediments generally makes them ineffective as productive aquifers.

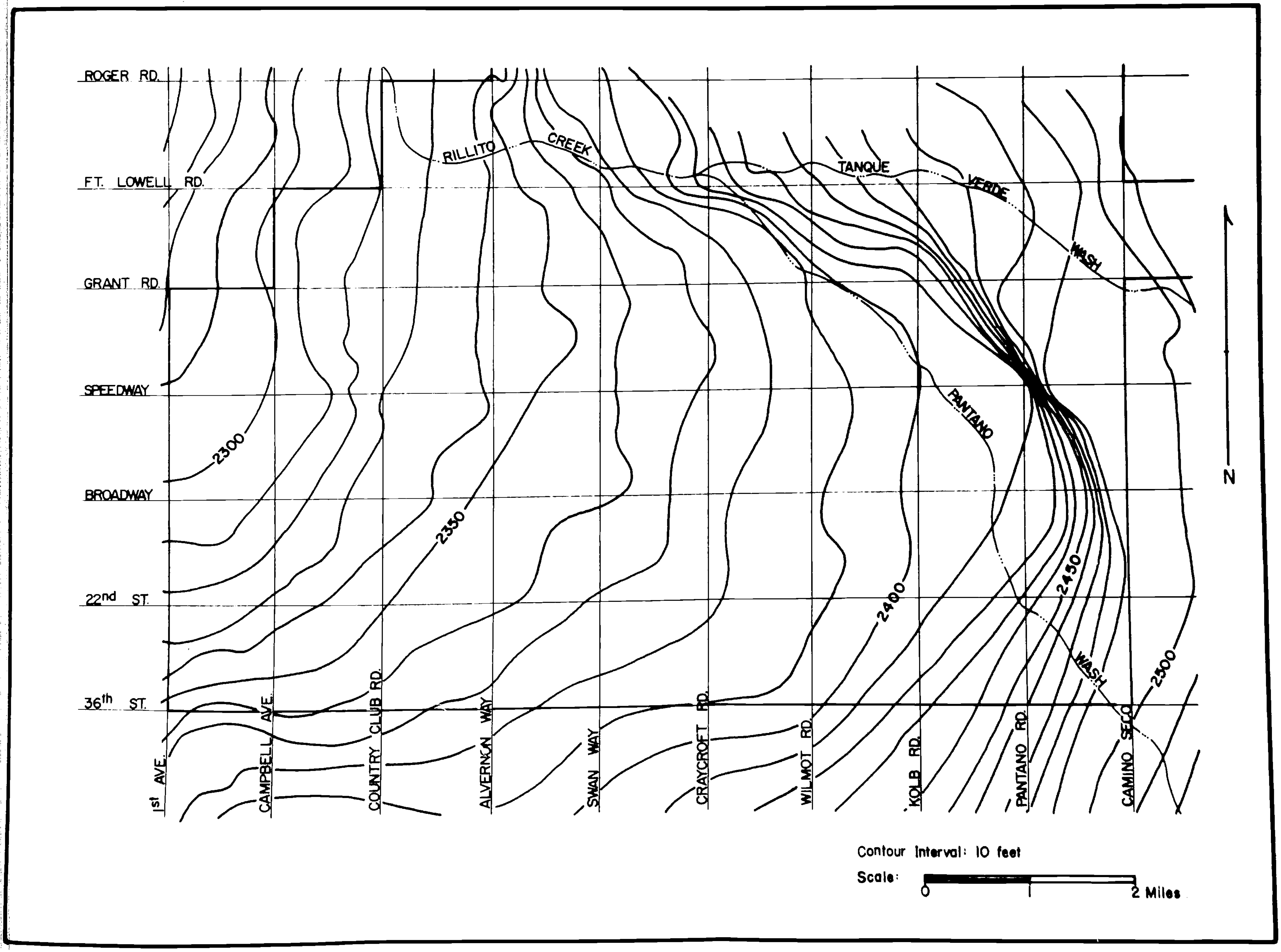


Figure 2. Water table map of the northeastern part of the Tucson basin for 1959. (Data obtained from the Agricultural Engineering Department, University of Arizona.)

METHODOLOGY

General Statement

The difficult problem of obtaining reasonably accurate knowledge of the subsurface stratigraphy of the Tucson basin has long been realized. In this study techniques of approach similar to the ones used by Kidwai (1957) and Coulson (1950), as previously described, were employed. Drillers' logs and well cuttings are the chief sources of lithologic data used. Drillers' logs of wells are abundant for the northern part of the basin, and therefore are expediently used in the investigation of the Rillito Creek-Tanque Verde Wash area.

Because of the drillers' casual method of recording, water-well logs have long been considered to be of doubtful validity in terms of stratigraphic correlations. Methods of applying standard procedures to stratigraphic correlations using drillers' logs, and resolving this information in the form of a conventional solution presented the greatest problem of this investigation.

From the standpoint of scientific examination, some types of well cuttings, just as some types of drillers' logs, leave much to be desired. Standardization of sampling procedures, accurate designation and marking of samples, and subsequent careful and conscientious handling of samples would alleviate some of the difficulties encountered in laboratory analysis.

Hydrologic data was confined to the areas where there are water-table maps, several selected specific well-yield values, and available publications. After a simplified picture of the subsurface stratigraphy was achieved, it was combined with appropriate hydrologic information to reveal local ground-water conditions—the most significant economic aspect of the investigation.

Drillers' Logs

Recording methods.--The drilling of water wells in the Tucson basin has been done chiefly by the cable-tool method. Generally there are many loose boulders and not enough clay in the local sediments to provide optimum conditions for rotary-drilling methods. Rotary methods are not used primarily because they involve the use of drilling muds which tend to seal off the well from water-bearing units penetrated. Rectifying procedures in the final development of the well are an added and unnecessary expense when compared with the cable-tool method.

Logging of the materials encountered by drilling is generally done by the driller as the borehole progresses. Drillers are usually able to determine the type of material penetrated by the rate of drilling progress, the amount of water entering the hole, the snap of the cable, and other criteria gained from many years of experience by the driller.

They also rely to a great degree upon the cuttings removed by the bailer.

The location of wells is usually recorded according to the section, township, and range; however, a few wells are located by metes and bounds, or street numbers. Occasionally the same well log may have two different locations, and two different logs given the same location, owing to careless documentation.

In a given area one driller may record a very detailed log with units as small as 4 or 5 feet in thickness, whereas, another driller may record only the major units or rock types. These differences in log types may be the result of different attitudes of the driller toward logging, insufficient time available for detailed logging, inability to recognize changes in rock type, or just simply a failure to appreciate the value of a complete file of detailed logs. Those drillers, who have not differentiated each lithologic change, envision the Tucson basin as being filled with sand, gravel, and clay, with greater or lesser amounts of each. Variations in cable-tool drilling rates, which vary from about 4 or 5 inches to approximately 30 feet per day, may also tend to influence logging practices.

Distribution and depth of wells.--The distribution of wells in the southern part of the area is, generally, rather uniform. Along Rillito Creek they are slightly more numerous, and in the Catalina

Foothills they are rather sparse where they are largely confined to the washes and creek beds (Fig. 3).

The depths of wells in this area range from about 100 to about 600 feet. In the foothills area, wells average about 400 feet in depth and commonly produce water of poor quality. Along Rillito Creek wells are about 100 feet deep but are deeper to the south. At the southern edge of the area studied (about 6 miles from Rillito Creek) wells average 500 to 600 feet, with a few as much as 800 feet in depth.

Construction of fence diagram. --Sedimentary units or individual beds are seldom traceable over an area greater than a square mile. In these small areas the units in most of the wells seemed to correlate rather well. This arrangement indicates the fabric of the basin fill as being composed of a number of sedimentary "blocks" seldom over a mile in area and precisely different from adjoining blocks. Generalized lithologic sections were made for each of the blocks by grouping the similar units into zones of approximately the same rock type and depth. These "composite" logs were placed in the center of their respective blocks and the generalized fence diagram was constructed (Pl. I). By using this method, fewer well logs were discarded because of lack of continuity; even so, a few logs had no apparent connection with the local stratigraphic section.

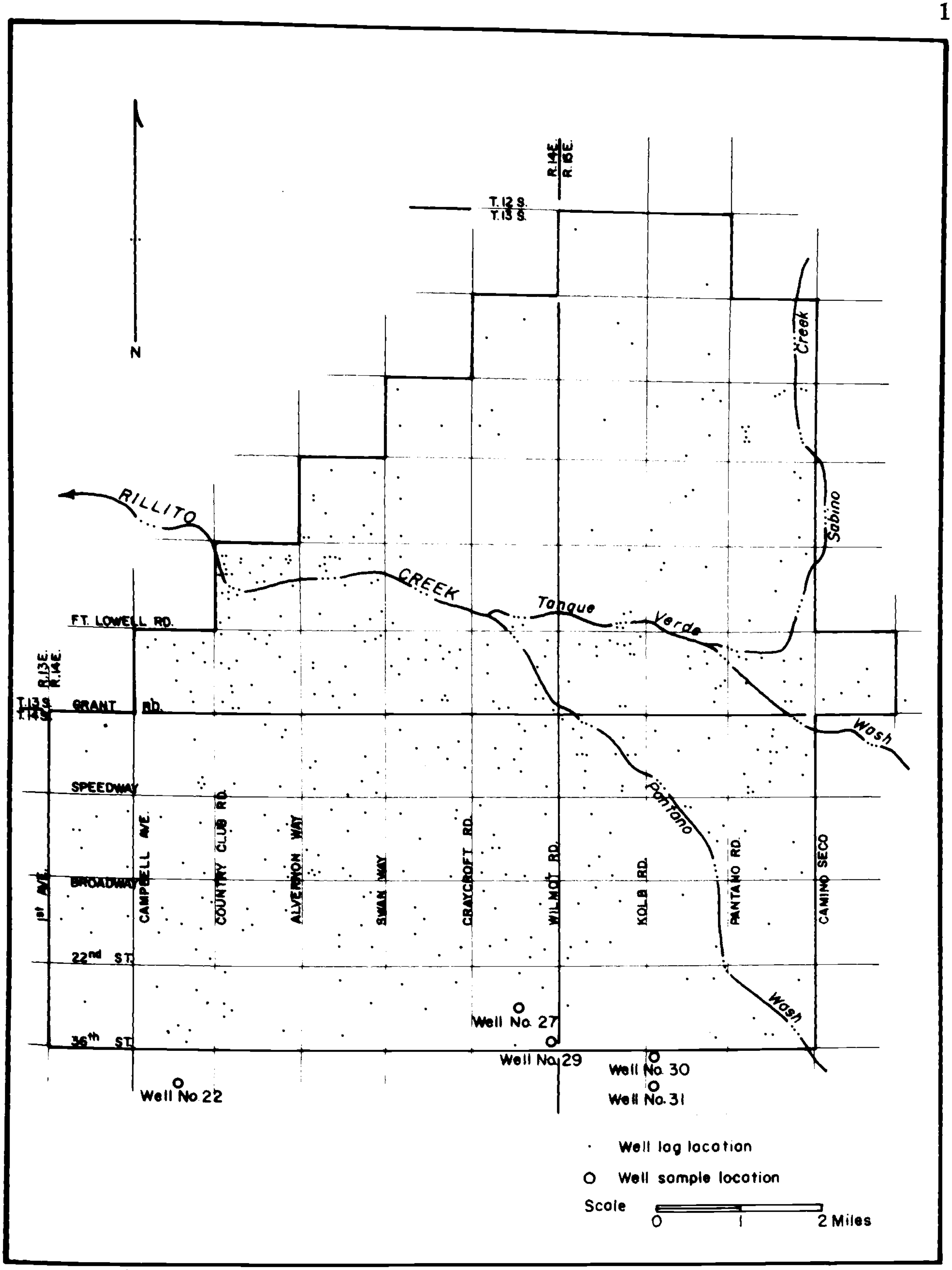


Figure 3. Map showing location of wells having drillers' logs and rock samples.

Well Samples

General statement.--As the particle size is of major importance for the movement of water through clastic rocks, it was deemed valuable to examine the available well cuttings from the standpoint of size distribution as well as petrologically. From the 22 wells having samples in storage at the University of Arizona, College of Agriculture, five were found to be located close to the area of this study and consequently chosen for detailed examination. The location of these wells is shown in Figure 3.

It was found that sampling techniques vary widely when left to the discretion of the drillers. Some prefer to sample the first bail of material that is removed from the borehole after a period of drilling, whereas others prefer the last bail, and some take samples at any time. All of the samples examined in this study were collected in 1-quart oil cans by unknown persons, and frequently were found to be contaminated by various and sundry articles.

The size analysis was made using Tyler standard screen sieves and a Tyler Ro-Tap mechanical shaker. The fine fractions of $< 4\ \phi$ (silt and clay) were separated by wet sieving and discarded after their percentage of total sample was determined. Cumulative curves were drawn from the data obtained by the sieving procedure and the median diameter (Mdϕ) was determined.

Descriptive sections are reproduced in Figure 4 using drillers' logs, and in Figure 5 using the Wentworth grade scale. Correlations made on this data seem valid; however, the true size ranges of the undisturbed sedimentary units involved are not implied.

The drilling procedure itself usually modifies the sample by reducing the size of large fragments to smaller particles. This modification generally precludes using the sedimentary parameter of particle shape, because nearly all of the well-represented fractions were angular to a greater or lesser degree. Roundness may be measured on those particles which have not been fractured; however, those particles showing greatest roundness were invariably the largest, and are herewith considered to represent caving from higher in the hole. This is not meant to exclude the validity of readily discernible bimodal curves.

The statistical parameters, such as median size, of each sample were considered to be somewhat altered by the drilling procedure. Correspondingly, some original relative values of these parameters were retained. Because each set of samples (single wells) was modified in the same general way, it is believed a more valid comparison can be made by contrasting relative parameter values of each set, rather than the absolute (numerical) values of the sample parameters. Therefore, it must be remembered that the resultant parameter curves obtained and shown in the figure describing these data are not those of the sedimentary units per se, but rather are curves of definite parameters of

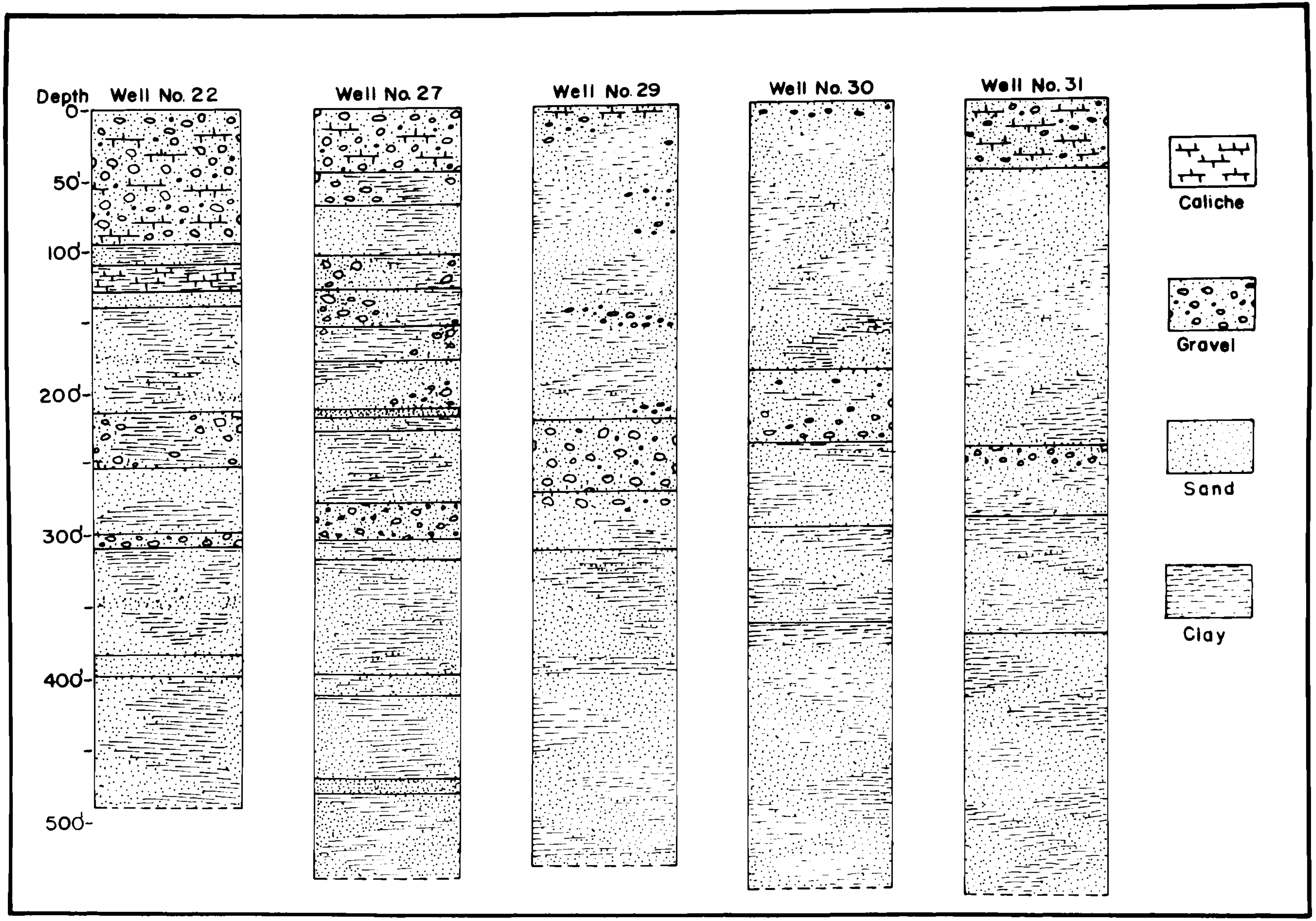


Figure 4. Typical columnar sections compiled from driller's logs.

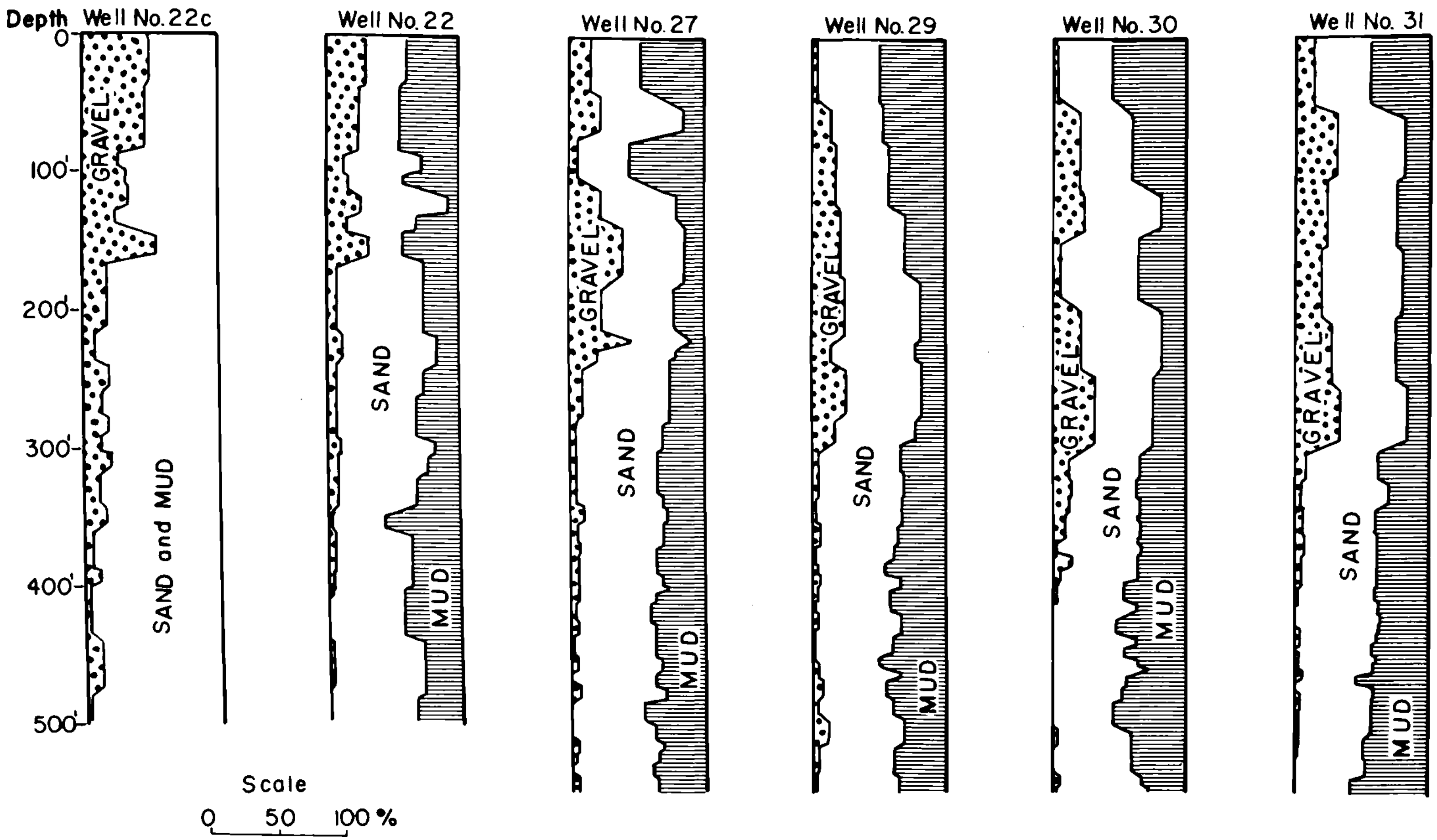


Figure 5. Variation of grain size as determined from well sample data.

modified sediments.

Following the mechanical analysis, cursory microscopic examinations of the samples were made to reveal any significant mineralogic changes encountered in the drilling of the individual wells. In addition, a detailed examination of the samples from Well No. 22 was made in order to compare petrologic differences of the two types: those washed by the driller at the well site, and of which only the coarse fractions remain (Well No. 22c, Fig. 5), and those representing all of the material penetrated (Well No. 22, Fig. 5). The major petrologic difference found in the comparison of washed and unwashed samples was the frequent loss of most of the micas—usually muscovite—in the washed samples. Other differences, besides the obvious loss of most of the clay- and silt-size particles, included slightly more garnet and magnetite and a few less "clay" cemented aggregates in the washed samples.

In the microscopic examination, it was found that gneiss fragments were common in all samples from each well. This would indicate that the wells examined penetrated only the upper member of the Rillito Formation and/or Recent alluvium (Voelger, 1953). Most of the samples were composed of quartz, feldspar, and gneissic fragments with very minor amounts of magnetite, mica, garnet, schist, and volcanic rocks. All of the wells except No. 22 contained only trace amounts of volcanics, whereas, Well No. 22 had up to 10 percent volcanics in some intervals and commonly 1 percent or more in each interval.

Mechanical analysis.--The particle size of the samples examined was classified according to the Wentworth grade scale and converted to the phi scale, where phi (ø) is the negative logarithm of the diameter in millimeters to the base two (Krumbein and Pettijohn, 1938).

Median diameter (Mdø) is plotted against depth in Figure 6, which shows a general decrease in median diameter with depth in all wells. Well No. 31 shows a gradual coarsening to about 300 feet where a large increase toward the finer values is seen; from 300 to 550 feet the median diameter consistently decreases. In general, the other wells show somewhat similar trends with occasional variations.

Figure 7 shows the samples plotted on Folk's (1954) triangular diagram for classifying mixtures of gravel, sand, and mud. In Figure 7, weighted values were used to compensate for the variance of the sampling intervals.

Summary.--Two subsurface units are recognized from the results of the mechanical analysis. In Well No. 31 an upper, coarse unit occurs at the surface to a depth of about 300 feet, and a lower fine unit in the remainder of the well. Figure 5 shows this change in size range explicitly in Wells Nos. 29, 30, and 31. In Well No. 22, this change in sediment size is found at 150 feet and in Well No. 27, it is found at 225 feet. From subsurface data, it is estimated that this

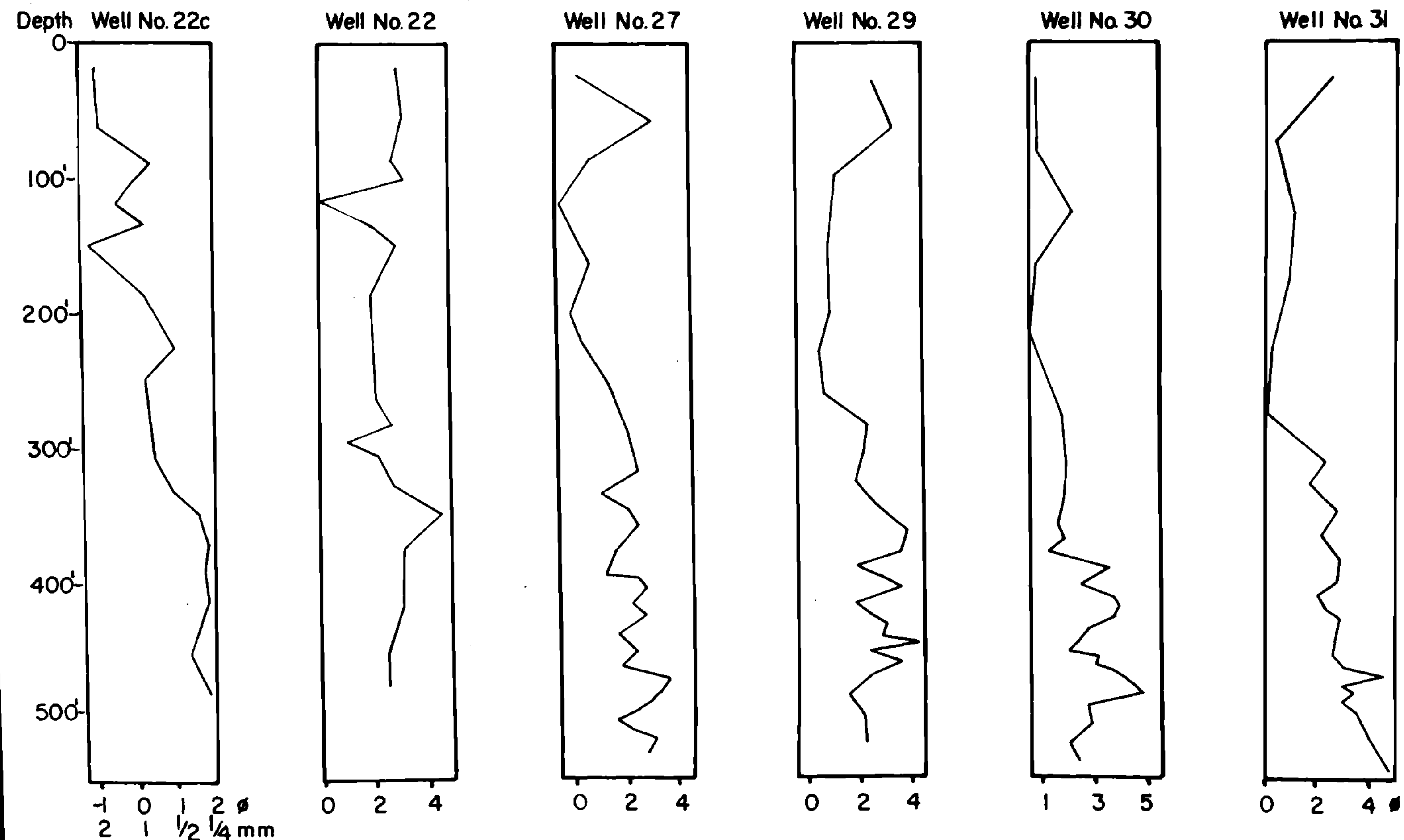


Figure 6. Median diameter (Mdø) variation of material from selected water wells.

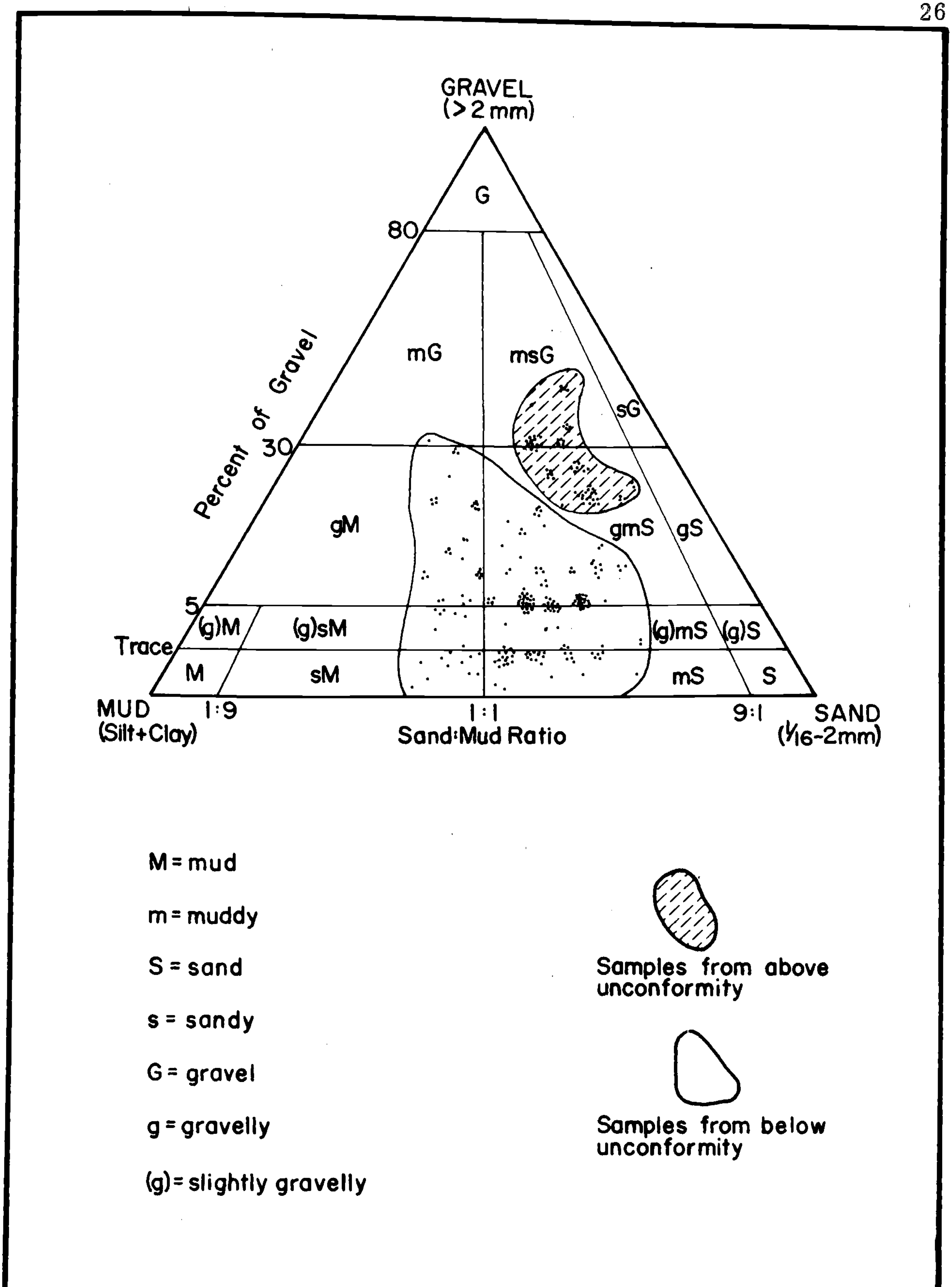


Figure 7. Ternary diagram of samples from selected water wells (after Folk, R.L., 1954).

unconformity slopes about 22 feet per mile to the northwest, whereas the land surface of these wells slopes about 50 feet per mile in the same direction. Sedimentary units above this unconformity lie nearly horizontal, and those below dip about 60 feet per mile to the west-northwest.

In Figure 7 samples occurring above and below the unconformity are indicated by their encircled fields. The sediments above the unconformity are coarser, falling in the muddy sandy gravel (msG) and gravelly muddy sand (gmS) textural groups. Sediments below the unconformity are finer and fall into the gravelly mud (gM), gravelly muddy sand (gmS), slightly muddy sand ((g)mS), muddy sand (mS), sandy mud (sM), slightly gravelly sandy mud ((g)sM), and muddy gravel (mG) textural groups.

The probable subsurface relationships resolved from well-sample data are shown in a schematic cross section (Fig. 8).

It must be remembered that the depth intervals shown on all columnar sections or depth curves obtained from sample data do not represent the thicknesses of sedimentary units but rather sampling intervals, and any calculations made from these values can give only very rough estimates of actual conditions.

Despite the many shortcomings of well samples and data thereby obtained, they remain far superior to well logs in the detailed resolution of subsurface conditions.

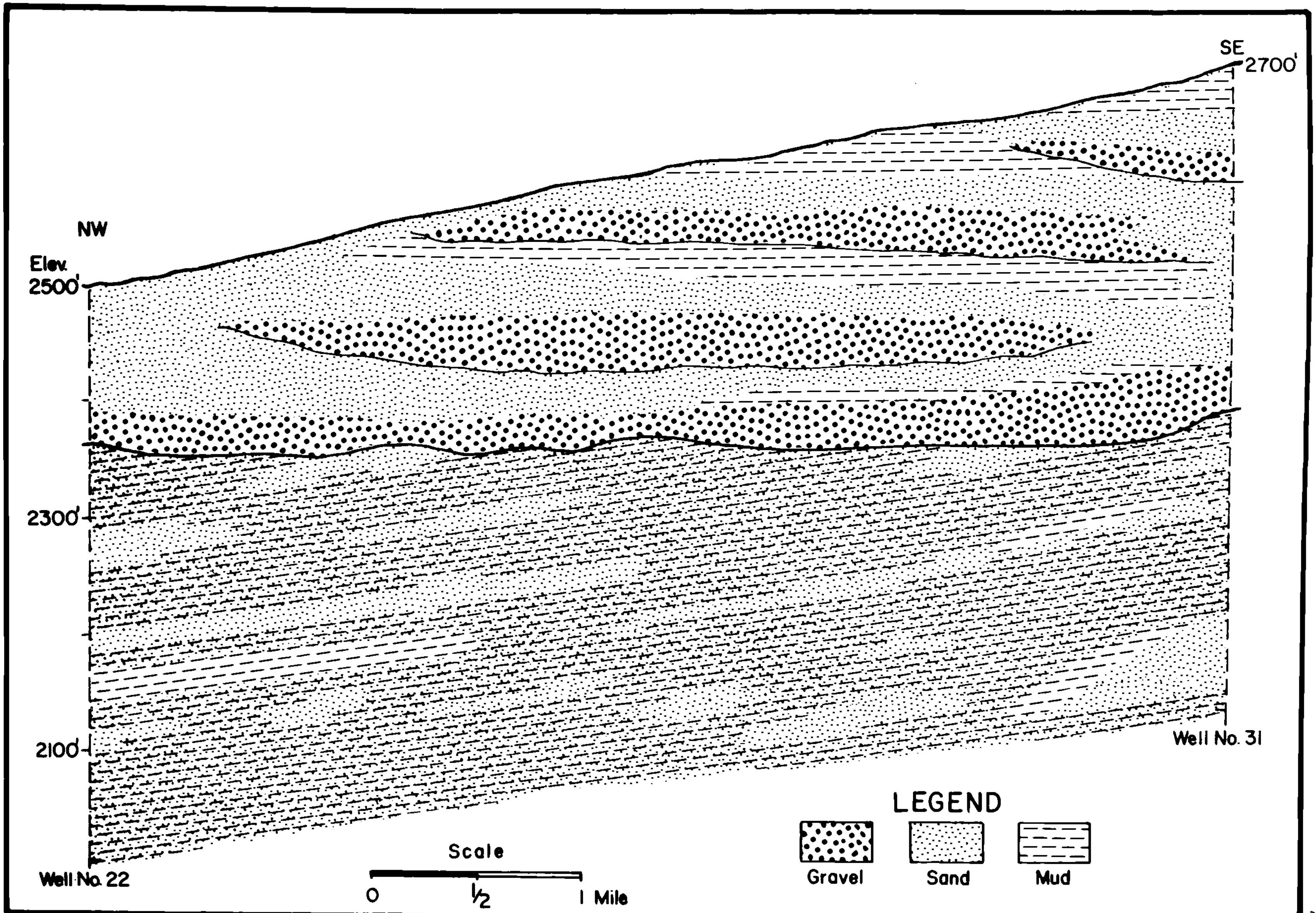


Figure 8. Diagramatic cross-section of the valley-fill derived from well sample data.

SUBSURFACE STRATIGRAPHY

General Statement

The sedimentary fill of the Tucson basin consists chiefly of clay, silt, sand, gravel, and conglomerate containing varying amounts of cementing material. Locally, calcium carbonate has cemented the otherwise loose surficial gravel, sand, silt, and clay into a very firm caliche caprock.

In the central part of the basin well logs disclose the sediments were derived from the surrounding mountain masses. These units are composed primarily of fragments of gneiss, schist, and some volcanic rocks. The wells of the Catalina Foothills area penetrate a detrital gneissic caprock, as well as the red silt, sand, clay, and conglomerate of the Pantano beds.

Plate I illustrates the probable relationships of the several sedimentary and structural units encountered. This fence diagram was compiled entirely from drillers' logs of water wells. A vertical scale 13.2 times that of the horizontal was employed to best show the essential features. Plate I is a highly simplified representation of a very complex stratigraphic sequence, and for the sake of clarity only the logs exhibiting the overall lithologic continuity are shown. In addition, rather large liberties were taken with drillers' terms in order to reduce the detailed logs to generalized sections and develop zones of similar hydrologic characteristics from them.

In several canyons in the foothills area, the contact between the Pantano beds and the capping gneissic detritus is well exposed. It was expected that by studying the well logs one could follow this upper contact of the Pantano beds from the foothills area into the central part of the basin. This was not possible because the wells were too shallow (100± feet) in the immediate vicinity of Rillito Creek, where the Pantano beds become obscured.

The abrupt disappearance of the Pantano beds near Rillito Creek and the straight alignment of the stream channel suggest the occurrence of a major fault in this area. Closely spaced faults in the Pantano beds are common and can be seen in nearly all exposures of this formation. Sedimentation subsequent to the truncation of the Pantano beds has continued in the central portion of the basin with only minor interruptions throughout the interval represented by well logs.

Based on a study of local outcrops, it is presumed that the actual sedimentary structure of the basin fill is one of superposed wedges and lenses conforming with stream conditions during deposition; not unlike the construction of an alluvial fan. The well-sorted deposits are believed to be the result of sustained streamflow in the particular area of occurrence; however, torrential deposits make up, by far, the larger part of the basin fill. Local faulting or rapid sedimentation or both is believed to account for the absence or marker beds, as none were observed to extend throughout the area. It may be true that the Pantano beds underlie Tucson and make up a large part of the basin fill, but because of erosion, faulting, and/or overlying cover, it cannot be shown from available data.

Lithologic Units and Correlations

The development of the broad zones of similar hydrologic properties from well-log data was done by grouping the various intervals representing similar properties into single units or zones. The nine broad zones shown in the fence diagram are: soil, caliche, clay, sand, gravel, sandy clay, gravelly clay, sand-and-gravel, and conglomerate.

The soil zone includes the true soils found in the area, as well as surficial sands, but does not include recent channel deposits or extend into the foothills area. This zone ranges in thickness from 1 to 20 feet and averages 7 feet.

The caliche zone generally lies just below the soil zone and ranges in thickness from 1 to about 100 feet. It is identified by interstitial calcium carbonate. The most common rock type is a cemented sand, gravel, or conglomerate. Figure 9 is an isopachous map of this caliche zone and may be significant in the study of local land subsidence, foundation design, storm-drain routing, or ground-water spreading

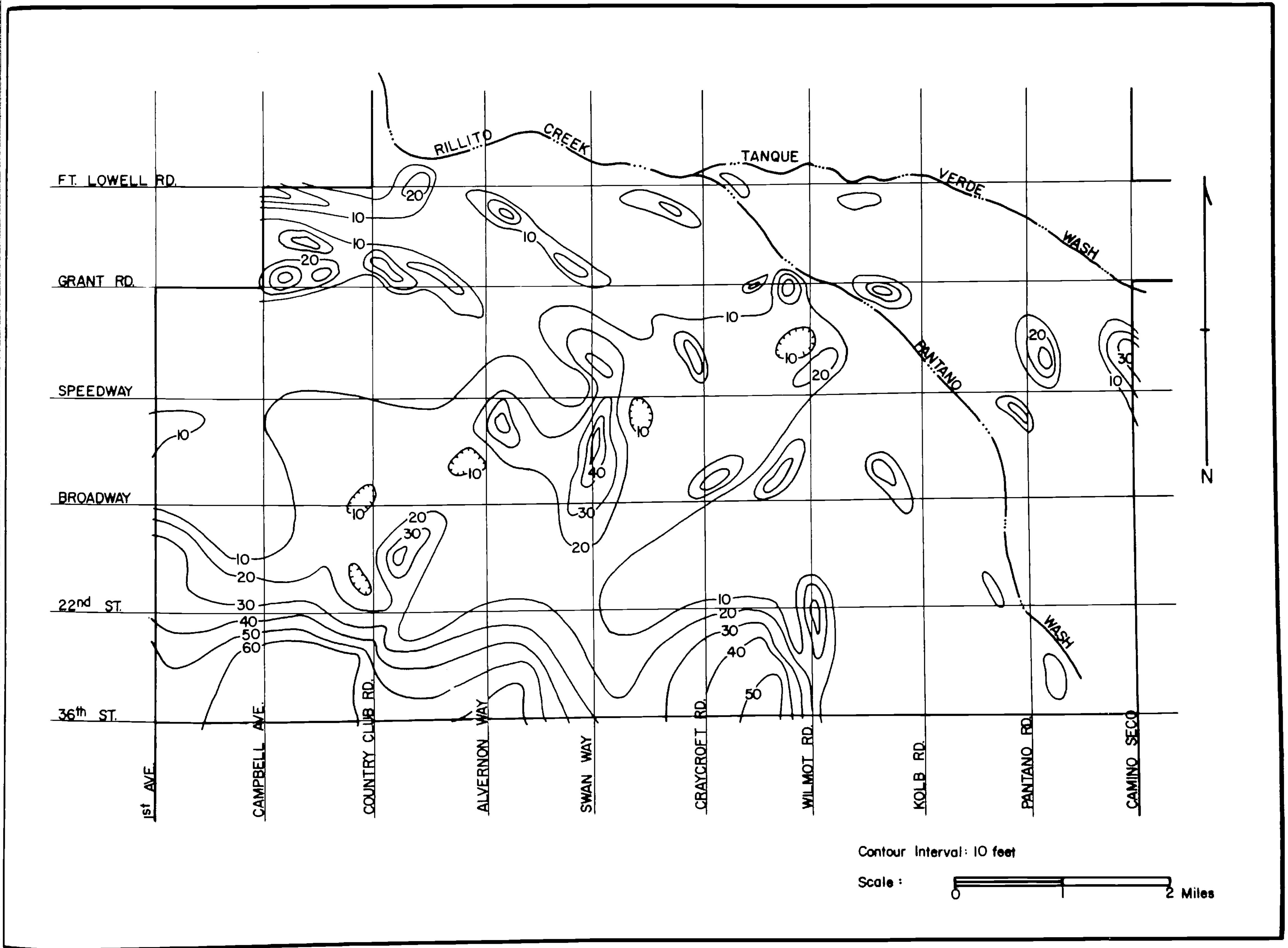


Figure 9. Isopachous map showing the distribution of caliche in the Rillito Creek-Tanque Verde Wash area.

areas. This zone was found to be thinnest in areas of surface drainage and to thicken southward from Rillito Creek. For the most part, wells in the foothills area are drilled in or near stream beds and therefore do not encounter the caliche in this area.

The sand, gravel, sand-and-gravel, clay and gravelly clay zones in general are not limited to specific areas or depths and are identified separately in Plate I.

The sand zones include the recent channel deposits, as well as the sand lenses at depth. Sand and silt are most abundant along the western edge of T. 14 S., R. 14 E., or west of Country Club Road, and between Speedway Boulevard and 22nd Street. Detrital sediments in this area are characteristically bedded in thicknesses ranging from 3 to 5 feet, which are rather thin for driller identification and description. They frequently alternate from red to white in color and vary radically in hardness or cementation. These units are about 100 feet below the surface and extend to more than 500 feet. Sand, comprising the Inner Valley fill or recent stream beds, averages about 65 feet in thickness and has narrow lateral extent in some areas but occurs over broad areas in other places.

The greatest total gravel section occurs beneath Country Club Road, between Ft. Lowell Road and Roger Road. This section is also part of the most persistent gravel zone encountered in the basin fill. It extends in a southeasterly direction through the central part of the area at about 2,350 feet above sea level. Other gravel zones are distributed randomly throughout the section.

The zones of sand-and-gravel are most persistent and best defined in the area between Ft. Lowell Road and Broadway, Country Club Road and Craycroft Road, and a short distance northwest and southeast of this area. This zone is encountered between 150 and 300 feet from the surface.

Clay zones were found throughout the section and include shale units where they appear to be correlative equivalents. The gray, white, and yellow clay were grouped together, while red and brown clay and shale, especially in the foothills area, were grouped with the Pantano beds. The areas of the thickest clay zones are found (1) beneath Grant Road between Wilmot Road and Craycroft Road, (2) at 22nd Street and Pantano Road, and (3) along 22nd Street between Campbell Avenue and Wilmot Road. These zones are approximately 30, 60, and 50 feet thick and lie 20, 100, and 150 feet below the surface, respectively.

Gravelly clay and sandy clay are found throughout the area south of Rillito Creek as the "fill" zones between the other, better defined zones. The sandy clay zone includes such drillers' terms as: sand-and-clay, muddy sand, clayey sand, clayey silt, silty clay, sandy shale, and shale.

The conglomerate zone includes materials designated by the drillers as conglomerate, clayey conglomerate, bouldery clay, and sand-gravel-and-clay. Conglomerate, identified as such, is most common above the Pantano beds in the Catalina Foothills area; especially between Sabino Creek and Ventana Creek. Conglomerate, sandy clay, and gravelly clay are the most common materials making up the basin fill.

The Pantano beds are characteristically red in color and defined by such terms as clay, shale, and sandy clay in the foothills area. This formation, which extends from the southern edge of the banded gneiss of the Santa Catalina Mountains to, or very close to, Rillito Creek, is capped with alluvial detritus which varies in thickness according to the relief developed upon its upper surface and the effects of recent stream channelling. Locally, this detrital cap is thickest where streams have cut and filled deep channels in the Pantano beds, and is here identified as a conglomerate.

Because of their characteristically definitive nature, clay zones seem to extend over wider areas than the other identifiable units, whereas the gravel deposits are the most local in areal extent. The mixed zones, such as sandy clay or conglomerate, are individually of unknown dimensions because of their poor definition.

Correlations of the well logs, in general, suggest a shallow west-northwesterly dip of the identifiable sedimentary units south of Rillito Creek.

Depositional Environment

The depositional environment of the valley-fill material was primarily one of fluvial conditions. Alluvial-fan deposits occur along the perimeter of the basin and represent an integral phase of this environment. River-channel and flood-plain deposits, common to the central part of the basin, make up by far the larger part of the basin fill.

The materials remotely resembling lake beds are (1) the thin clay lenses of local areal extent and random lateral distribution, and (2) the thick silt deposits which vary in their degree of induration. The silt in the western part of the area studied is the unit most similar to lake beds, and may be the superjacent equivalents of typical lake deposits. However, no sedimentary units were encountered which could not have been fluvial in origin.

The chief cause of deposition in the Tucson basin has been a loss of stream competence due to a flattening of gradient or depletion of transporting medium by evaporation or infiltration.

All the various types of sediments observed may be described as products of different phases of a single flooding period. The sandy clay phases probably represent flash floods, broad sheet wash, and general flood conditions. Coarse conglomerates of the basin perimeter may be headward equivalents of these flood deposits and alluvial-fan apex deposits. Well-sorted sand and gravel are probably channel deposits representing prolonged periods of fairly constant streamflow maintained between flood periods, or deposits emplaced immediately following flood conditions. Correspondingly, the clay units would represent the flood-plain deposits laid down during periods of rather quiet water, in overflow areas or enclosed ponds. Flood deposits are characteristically poorly sorted and widespread, whereas channel deposits are better sorted and narrow in breadth.

As can be seen from the well-sample data (Fig. 6), sediments in the upper part of the section are coarse, indicating streams of greater competency. Of particular note is the relative absence of volcanic materials in the eastern wells of the alluvial slope. This suggests that the Santa Cruz River had not meandered that far east during the period of deposition of the last 500 feet of material, as volcanic outcrops are rather common in the drainage system of this river. Streams depositing alluvial material in the eastern area flowed from an area composed of granite, gneiss, and schist.

Well No. 22, 5 miles due west of the above group, shows the influence of the Santa Cruz River by the rather common presence of volcanic fragments.

The color of the sediments is usually gray, tan, buff, or cream. The red units of the valley fill are chiefly found near the basin edge and are believed to have received their color from the adjacent Pantano beds. The anomalous conditions of a reducing environment are represented by blue, green, and black clay in the immediate vicinity of Tanque Verde Wash, between Wilmot and Pantano Roads, at a depth of 20 to 40 feet below the surface.

GROUND-WATER HYDROLOGY

General Statement

Water for the City of Tucson is obtained primarily from the unconsolidated alluvial sediments in the Tucson basin. The porosity and permeability of these sediments basically determines the rate of yield and quantity of water available to wells. Presently, the ultimate quantity of water available for municipal consumption is restricted by the depth of this alluvial fill and its specific yield.

The ground-water body of the Tucson basin is generally believed to exist under unconfined or water-table conditions. Ground water moves under the influence of gravity in the direction of the hydraulic gradient and in the area examined moves in a general northwesterly direction as shown in Figure 2.

In general, water may be obtained from the three types of sediment making up the basin fill. Water from the Inner Valley fill constitutes the shallowest and most easily pumped from wells. The older alluvium is the major source of water for the Tucson area. The effect of water withdrawal is dramatically shown by the central water-table depression which receives little or no recharge. Water available in peripheral areas of the basin from the Pantano beds is generally of poor quality and low yield. The ground-water depression about the City of Tucson is probably due to large withdrawal of municipal water, as well as a predominance of fine sediments to the south having low permeability. In the southern part of the depression, about 36th Street, ground water moves parallel to the depression slope in a north-northwesterly direction; about Pantano Road it moves westward; and in the area of the Rillito Creek ground-water ridge it moves westward and southwestward. Subsurface water movement in the vicinity of Rillito Creek may also be influenced by the fault zone proposed for this area.

The steep ground-water gradient in secs. 4, 5, 8, and 9, T. 14 S., R. 15 E., probably represents a relatively impermeable fault zone, as drillers' logs of surrounding wells indicate no "bedrock" or Pantano beds within the vertical interval of the ground-water cascade, or even within the total reach of the wells. About 6 miles to the southeast, water-table contours show a curious convergence, which is probably an extension of this fault. Lateral stratigraphic changes occur throughout this local area, but none are seen to coincide with or even resemble this water-table anomaly.

Permeability and Specific Capacity

The stratigraphic units chosen to represent the basin-fill material range widely in permeability. The compact units such as clay and caliche would undoubtedly have a low permeability. The soil, gravelly clay, sandy clay, and conglomerate units have a fair or moderate permeability. The most permeable units of the basin fill are the gravel, sand-and-gravel, and well-sorted sand, including the stream channel deposits or Inner Valley fill.

Only a relative comparison of permeability can be made at this time and the translation into precise coefficient of permeability units is deferred until more hydrologic data are available.

Specific capacity of wells is related to aquifer thickness, well diameter, and coefficient of permeability of aquifer material. It has been computed for many wells in the Tucson area by the Agricultural Engineering Department of the University of Arizona. Figure 10, a map showing the contoured values of specific capacity, is provisionally included and should be considered with reservation because of the gross inequalities involved. Not only because of the complex nature of the unit described, but because of the frequent inconsistencies and anomalous values observed in the raw data, this map is of dubious value. Nevertheless, it remains the only hydrologic data available for this area reflecting a permeability factor.

An effort was made to compare the specific capacity values with stratigraphic data. This resulted in only several favorable correlations and frequent contradictions of data.

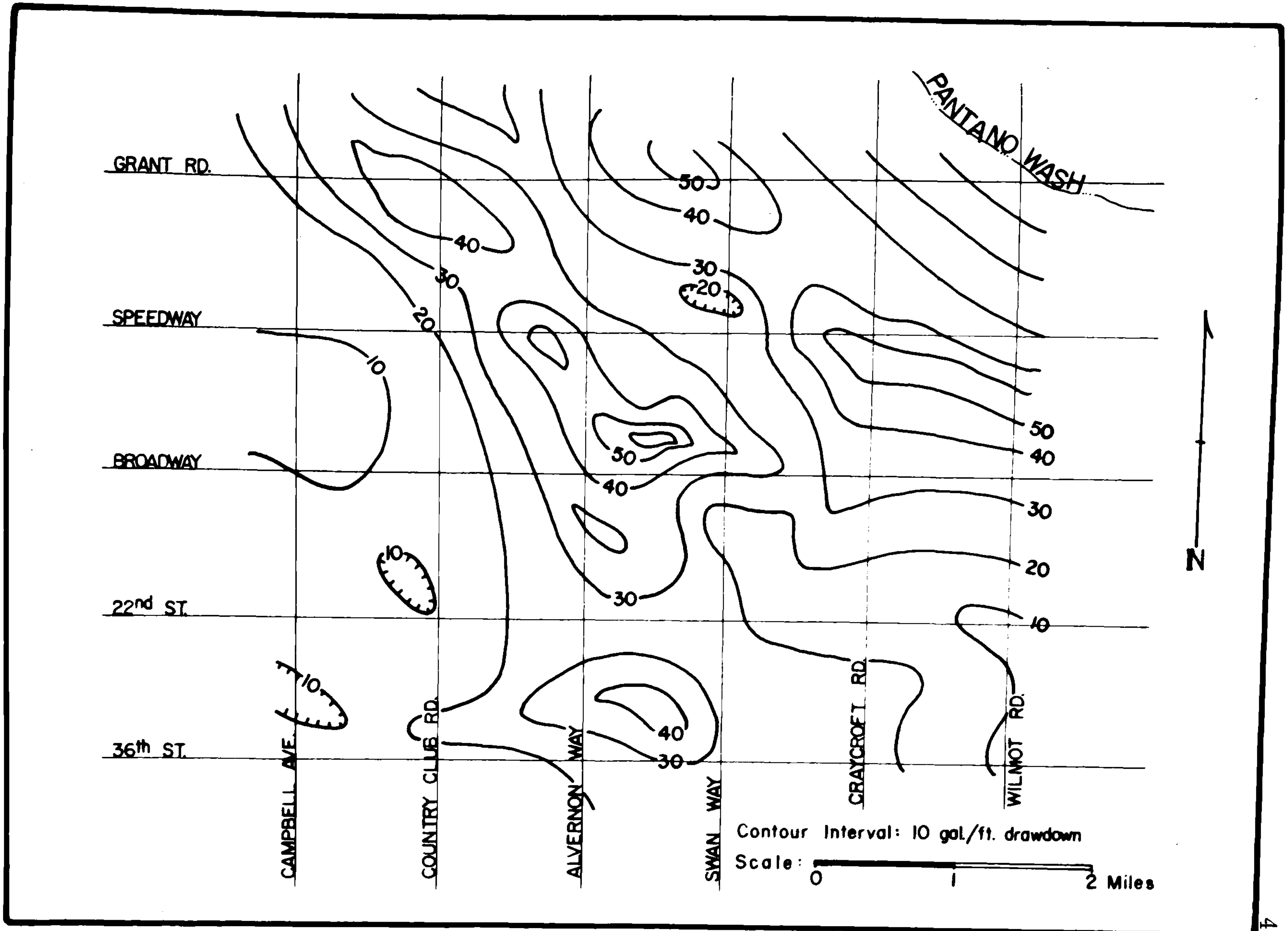


Figure 10. Iso-specific capacity map of water wells of the northeastern part of the Tucson basin.

Water-Table Changes

The lithologic fabric of an aquifer is reflected by the shape of the water table. Other factors effecting the water-table shape are discharge, recharge, and boundary conditions.

As shown in Figure 11, the thickness of the sediments dewatered between 1908 and 1959, the greatest decline in the water table is in the central part of the city, where it amounts to more than 55 feet. This illustration was made using the 1908 water-table map (Smith, 1910) and data available at the Agricultural Engineering Department of the University of Arizona in 1959.

Water-table decline is also relatively large in the vicinity of Grant Road and Kolb Road. This anomalous situation coupled with the gently sloping water table to the northeast suggest a ground-water barrier, such as a fault zone, in this area.

Along Rillito Creek there has been only a relatively small decline in the water table. This may be due to the fact that most wells in this area are shallow and penetrate only the Inner Valley fill which receives annual recharge.

In the Irvington Road and Campbell Avenue area, little or no loss is observed. In 1908, water moved to the northwest with a uniform slope throughout this area. In 1959, water moved northwest, north, and northeast (Fig. 2) from a ground-water mound in this area. This mound

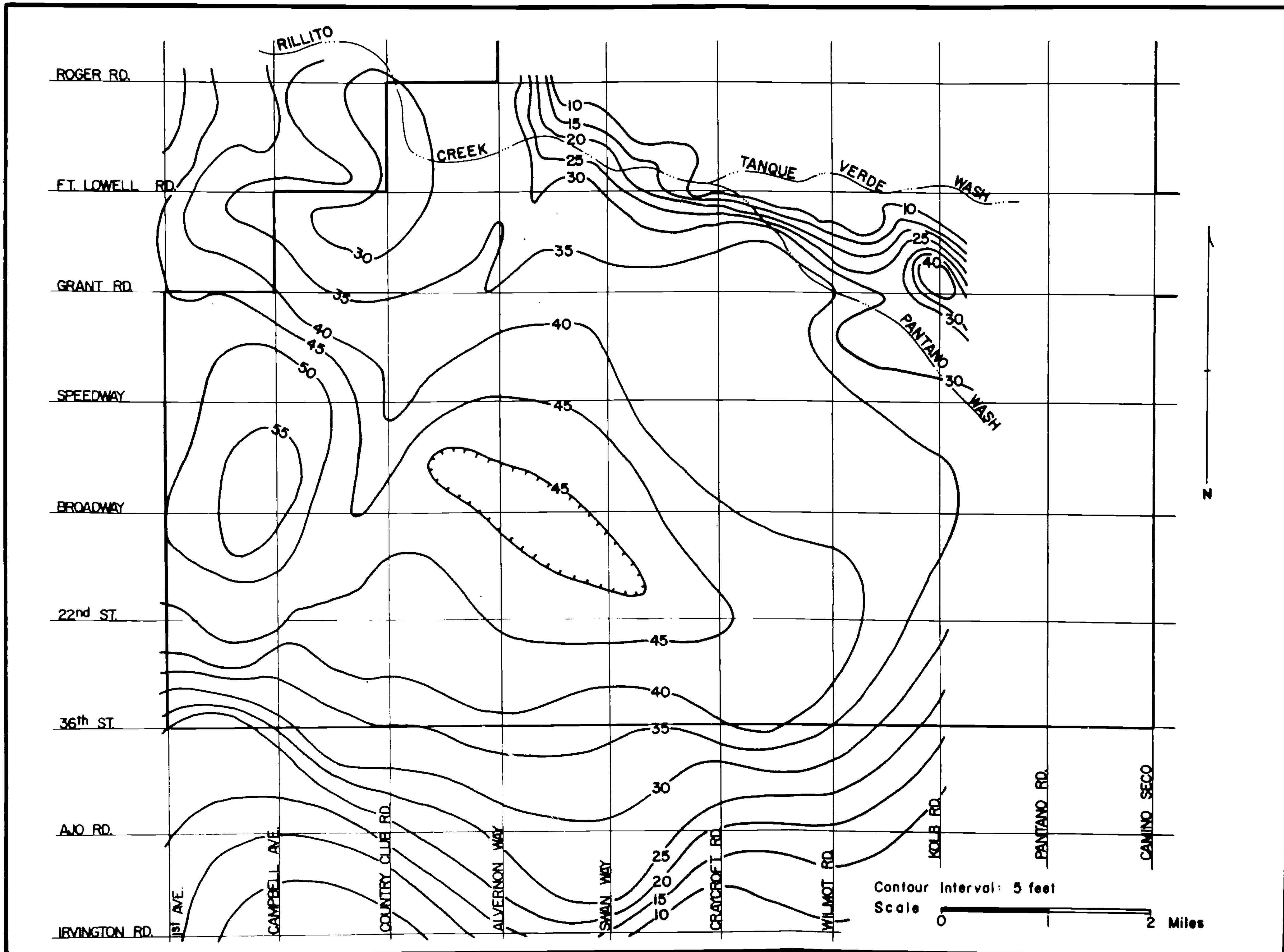


Figure 11. Isopachous map of the dewatered sediments of the Rillito Creek-Tanque Verde Wash area (1908 to 1959).

may well be effecting ground-water recharge in this area from farther south, and the Santa Cruz River.

The central ground-water depression shown in Figure 2 trending northwest is well displayed in Figure 11; however, the axial flexure within this trough is only vaguely apparent from curves in the water-table contours of Figure 2. Figure 11 also shows a transecting positive anomaly from the north-northeast, in the vicinity of Country Club Road and Speedway Boulevard, cutting partially across the central depression and dividing it into two lesser areas of water loss. Both of these positive anomalies may reflect permanent although minor channels of recharge or zones of greater permeability.

In the area of Wilmot Avenue and 22nd Street, or the upper end of the central ground-water depression, water loss gradually diminishes. This appears to indicate a close correlation with a tightening of the sediments (Fig. 10) and is generally consistent with increased clay content of the sediments beginning in this area and continuing south and southeast.

The 10-foot contour interval of the water-table map (Fig. 2) leaves much to be desired in outlining detailed features of the free-water surface. It is here suggested that a water-table map incorporating a 1-foot contour interval would show many features presently unobserved and would be of great value in future ground-water movement studies.

Water in Storage

The quantity of recoverable water in storage within the local subsurface reservoir is of vital importance to the planning and development of the City of Tucson. To determine the volume of water within the Tucson basin the dimensions of the basin must first be determined, and in this area the depth of the basin has not been definitely established.

The effective depth is established by the depth of wells drilled into the water-bearing materials. For the purpose of this study then, the basin depth is equal to the local well depth and is at an average maximum of 500 to 600 feet in the southern part of this area.

The physical nature (particle size and shape) of the sedimentary materials penetrated and the effective porosity also are factors effecting the amount of water in storage. The term usually used to compare the volume of water available to wells to the total volume of the sediment is specific yield. Locally, this factor too is imperfectly known and estimates of values are subject to correction. The specific yield of gravel, sand-and-gravel, and sand zones may range as high as 20 percent, primarily because of their composite nature. The group of materials composed of conglomerate, sandy clay, gravelly clay, and the soil zone probably has a specific yield of about 5 percent or less. Clay and caliche may have a specific yield of 2 percent or less.

An estimate of the volume of these three generalized hydrologic units below the water table was made using well logs. The volume of the unit consisting of gravel, sand-and-gravel, and sand totals about 600,000 acre-feet. The unit consisting of conglomerate, sandy clay, gravelly clay, and the soil zone totals about 2,000,000 acre-feet. The volume of the unit consisting of the clay and caliche zones totals about 190,000 acre-feet. Using these values, it may be computed that approximately 260,000 acre-feet of water can be withdrawn from the present wells within the area examined. The total area here under consideration lies south of Rillito Creek and constitutes some 45 square miles or 28,800 acres.

From an examination of well logs, it may be observed that the sediments generally are fine grained and more compact with depth. It is therefore estimated that the total quantity of recoverable water in storage in this area is not more than several times that of the zone penetrated by present wells. The effective porosity and permeability may well be permanently diminished, to a greater or lesser extent, by aquifer compaction when water levels are permitted to decline greatly. Any calculations of specific yield, based on the initial free-water surface decline, may well have to be revised when considering recharge and storage capacity.

Ground-Water Recharge

Replenishment of ground water in the Tucson area may be achieved by (1) direct penetration of rainfall on the basin floor, (2) underflow by way of permeable sediments from higher in the basin, (3) infiltration from stream beds, and (4) leakage of waste-water seepage from agricultural or industrial processes.

Deep infiltration of water from rainfall in the Tucson basin is considered to be very slight, if present at all, because of a severe soil-moisture deficiency. Recharge by subsurface flow to the ground-water body in the Tucson area is very meager because of the slow rate of movement involved. Infiltration from streamflow is significant only in the immediate vicinity of the stream, and then only during periods of streamflow. Agricultural endeavors are carried on primarily in the areas of Inner Valley fill and recharge in these areas is immediately available to re-use in a similar manner. Industrial operations have not returned sufficient water to the subsurface reservoir to be identified as coming from this source. The most effective method of natural recharge here is from stream seepage in the permeable stream-channel deposits.

Artificial recharge for the purpose of storing water for future use may be achieved by using (1) spreading basins, or (2) injection wells.

Spreading basins are most effective in areas where the sediments are highly permeable and overlie a deep water table. From the study of well logs in this respect, it was found that the most efficient local areas for spreading basins are in the Rillito Creek flood plain and lower Pantano Wash opposite drainages from the Santa Catalina Mountains. Effective sedimentary conditions may possibly be found in the structural trough immediately north of the northwest-trending line of buttes in the Catalina Foothills, especially in the Sabino Creek and Ventana Wash drainages.

Injection recharge is most effective in areas where thick, permeable, recently drained sediments are found at depth. From well logs and hydrologic data, the area where such conditions are best expressed is found centered beneath Broadway half a mile west of Swan Road and extending north and south of Broadway for half a mile or slightly more. Other areas are lacking in depth of permeable sediments, specific capacity, or thickness of unsaturated materials at sufficient depth to deter evapotranspiration.

Within the central ground-water depression the water table lies at the lower edge of the major gravel zone (Pl. I). If this gravel maintains sufficient continuity and permeability, recharge within a large part of this depression may be possible.

CONCLUSIONS

In the future expansion and development of the City of Tucson, all available water supplies in the area will have to be employed in their most efficient uses. Therefore, to achieve the greatest benefit from the available water resources, coordinated effort along the lines of conservation of both surface and subsurface supplies will be necessary. Presently, only subsurface water is being utilized extensively, and this, with an acute lack of understanding of basic subsurface-reservoir functions.

Detailed analysis of systematically sampled well cuttings is probably the most efficient method of obtaining an authentic description of the Tucson basin-fill deposits. Drillers' logs, although abundant, are rather unreliable, inconsistent, and in need of a universal system of nomenclature. From the data obtained in this investigation, it may be stated that the Tucson basin is filled with several phases of fluvial deposits. The coarse, better sorted deposits represent channel deposits, which are frequently cut by poorly sorted flash-flood type deposits. Other fine materials displaying better sorting and probably flood-plain deposits identified with periods of overflow or quiet backwaters. Few of the individual sedimentary units can be identified over a very large area. However, by grouping the units into zones exhibiting similar features of composition, texture, and hydrologic properties illustrations such as Plate I and Figure 8 may be obtained.

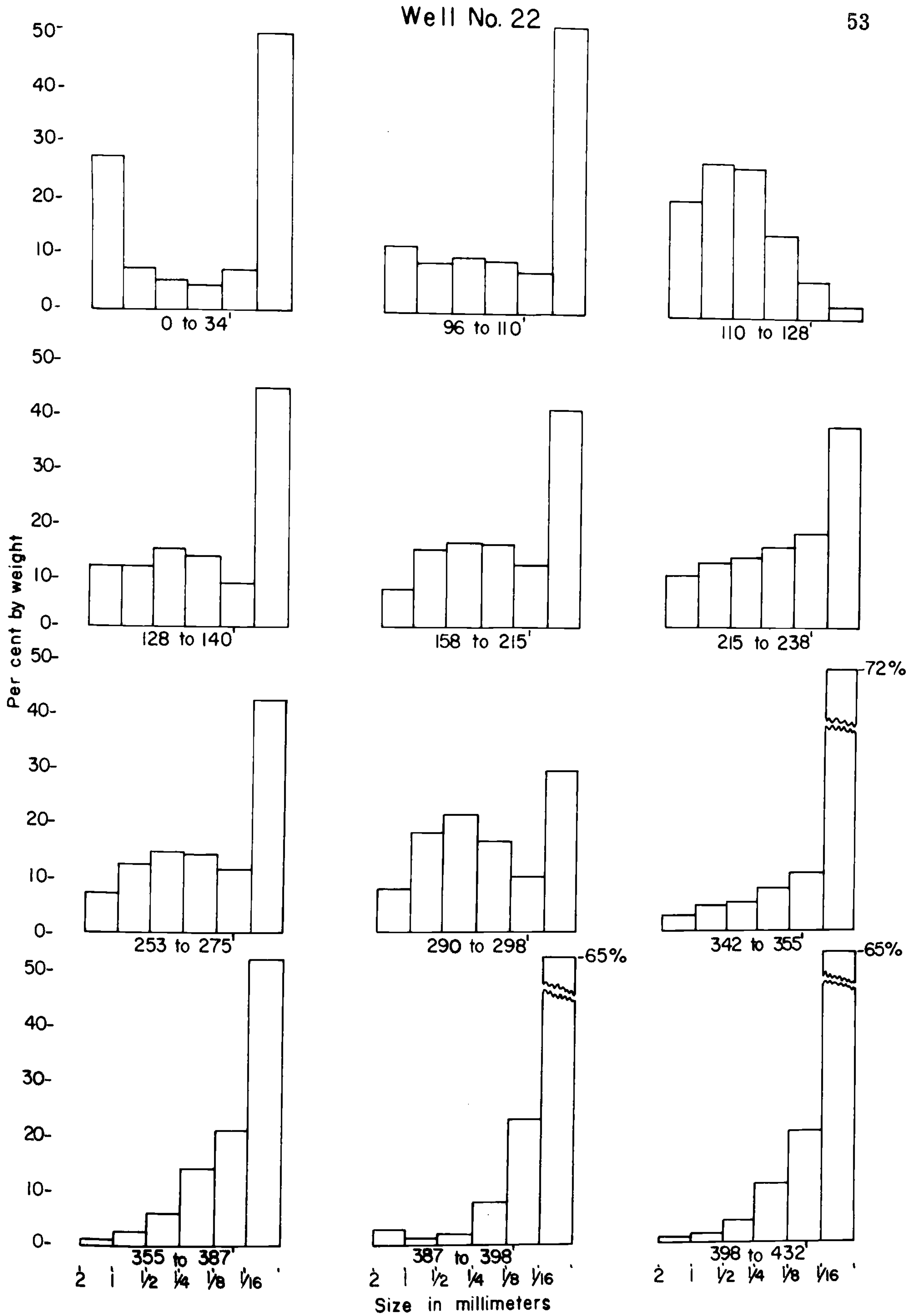
Although several sedimentary parameters were observed and described, no attempt was made to translate these characteristics into hydrologic units. The influence of median size, shape, sorting, and packing upon porosity and permeability has been examined by numerous persons; however, much basic research on sediments such as fill the local basin has yet to be done. Specific yield of Tucson basin-fill deposits can only be estimated at this stage of their study. It was calculated that about 260,000 acre-feet of water can be readily withdrawn from storage in the 45 square miles studied.

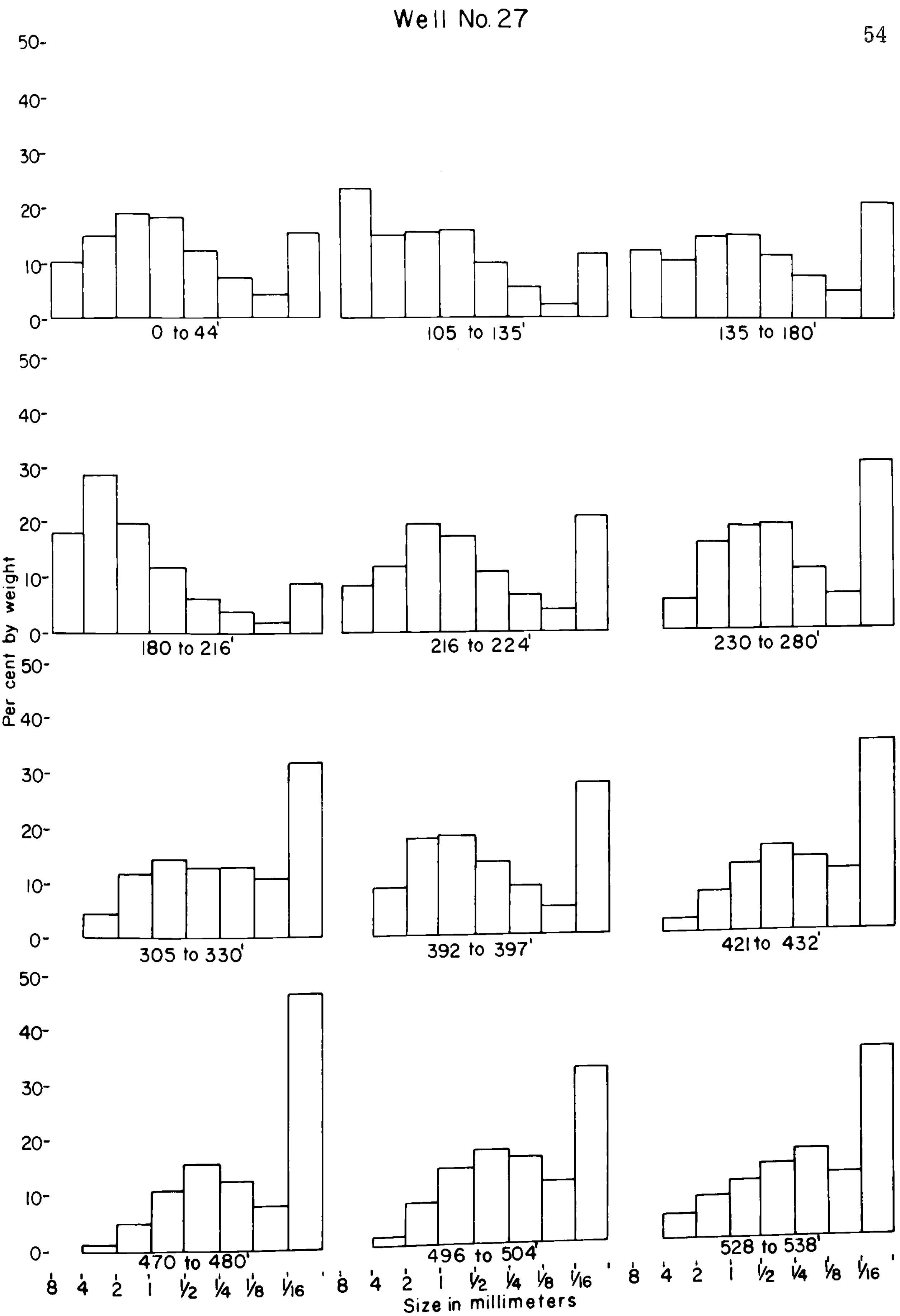
In other regions, ground-water recharge has long been effective in maintaining efficient pumping levels, emergency water storage, and local water supplies relatively free of pollution. Because of the characteristic seasonal runoff, lack of natural recharge, and declining water table, the local reservoir conditions would seem to present an excellent illustration of the optimum conditions to develop extensive artificial-recharge operations.

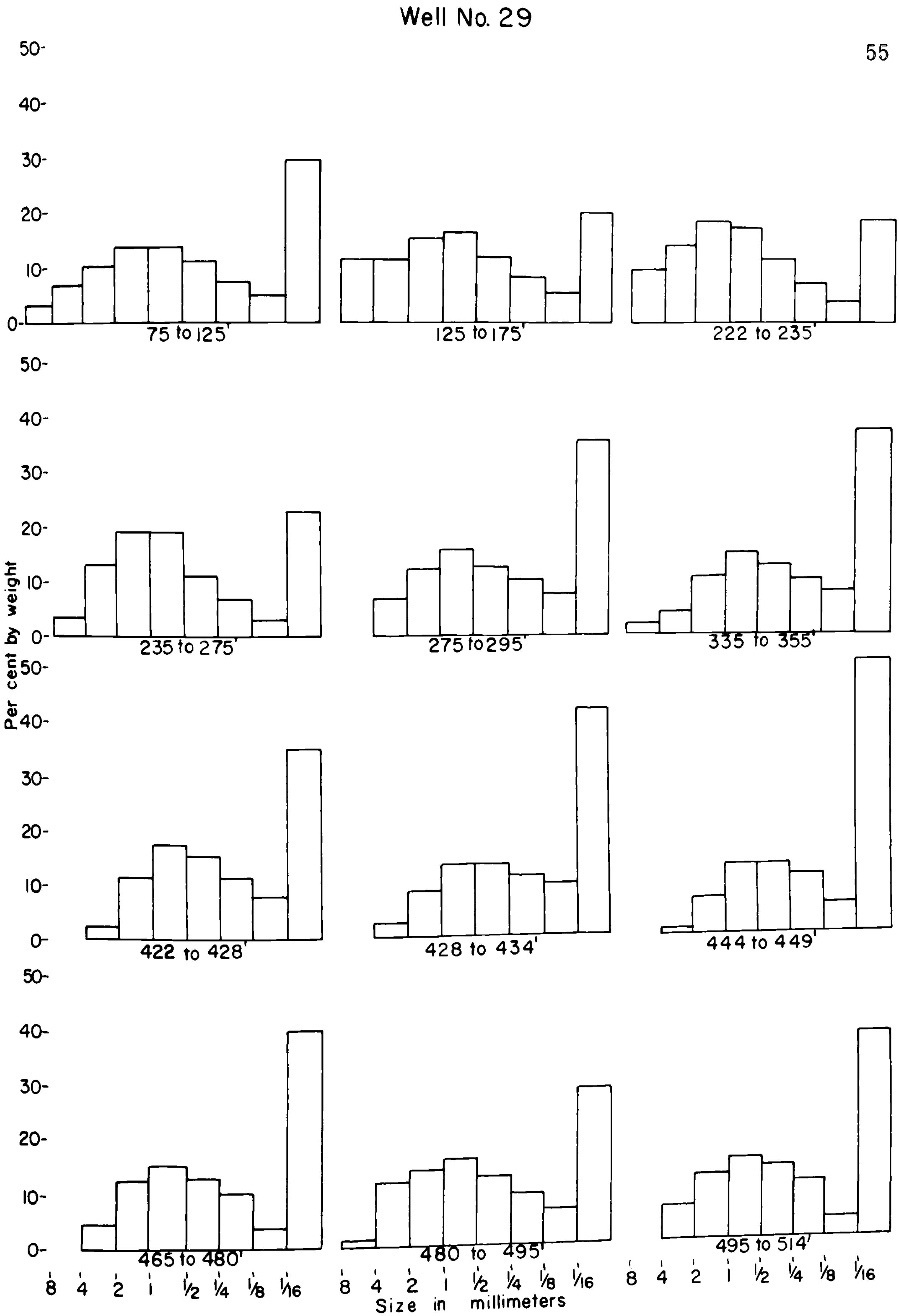
APPENDIX

APPENDIX

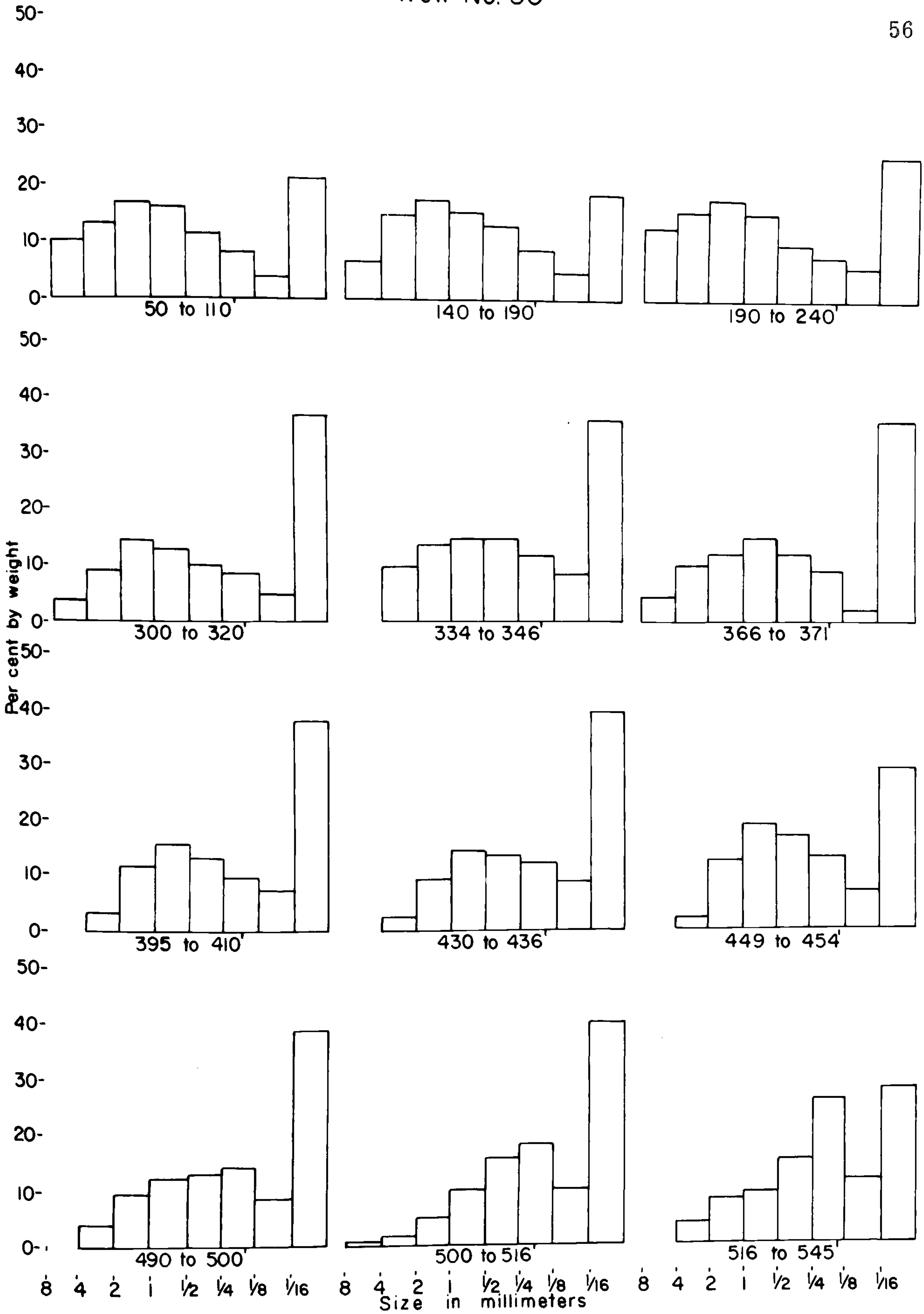
Histograms of selected well samples representing typical sample intervals.



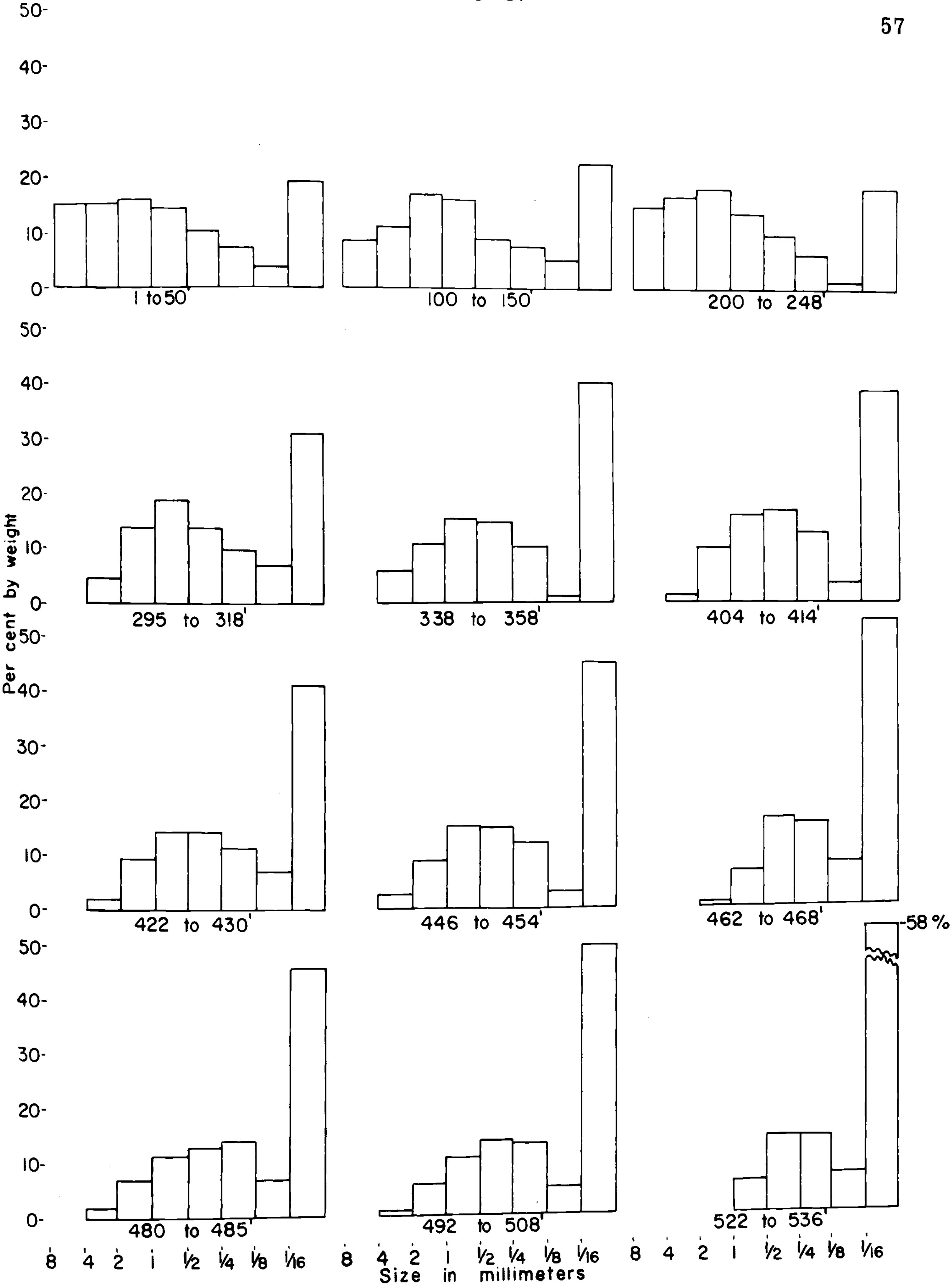

Well No. 27
Per cent by weight
0 to 44'
105 to 135'
135 to 180'
180 to 216'
216 to 224'
230 to 280'
305 to 330'
392 to 397'
421 to 432'
470 to 480'
496 to 504'
528 to 538'
8 4 2 1 1/2 1/4 1/8 1/16
Size in millimeters


Well No. 29
Per cent by weight
0
10
20
30
40
50
75 to 125'
125 to 175'
222 to 235'
235 to 275'
275 to 295'
335 to 355'
422 to 428'
428 to 434'
444 to 449'
465 to 480'
480 to 495'
495 to 514'
8 4 2 1 1/2 1/4 1/8 1/16
Size in millimeters

Well No. 30


50-
40-
30-
20-
10-
0-
50 to 110'
140 to 190'
190 to 240'
300 to 320'
334 to 346'
366 to 371'
395 to 410'
430 to 436'
449 to 454'
490 to 500'
500 to 516'
516 to 545'
Per cent by weight
8 4 2 1 1/2 1/4 1/8 1/16
Size in millimeters

Well No. 31



Per cent by weight
50-
40-
30-
20-
10-
0-
1 to 50'
100 to 150'
200 to 248'
295 to 318'
338 to 358'
404 to 414'
422 to 430'
446 to 454'
462 to 468'
480 to 485'
492 to 508'
522 to 536'
-58%
8 4 2 1 1/2 1/4 1/8 1/16
Size in millimeters

BIBLIOGRAPHY

Blissenbach, E. B. K. (1957), The geology of alluvial fans in Arizona: University of Arizona M. S. thesis, 101 pp.

Brennen, D. J. (1957), Geological reconnaissance of Cienega Valley, Pima County, Arizona: University of Arizona Ph. D. thesis, 53 pp.

Chew, R. T. (1952), The geology of the Mineta Ridge area, Pima and Cochise Counties, Arizona: University of Arizona M. S. thesis, 53 pp.

Coulson, B. O. (1950), Geology of the Sweetwater Drive area and correlation of Santa Cruz Valley gravels: University of Arizona M. S. thesis, 75 pp.

Folk, R. L. (1954), The distinction between grain size and mineral composition in sedimentary rock nomenclature: Journal of Geology, Vol. 62, pp. 344-351.

Kidwai, Z. U. (1957), The relationship of ground water to alluvium in the Tucson area, Arizona: University of Arizona M. S. thesis, 55 pp.

Krumbein, W. C., and Pettijohn, F. J. (1938), Manual of sedimentary petrography, New York, Appleton-Century, pp. 91-181.

Maddox, G. E. (1960), Subsurface geology along northwest Rillito Creek: University of Arizona M.S. thesis, 232 pp.

Moore, L. M., Tolman, C. F., Butler, B. S., and Hernon, R. M. (1932), Geology of the Tucson quadrangle: U.S. Geological Survey open-file report. (On file at the Arizona Bureau of Mines, Tucson, Arizona)

Schwalen, H. C. (1942), Rainfall and runoff in the Upper Santa Cruz drainage basin: University of Arizona Agricultural Experiment Station Technical Bulletin 95.

Schwalen, H. C., and Shaw, R. J. (1957), Ground-water supplies of the Santa Cruz Valley of southern Arizona between Rillito Station and the International Boundary: University of Arizona Agricultural Experiment Station Bulletin 288.

Smith, G. E. P. (1910), Ground-water supply and irrigation in the Rillito Valley: University of Arizona Agricultural Experiment Station Bulletin 64.

__________ (1938), The physiography of Arizona valleys and the occurrence of ground water: University of Arizona Agricultural Experiment Station Bulletin 77.

Turner, S. F., and others (1943), Ground-water resources of the Santa Cruz basin, Arizona: U.S. Geological Survey open-file report, 88 pp.

___________ (1947), Further investigations of the ground-water resources of the Santa Cruz basin, Arizona: U. S. Geological Survey open-file report, 45 pp.

Voelger, I. (1953), Cenozoic deposits in the southern foothills of the Santa Catalina Mountains near Tucson, Arizona: University of Arizona M. S. thesis, 101 pp.

Rillito Creek Hydrologic Research Committee of the University of Arizona and U. S. Geological Survey (1959), Capturing additional water in the Tucson area (a report for administrative use only), 68 pp.

FENCE DIAGRAM
OF THE GENERALIZED
STRATIGRAPHIC UNITS
OF THE
RILLITO CREEK-TANQUE VERDE WASH
AREA,
TUCSON, ARIZONA