LITHOLOGIC AND STRUCTURAL INFLUENCES ON THE HYDRODYNAMICS OF THE TUCSON BASIN, ARIZONA

by

William J. Ganus

A Thesis Submitted to the Faculty of the

GRADUATE COMMITTEE ON HYDROLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1965

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 his 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: William J. [illegible]

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

John Harshbarger
J. W. HARSHBARGER
Chairman of Hydrology

June 7, 1965
Date

ACKNOWLEDGMENTS

To my major advisor and thesis director, Dr. J. W. Harshbarger, for his guidance and counselling, I am especially thankful. I also wish to express my gratitude to Dr. J. J. Wright, and to Professor T. L. Smiley for their very worthwhile criticisms and suggestions. To John Ferris, U. S. Geological Survey, for his teaching and counselling, and to Gordon Davis, Tucson Water Department, for his cooperation in providing well test data, I am grateful. For assistance in the editing and typing of the thesis, I am especially indebted to my wife, Sue.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

page

FIGURES

PLATES

(in pocket)

LITHOLOGIC AND STRUCTURAL INFLUENCES ON THE HYDRODYNAMICS OF THE TUCSON BASIN, ARIZONA

by

William J. Ganus

ABSTRACT

The Tucson Basin is a structural feature of middle Tertiary age. Since middle Tertiary time clastics derived from surrounding mountains and carried by intermittent streams have filled the basin with more than 3100 feet of sediments. The present supply of water for the Tucson area is taken from groundwater in the upper 500 to 800 feet of these basin sediments. Groundwater withdrawal from the basin-fill sediments has resulted in a continual decline of the water table, especially since World War II. This decline has not been uniform and is cause for concern in the future water development in the basin. Data from recent deep wells, combined with information from shallow producing wells, has made possible a better understanding of the structure, stratigraphy, and groundwater movement in the basin. A prominent northeast-southwest structural trend across the basin is interpreted and substantiated by gravimetric survey data. The upper basin-fill sediments, considered generally to be of Pleistocene age, are found to be underlain by very fine grained deposits (Pliocene ?), which are underlain by an unknown thickness of conglomerates, sands, and clays (Miocene ?). By using well control, correlation of the thicker units

appears to be generally possible across the basin; however, detailed correlations within some of these units are difficult to make from well to well as lateral variations over short distances, characteristic of alluvial deposits, are very common. Descriptions of the lithologic characteristics of the upper basin sediments have been recorded on drillers' logs for hundreds of wells in the basin. The synthesis of this well log information into maps of lithologic distributions was made in this study by a method of plotting the characteristic lithology of selected 100 foot intervals from drillers' logs of representative wells. From these distribution diagrams, an interpretation of the depositional environment was made. The lithologic distributions are correlated with hydrologic features shown on maps of isospecific capacity, dewatered sediments, and lateral head displacement changes in order to better understand the relationships between the groundwater movement and the geologic controls. Decline of the water table was found to be the result of, or combination of, well density, well capacity, lithologic variations, and permeability boundaries. Good correlations which exist between the geologic and hydrologic characteristics permit outlining areas of good and poor permeability and projected yield.

INTRODUCTION

Statement of Problem

Since World War II, the population growth in the Tucson area has been remarkable and the resulting demand for water has been met by exploitation of the groundwater of the area. The withdrawal of groundwater from the Tucson basin by man has resulted in a differential response of the groundwater table elevation across the basin. Resulting anomalous areas of water table decline indicate inhomogeneity in the spatial distribution of the water bearing sediments. Postulated structural configurations within the basin are believed to also influence the groundwater movement. From recent drilling of deep wells within the basin, additional lithologic and structural information is now available which permits new interpretations of the subsurface geology. These interpretations, combined with a study of the lithologic distribution, need to be related to such hydrologic aspects as the rate of water table decline, well productivity, and radial zones of influence, in order to explain the anomalous and diverse character of the groundwater response to pumping by man. Continual correlation of these geologic and hydrologic characteristics should permit the outlining of favorable future water reserves.

Location

The Tucson Basin is surrounded on the north and east sides by the Santa Catalina and Rincon Mountains; on the southeast by the Santa Rita Mountains; on the southwest by the Sierrita Mountains; and on the northwest by the Tucson Mountains.

The basin area is considered to be on the order of 460 square miles, however, due to the sparcity of wells in the southern half of the basin, the area of study, approximately 230 square miles, is concerned primarily with the city of Tucson and adjacent areas where well density provides good control. Geographically the study area extends from the Santa Cruz River on the west to the Rincon Mountain foothills on the east and from the Rillito Creek and Santa Catalina Mountain foothills on the north to approximately midway in the basin to the south.

The legal description of the area studied is the southeast quarter of T13S, R13E, the south half of T13S, of R14&15E; T14S, the west half of R13E, and all R14&15E; and T15S, the west half of R13E, and all of T14&15E.

Ground elevation in the study area has a low of +2260 feet in the northwestern corner and a high of +3080 feet in the southeastern corner. The drainage pattern, generally to the northwest, exemplifies the regional slope of the area.

Previous Work

Hydrologic and geologic studies of the Tucson Basin were made in 1910 and 1938 by G. E. P. Smith. Moore and others (1941) and Turner and others (1943) have made studies of basin features as open file

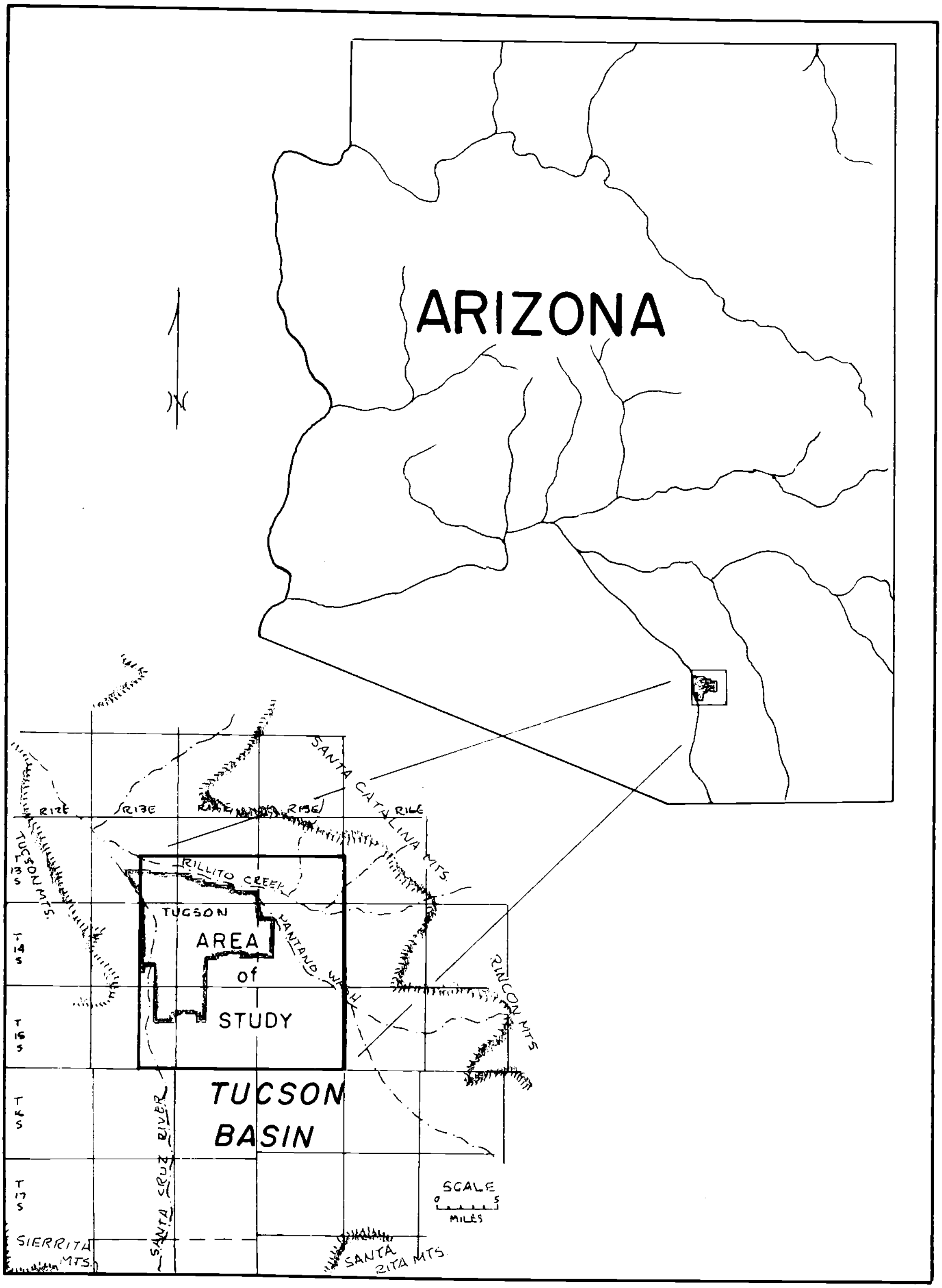


Figure 1.--Maps Showing Location of Tucson Basin and Area of Study

reports for U. S. Geological Survey. Schwalen and Shaw have published reports and water table maps of the basin in 1957 and 1961. Kidwai (1957), Maddox (1960), and Streitz (1962) have written Master's theses dealing with the basin sediments. Several geologic investigations of surrounding areas which relate to the subsurface geology of the basin have been made by Coulson (1950), Voelger (1953), Blissenbach (1957), and Brennan (1957).

The Rillito Creek Hydrologic Research Committee of the University of Arizona and the U. S. Geological Survey completed a study in 1959 of the water occurrence in the Tucson area. All phases of surface and subsurface water were analyzed to show their interrelationships and to point out the investigations that should be conducted in order to obtain a better understanding of the problems facing man in any water deficient area such as the Tucson Basin. This thesis is one of the investigations recommended by the Research Committee.

REGIONAL GEOLOGY

Throughout the Cenozoic Era southeastern Arizona has been an area of relative instability. Faulting and uplifting in the early Tertiary period probably marked the beginning of the structural development of the area that resulted in a series of basins and ranges by middle Tertiary time. Since that time, modifications of these basins and ranges have taken place as the earth's crust has continued to respond to differential erosion and deposition on the surface. Structural activity in these basins and ranges has occurred as recently as the Quaternary Period, giving the physiographic setting that we see today (Fenniman, 1931).

The prominent trend of mountains and valleys in southeastern Arizona is generally northwest-southeast. However, less conspicuous structural trends do exist and are revealed only by fragmentary evidence.

The basin sediments in a basin and range environment are generally clastics derived from the surrounding mountains. The predominant clastic size that is deposited in the basin at any one time is dependent on the source rock type, the relief of the source area, the length of transport, and the energy of the transporting agent. Since middle Tertiary time, variations in these controls have resulted in a variety of lithologic deposits.

Stratigraphy

Well data indicates the thickness of basin sediments within the Tucson Basin to be in excess of 3100 feet. Preliminary gravimetric surveys and tenuous correlations of the deepest well data with surface units indicates that Mesozoic rocks similar to those cropping out in nearby mountain areas may be overlain by 7,000 to 10,000 feet of basin sediments.

Recent exploration for new water reserves within the basin has resulted in several deep wells to depths of 3145 feet. These wells have aided in defining the lithologic units of the basin. The deepest well (Plate I, cross-section B-B') encountered a clay, sand and conglomerate sequence in the bottom 1300 feet. It is speculated that this subsurface unit is correlative with the Pantano (Miocene ?) beds of Brennan (1957). At the type section in Cienega Gap area southeast of the Tucson Basin (Figure 2), Brennan measured 13,762 feet of faulted and folded clays, sands, and conglomerates with minor igneous extrusives. Potassium-argon age dating of one of these extrusives, a rhyolite ash flow in the upper beds, has indicated an age of 32.8 ± 2.7 to 36.7 ± 1.1 million years ago (Damon and Bikerman, 1964) which is upper Oligocene to Lower Miocene time. Uplifting and faulting of the Pantano beds probably occurred in late Miocene and early Pliocene (Cooley and Davidson, 1963).

The clay, sand, and conglomerate sequence in the deepest well is overlain by a clay and silt unit, in part gypsiferous, approximately 1200 feet in thickness. Several other deep wells within the basin have encountered similar fine grained sediments (Plate I, cross-section B-B'). Correlation of these clays and silts with surface units has not

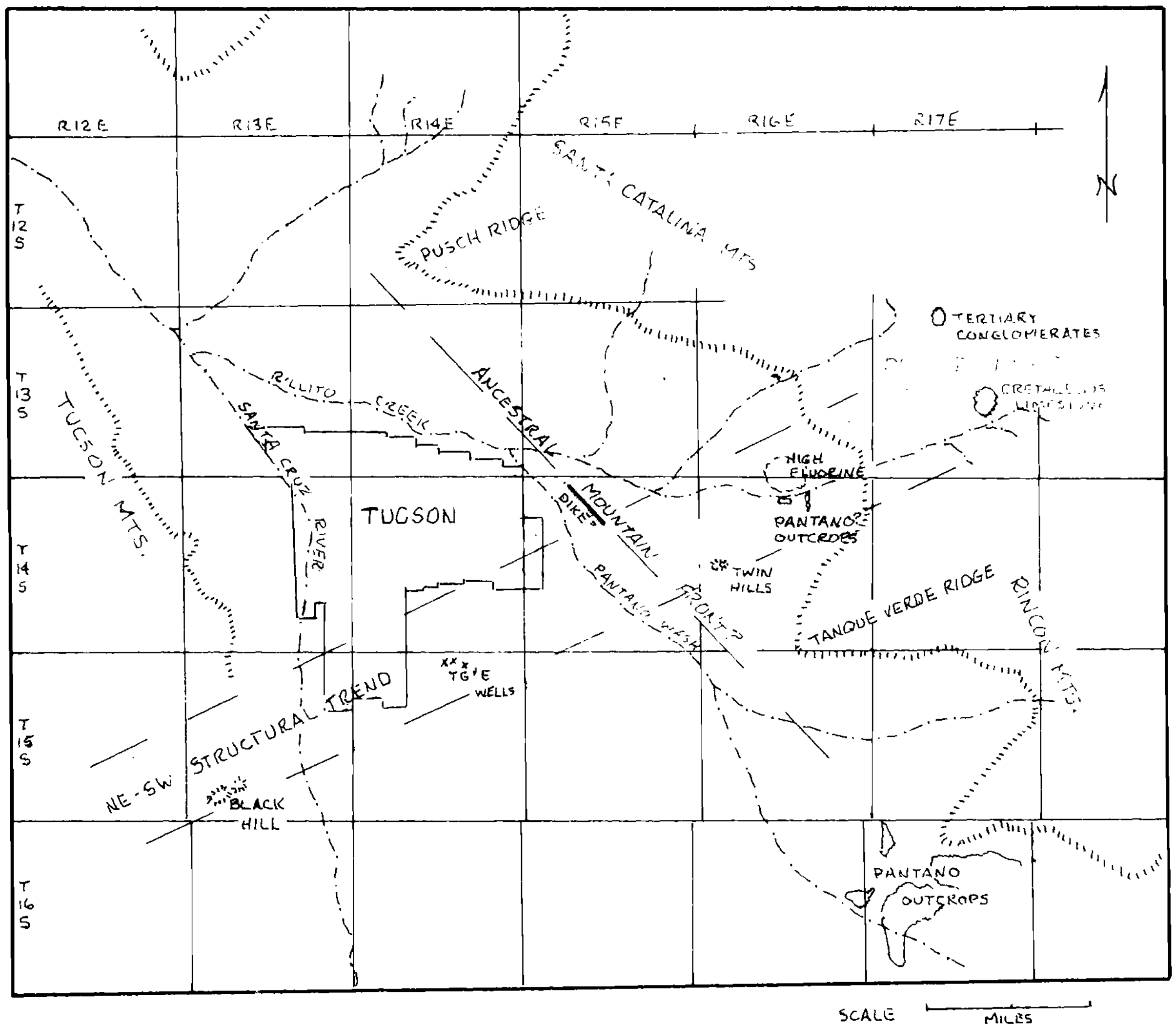


Figure 2.--Map Showing Certain Geologic Features of the Tucson Basin

been established; however, their position in the subsurface relative to other units suggests lateral equivalents. In 1925 Bryan assigned a Pliocene age to the bedded conglomerates, sandstones, and mudstones which form the pediment south of the Santa Catalina Mountains. Voelger (1953) named these sediments the Rillito beds. Blissenbach (1957) described these sediments as being deltaic and derived from a low lying land mass north of the depositional area. He reported that outcrops of these beds show coarse grained topset beds grading basinward into fine grained bottomset beds within a distance of a few feet. If this was the characteristic depositional environment of the Rillito beds, then the thick clays and silts encountered in wells in the basin are probably stratigraphic equivalents of these beds and therefore Pliocene in age.

Overlying the clays and silts in the basin is a 500 to 800 foot thickness of generally mixed and poorly consolidated clays, sands, and gravels, which are assigned a Pleistocene to Recent age. It is from these upper basin-fill sediments that groundwater is withdrawn for the demands in the Tucson area and therefore their spatial distribution is very important in locating areas of best water yield. As well development takes place, more detailed lithologic information of these sediments becomes available, primarily in the form of drillers' sample logs. However, since most water wells are drilled solely for water, many sample descriptions lack sufficient detail of lithologic or induration characteristics to be of use in a geologic study.

Structure

In addition to lithologic data, the deep wells in the basin indicate certain structural features which previously have not been interpreted from isolated surface features.

In the three deep wells of Sections 2 and 3, T15S, R14E, the lower conglomerates, sands, and clays of probable Pantano equivalent were found to be structurally higher than in any other deep wells in the basin. Even though other wells are as deep or deeper, none have penetrated these conglomerates (see cross-section A-A', Plate I). This anomalous subsurface structure is believed to be associated with a cross-trend in a northeast-southwest direction that includes Black Mountain (intrusives and extrusives) southwest of the basin, the three deep wells referred to above, Twin Hills (intrusives) east of the basin, and Redington Pass between the Santa Catalina and Rincon Mountains in the same structural belt (Figure No. 2). The deep, but structurally high conglomerates indicate a possible horst block feature in the subsurface with a northeast-southwest trend. Heindl (1959), in a geological investigation of the Black Mountain area, discussed surface structural features which are consistent with this subsurface structural interpretation. The intrusive and extrusive igneous material in this belt may indicate zones of structural weakness. The magnitude of displacement of the uplifted horst block cannot be estimated as no other wells in the basin have encountered the lower conglomerates. A north-south gravimetric survey profile across the area, along Wilmot Road, has clearly shown that a basement fault of several thousand feet does exist in this area with a downthrown block to the south (Sumner, J. S., personal communication). A large scale downthrown block to the north was not detected by the gravimetric survey, which leads one to believe that the horst is bounded by a large normal fault to the south and by a smaller normal fualt to the north. Most wells in the area are too shallow to provide the information necessary to delineate this belt.

If this structural belt were present since middle Tertiary time, the reentrant between the Rincon and Santa Catalina Mountains may be an expression of the structurally weak zone. From Pusch Ridge to Tanque Verde Ridge, an ancestral mountain front closely paralleling the Tucson Mountain eastern front may have existed in middle Tertiary time, and only these ridges now remain as evidence. The line between these ridges also separates the basin type sediments from the indurated, tilted, and faulted sediments of Pliocene Age which crop out in this area as the partially exposed pediment.

Preliminary gravimetric surveys in this area have indicated that across part of this mountain reentrant, a dike or similar dense rock exists (Fenzel, F. W., personal communication), which may be evidence of an ancestral mountain front weak zone for intrusives or subsequent faulting of basin sediments. No surface evidence to substantiate this has been found, however groundwater contours in this area definitely indicate an impermeable subsurface barrier (Plate No. III-A). Groundwater contours southwest of this feature show the dewatering of basin sediments, whereas northeast of the barrier no noticeable displacement of the contours has taken place in the last twenty years. The barrier appears to have been developed subsequent to Rillito bed deposition. It was then intersected by the northeast-southwest structural development which left only the small remnant now present which is "blocking" the subsurface water flow from the mountain reentrant area to the basinal area. Groundwater contours indicate that the barrier rises to an approximate elevation of +2470 feet.

It is interesting to note that within the northeast-southwest structural belt, and possibly related to this trend, Tertiary (Pantano ?) conglomerate beds and Cretaceous limestones are found as outliers on the Catalina gneiss near Redington Pass. Also notable is the anomalously high fluorine content of the groundwater near the mountain front, where outcrops of sands and conglomerates (Pantano ?) are present (Figure No. 2). High fluorine content is characteristic of the deep sediments found in the basin. Detailed structural work across this area may show the relationships of these features.

REGIONAL HYDROLOGY

A cursory examination of the groundwater map of the Tucson Basin shows that groundwater moves from the south through the Continental narrows, spreading out across the broad Tucson Basin and leaving to the northwest through the narrows at Jaynes. Some groundwater enters the basin from the west near Black Mountain and from the east along Rincon and Cienega Creeks, south of the Rincon Mountains. Runoff from precipitation on the surrounding mountains contributes some natural recharge to the basin. The heavy thunderstorm activity of the summer months provides almost one-half of the annual precipitation on the basin; however, most of this summer rainfall is lost by evaporation before reaching effective recharge areas.

The regional northwest-southeast groundwater gradient across the basin proper in the early 1900's was uniformly twenty to twenty-five feet per mile (Smith, 1910). Today, gradients in the basin are locally from ten feet per mile to more than seventy feet per mile. This thesis correlates the structure and lithology with some of these extreme variations in the gradient.

Groundwater System in Natural Environment

Water Table Aquifer

In 1908 G. E. P. Smith constructed the first water table map in the Tucson Basin. Because of the limited well control at that time, the map area was restricted to only the northwestern portion of the basin. Even though extrapolation between points was necessary in many areas, due to lack of control, this first map is important to the understanding of the groundwater movement in the natural environment before man's intervention with the system.

Notes of travelers and settlers in the early 1900's in the Tucson area indicate that groundwater often was encountered at less than a twenty foot depth in and near the Santa Cruz River and Rillito Creek, and frequently intersected the surface during the spring months after winter recharge essentially filled the upper sediments to capacity. The Santa Cruz River near Tucson was often observed and described as a flowing stream. Lush stands of riparian phreatophytes were reported along most drainages. The water demand by this vegetation was the major draft on the groundwater supply in these early days. However, their demand on the groundwater during the summer months of growing did not exceed the winter and spring recharge. An annual state of equilibrium resulted, where transpiration discharge of groundwater by phreatophytes was generally equalled and offset by the natural recharge. Under these conditions, the groundwater contour pattern of the 1908 water table map was relatively smooth and uniform. No permeability variations in the basin-fill sediments were indicated on this first map. Sparce well control and very small withdrawals of groundwater by man precluded the detection of any permeability variations. These variations were not recognized until man interrupted the equilibrium of the natural environment by an overdraft of the groundwater. The incongruent and irregular nature of the 1964 water table contours contrasts sharply with the smooth and uniform water table contours of 1908 and 1947 (Plate III-C).

The quality of groundwater in the water table aquifer is regarded as good and is generally untreated for municipal use. It is characteristically high in hardness.

Estimates of natural recharge to the water table aquifer can be made from precipitation data versus runoff-evaporation data or from channel infiltration rates of surface water to the groundwater. Schwalen and Shaw (1961) used a five year period, 1956-1961, to determine recharge to the basin by calculating the volume of water withdrawn and the volume of sediments dewatered, assuming a certain percentage of the total water that these sediments would release as the water table was lowered. Their estimates of natural recharge to the basin-fill sediments for the five year period were about 50,000 acre feet per year, which is similar to values calculated from rainfall, evaporation, and infiltration data. Because of the observed losses of surface water flow and the time of wetted channel in the Rillito Creek, it is expected that this area receives much of the natural recharge to the basin during late winter and early spring months. Some sporadic surface flow in the Santa Cruz River accounts for additional recharge.

Artesian Aquifer

The deep wells of Tucson Gas and Electric Company in Sections 2 and 3, T15S, R14E have contributed valuable information to the evaluation of the hydrodynamics of the Tucson Basin. The thick sequence of clays and silts from 500 to 1800 feet acts as a confining layer to the upward movement of water from underlying sands and conglomerates (Pantano ?). The water encountered in these lower clastics rises in the wells to an elevation very near that of the groundwater table, indicating that artesian conditions exist in this lower aquifer. The piezometric surface, i.e. the elevation to which the confined water will rise when released, is approximately 1600 feet above the top of the sands and conglomerates.

Subsequent to the drilling of these deep wells, a change in the chemical and thermal characteristics of the water from the shallow wells of the area has indicated an apparent upward migration of the deep artesian water, probably around the well casings. High temperature, high fluorine content and low values of hardness, characteristic of the artesian water, are now noted in the shallow wells of the area. If this difference in hydrostatic head between the two aquifers exists throughout the basin, then continual lowering of the groundwater table in other areas will cause an increased differential in hydrostatic pressure and a net migration upward of the less desirable artesian water. Irreparable damage to the groundwater quality of the water table aquifer could result. Current studies of the groundwater chemistry of the basin will more clearly outline the magnitude of this potential problem.

The area and amount of natural recharge to the artesian aquifer are unknown, because of tenuous correlations with surface units.

Groundwater System Response to Man's Intervention

Aquifer Response to Pumping

As Tucson has expanded areally, the well development program has likewise expanded and therefore the pumping center, or middle of the pumped area, has migrated. Because of the heterogeneous nature of the saturated basin-fill sediments, some areas have not yielded water as readily as others. This is evidenced by the differential decline of the water table across the basin, even when unequal rates of pumping are considered.

Fine grained rocks, i.e. clays and silts, although very porous, do not readily release water from the interstices. Because of the large amount of sediment particle surface area in contact with water in a fine grained rock, the forces due to molecular attraction that are resisting fluid migration are much greater than the opposing force of gravity, which is attempting to move the water into the cone of depression developed by the pumping well. Conversely, the coarse grained rocks, i.e. sands and gravels, having supercapillary openings and less surface area in contact with the water, will readily release water to a well by gravity drainage. Therefore, as the cone of depression is being developed, a saturated rock type will release, in a reasonable amount of pumping time, a certain amount of the total water from the pores. The volume of released water, expressed as a percentage of the total volume of the rock, is called the specific yield, and that percentage of the rock volume that is retained water is called the specific retention (Todd, 1960, p. 24). However, the specific yield or retention by a rock type is primarily important only in the drawdown and dewatered zone of a water table aquifer. More important to the production of water in a well is the ability of the rock to transmit water, called the permeability, expressed as the volume of water that is transmitted through a given distance of porous media in a unit of time under a given pressure gradient, is also dependent on the relative sediment size and the attendant resisting forces of molecular attraction between the porous media and fluid. With less surface area of water contact, coarse grained sediments have a small resisting force for migrating fluids, while fine grained sediments with large surface area have a large resisting force. Permeability values alone do not describe the overall characteristics of an aquifer. The saturated thickness of the aquifer is important in the water production of a well. A well completion generally includes casing with openings for water intake from the entire thickness of saturated sediments. Therefore, a more useful term to describe the aquifer as a whole is the coefficient of transmissibility, which is the coefficient of permeability times the saturated aquifer thickness. The coefficient of transmissibility is defined as the volume of water flowing through an aquifer of unit width and saturated thickness, in a unit of time and under a given hydraulic gradient.

To show the geographic distribution of the transmissibility of an aquifer, isospecific capacity maps can be made. The specific capacity of a well is the ratio of the volume of water produced in a given time to the amount of drawdown due to pumping in that well; this is generally expressed as gallons per minute per foot of drawdown. It can be seen that this ratio can also be interpreted as the gallons of water per minute necessary to be produced to cause a one foot lowering of the water table. The coefficient of transmissibility (gallons/day/foot) can be shown by fundamental equations of well performance to be approximately equal to 2000 times the specific capacity (gallons/minute/foot of drawdown) if certain well and aquifer characteristics are assumed. Even though these assumed conditions seldom exist for wells in the heterogeneous basin-fill sediments, isospecific capacity maps are valuable in showing the areal distribution of the relative transmissibility values of the aquifer.

Since the specific capacity is dependent on the transmissibility and permeability, and therefore on the sediment size, it can again be noted that coarse grained sediments, readily yielding and transmitting water, will have small drawdowns with large production, and thus large values of specific capacity. Conversely, fine grained sediments are characterized by small specific capacity values.

In the heterogeneous sediments of the Tucson Basin, a well of several hundred feet is generally receiving water from a variety of sediment sizes and thus the specific capacity and transmissibility are actually measures of the average values of the aquifer. The transmissibility approximation, specific capacity times 2000, if used cautiously to determine values for the inhomogeneous basin-fill sediments, gives a transmissibility range of less than 20,000 gallons per day per foot to more than 150,000 gallons per day per foot.

The isospecific capacity map (Plate III-B) of the Tucson area shows well defined areas of large and small values. Large values are generally found along the Santa Cruz River. Within the north-central area of study a definite northwest-southeast trend of large specific capacity values is present. Extending to the south from this trend is an area of relatively large values bounded on the east and west by areas of small values. The southern extent of these areas is poorly defined because of sparce well control.

The completion technique in well construction is very important in determining the specific capacity of a well. Care must be taken, upon completion, to clean the well of any fine material that may tend to clog the well casing openings. The less fine material there is to clog the openings, the better passage of water and the less drawdown the well will experience. Because of the dependence on proper well completions, one specific capacity value is not always a valid representation of the areal values. Therefore, a single small value found within an area of large values was generally not used on the map and was considered to be due to poor well completion or subsequent plugging of the casing openings.

The values used in constructing the isospecific capacity map were obtained from the pump tests of the city wells during the fall and winter months, 1964-1965 (Figure No. 3).

Overdraft and Dewatering

Before World War II, when Tucson's population was less than 50,000, the combined industry, irrigation and municipal demand for water did not exceed the natural recharge to the basin. The changes in the water table and the dewatering of the sediments were local and of very small magnitude. Local withdrawals of groundwater were annually renewed by the natural recharge, and thus safe yield conditions existed (Todd, 1960, p. 201). Since World War II, however, the population increase of Tucson has resulted in an ever increasing demand for water, all of which has been taken from the basin groundwater reservoir of unknown size and water quality. The rate of groundwater overdraft is currently exceeding the safe yield and natural recharge by a factor of 3 or 4. This necessarily has resulted in the dewatering of large areas of the basin-fill sediments.

A dewatered sediments map from 1908-1964 was constructed but found to be unsatisfactory because of poor well control over part of the 1908 area. Areas of recharge or increased saturated thickness were indicated in Sections 31 to 36, T14S, R14E, where recharge would be least expected. Therefore the more reliable 1947 water table map was employed as the reference map for this study. The maximum water table lowering from 1908 to 1947, approximately 20 feet, occurred northwest of the City of Tucson where irrigation demands were highest.

The 1947-1964 dewatering has been found to be the composite result of four factors: the location of pumping well density, the capacity of each pumping well or well field, the lithology of the sediments yielding water, and any permeable or impermeable boundaries that exist in the basin.

The general shape of the dewatered zone (Plate III-C) indicates a slight eastward trend which is attributed to the expansion of the city in that direction. However, the large area of more than sixty feet of dewatering in the southeastern part of Tucson is due, not only to city expansion, but primarily to a large deposit of fine grained alluvial material with poor aquifer characteristics. Some wells in this area have experienced more than seven feet per year of water table lowering with average pumping rates, whereas the normal average decline for the basin in recent years has been two to five feet of lowering per year.

In Sections 34 and 35, T14S, R14E, and Sections 2 and 3, T15S, R14E, the Tucson Gas and Electric Company's high water production rates have caused a considerable area of dewatering which has coalesced with the area of dewatering of the fine grained sediments mentioned above to give the large area of maximum dewatering.

The dewatering in northeastern Tucson, already in excess of 50 feet, may be expected to continue in the future; the impermeable sub-surface boundary, discussed in the section on <u>Structure</u>, appears to be exerting considerable influence on the pumping in this area. Dewatering in excess of ten feet has been experienced from the 1963-1964 pumping southwest of this boundary. The annual recharge from the Rillito Creek, acting as a periodic positive boundary, undoubtedly lessens the negative boundary effect of the impermeable barrier.

Most of the dewatering along the Santa Cruz River can be attributed to the high production and large capacity wells in that area. Pump capacities in this area are generally triple the capacity of wells within the city.

Superimposed over the isopachs of dewatered sediments are certain water table contours of 1947 and 1964 (Plate III-C) to show the lateral displacement of these contours. As indicated and expected, there is a definite correlation between displacement and the dewatering.

SYNTHESIS OF WELL LOG DATA

Methodology

Fluviatile deposits, such as those comprising most of the basin-fill sediments of the Tucson Basin, are difficult to map and correlate laterally even when they are closely exposed in outcrops. When several hundred feet of these sediments are examined as well cuttings from water wells, it is even more difficult to correlate them; therefore detailed cross-sections and fence diagrams must be very interpretative. In order to synthesize the well log data into useful information for lithologic studies, a systematic method of plotting these data must be devised and some consistent feature in sedimentation must be recognized which can be traced laterally and vertically.

Of the hundreds of water wells drilled in the Tucson Basin, many are too generally described as to sample cuttings to be useful in interpreting the subsurface lithology. As no other logging procedures are usually employed, those sample log descriptions which appear to be in sufficient detail must be sought out and used.

Maddox (1960) analyzed and synthesized the well sample information by a numerical designation of each type of lithologic combination and induration. He used all available wells in his area of study, giving each unit in the well a numerical description. His final conclusions and interpretations of the subsurface structure and stratigraphy were based on the correlation of numerical designations of the

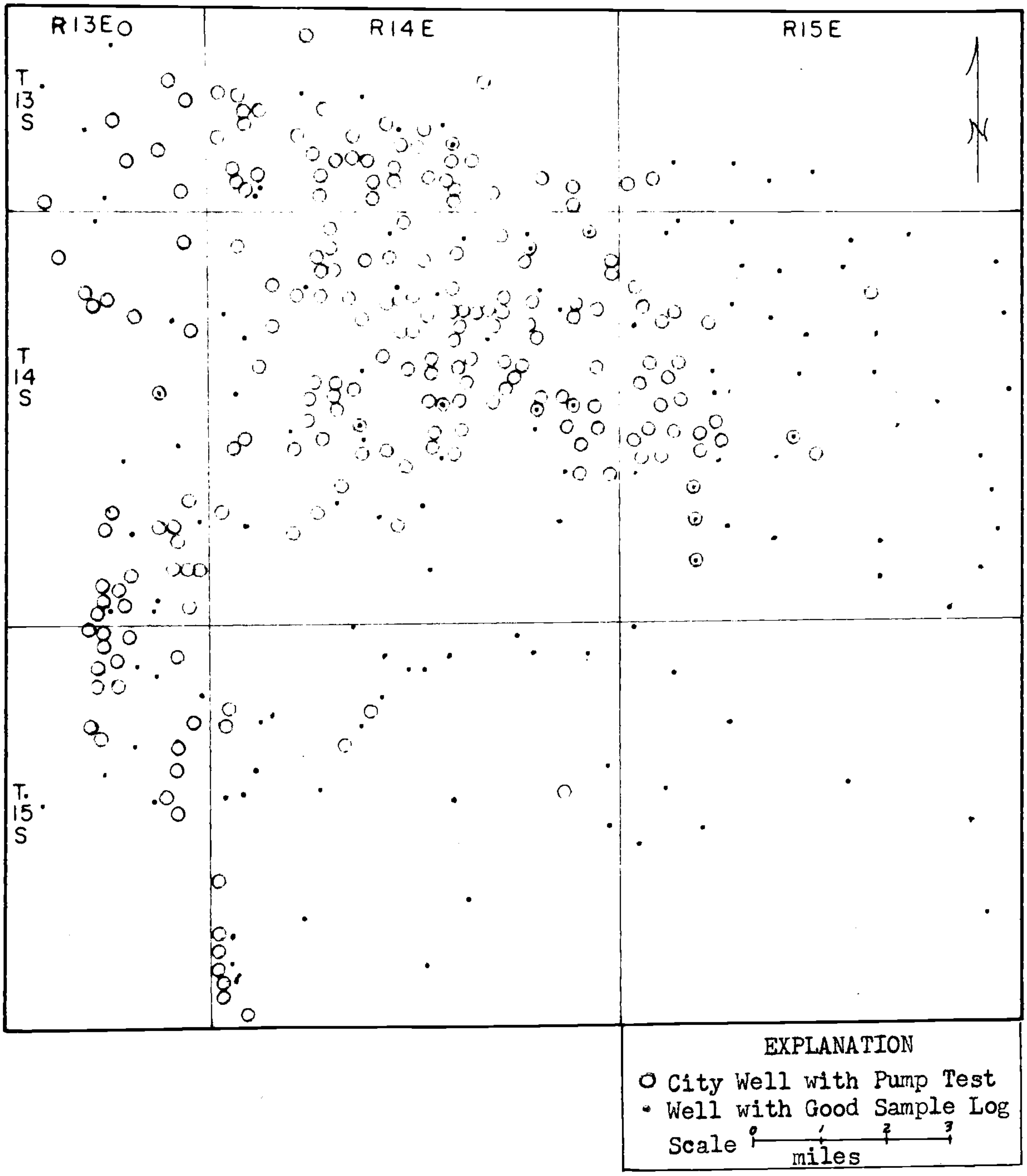


Figure 3.--Map Showing Location of Wells Studied

various lithologic units.

Streitz (1962) used a mechanical separation analysis of samples from selected wells. He also combined well descriptions of similar lithologies in local areas to arrive at a composite log which he then employed in a fence diagram. His conclusions as to the lithology and structure are informative but limited in areal extent.

The author, in attempting to synthesize the well information of a much larger area than either Maddox or Streitz included, found that neither of their approaches was entirely satisfactory, but, taking ideas from both, the author combined the elevation of each well with the well log description to develop a slightly different technique.

Using the method illustrated in Figure No. 4, 167 well log descriptions from the drillers' logs were plotted on log strips. The wells used in the study are shown in Figure No. 3. In some areas of good well control the deepest, most descriptive well log was used. In other areas sparce well control did not allow a choice of logs. Well elevations were taken from the drillers' report or from a topographic map, and the even one hundred foot elevations were then entered on the log. For each well and for four different contiguous intervals, a gravel (conglomerate), sand, or clay designation was determined from the log plot and entered on a distribution map. Seven different lithologies or combinations were recorded on the maps: clay; sand; gravel; clay and gravel; clay and sand; sand and gravel; and sand, clay and gravel. Since relative sediment size was of primary importance, conglomerates were logged as gravels and any information concerning the cementation or induration was recorded on the logs for reference. Because of the use

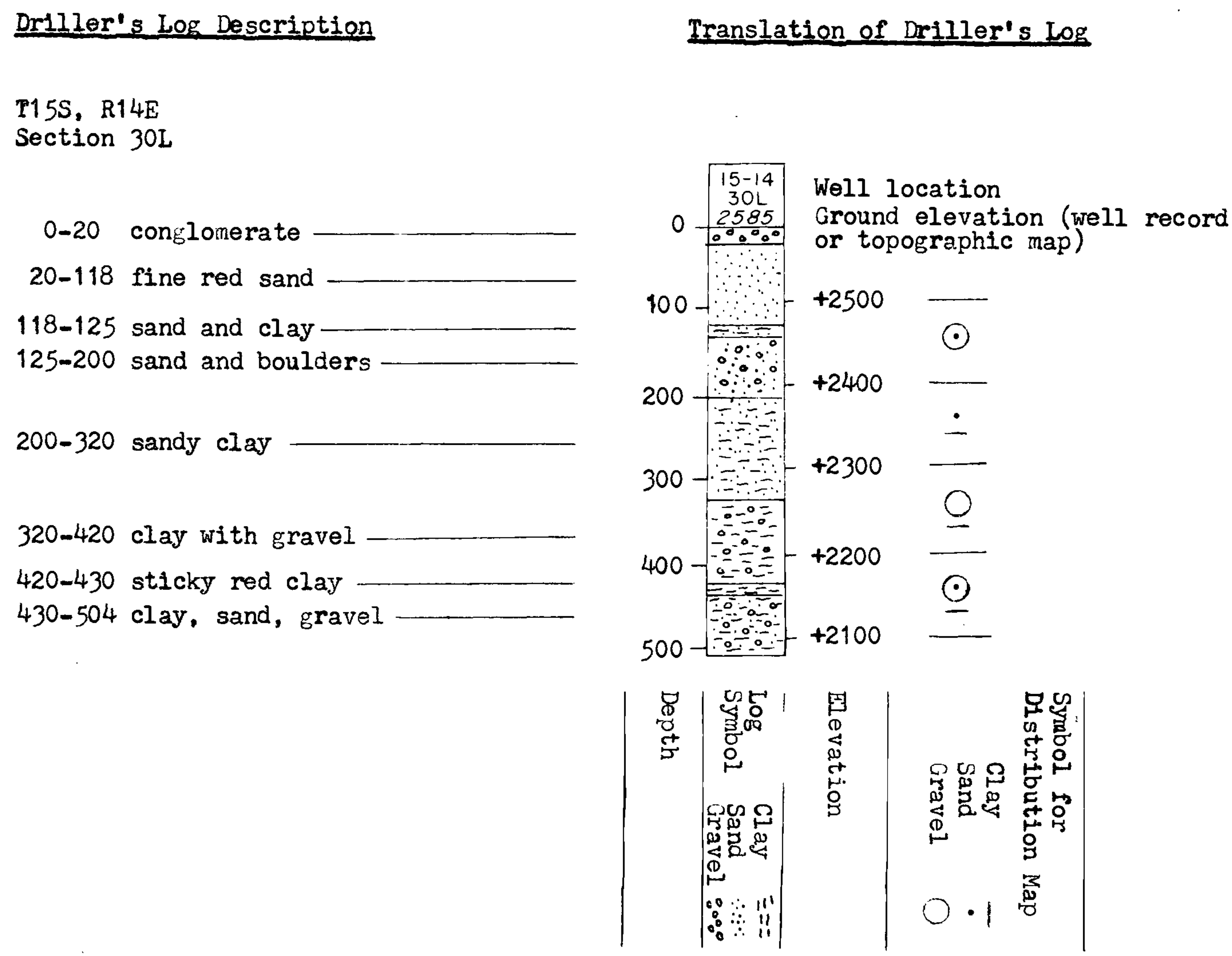


Figure 4.--Typical Sample Log Showing Methodology

drillers' descriptions of sediments, relative clastic grain sizes, rather than actual determined particle sizes, are necessarily implied in the use of these terms in this study. Plate No. II shows the distributions found by using this method of synthesis for the lithologic data from the 2100 to 2500 foot elevation intervals.

The author does not necessarily imply that for any one hundred foot interval all sediments within the study area were deposited contemporaneously or are correlative. However, if any lithologic distributions are indicated, then this method of locating them has served a purpose.

Initially, the well elevations were not considered and one hundred foot depths were taken as intervals of analysis. This proved to be unsatisfactory because of surface elevation changes.

From the distribution maps, a composite panel diagram was constructed (Plate III-D) which shows the vertical and lateral lithologic distributions of the four hundred feet of dewatered or water-bearing sediments which are most important in the present Tucson water supply.

Resulting Geological Interpretation

In this study, it was not anticipated that the numerous sample logs of heterogeneous basin-fill sediments would show as much vertical consistency as the distribution diagrams indicate for the 400 foot interval examined. However, the results of the study (Plates II and III-D) indicate that most of the upper basin-fill sediments have been deposited in consistent, fairly well defined, lithologic environments. Thus the "heterogeneity" of the sediments that is demonstrated in any one well does not appear to be as evident when the areal distribution of the predominant lithologic units is noted across the basin.

The distribution maps show, as expected, coarser material adjacent to the source areas. This is particularly apparent in the northeastern part of the area, where the Santa Catalina and Rincon Mountains bound the basin. However, in the basin where well development and water withdrawal have taken place, old stream channels, flood plains, and lake beds that previously have not been clearly defined are interpreted from the distribution diagrams.

The Santa Cruz River channel appears to have been confined to its present location during much of the basin-fill deposition, and to have deposited fine gravels, sands, and occasional silts and clays. Normally these sediments are coarse and well enough sorted to allow good well completions. Some coarse material, of igneous volcanic origin, is commonly found to the west side of the Santa Cruz River, undoubtedly derived from the Sierrita and Tucson Mountain areas.

Along the east side of the basin, coarse material is predominant. Channel deposits along the present Pantano and Rillito Creeks appear to have been common throughout most of the time of basin-fill deposition. In the vicinity of the confluence of the Pantano and Rillito Creeks and slightly basinward, the area of highest specific capacity, relatively clean sands and gravels are present, probably due to through-flowing streams which winnowed the fine material from the coarse channel fill.

Of particular interest is the distribution of sediments toward the center of the area of study. In this area prominent fine grained facies are encountered in the southwest of T14S, R15E, which is the area of excessive dewatering and low specific capacities. Adjacent to this area on the west is a zone of relatively coarse material which grades into the coarse clean material to the north. High specific capacity values are found to correlate with this facies distribution. This is interpreted as an old stream channel entering probably from the south-southeast. To the west of this channel, where well control is sparce, another larger area of fine grained sediments is present. These fine grained units may be a flood plain deposit of either this central channel or the ancestral Santa Cruz River.

The northeast-southwest structural trend across the basin, as described in the section on Structure, does not appear to have been a major control on the depositional environments of this stream channel and adjacent flood plains. It would therefore appear that the postulated horst block was actively displaced in late Pliocene time and largely eroded by the time of the basin-fill deposition.

CORRELATION OF THE GEOLOGY AND HYDROLOGY OF WATER TABLE AQUIFER SEDIMENTS

The ultimate purpose of the synthesis of the well data and analysis of the lithology is to determine the relationships between the hydrodynamics and the geologic controls in the basin.

The facies distribution maps were overlaid with the isospecific capacity map and the dewatered sediment and lateral displacement map. The irregularities and anomalies in the water table contours were interpreted and related to probable causes (Plate III-C).

As previously stated, dewatering in the Tucson Basin was found to be due to well density and capacity, lithologic controls and permeability boundaries. However, it is difficult to determine the exact amount of dewatering in any one area which is attributable to each factor. From analyzing the lithologic and permeability controls and the pumping history of the city's expansion, a relative value of dewatering due to each factor may be estimated.

It should be pointed out that as the City of Tucson has grown, the municipal water demands have been met by increasing the number of wells in the area and also extending the area of pumping. The result of this has naturally led to the increased drawdown in the area as each well's radius of influence reaches that of other wells. Because of this resultant drawdown and dewatering of the aquifer, a decreased saturated thickness (and transmissibility) has caused a decline of production in many wells. It is expected therefore that production from any one well should decline as the water table is continually lowered.

In the northwestern portion of the area, appreciable dewatering and resultant displacement has been due to the large water demand for irrigation and the narrow extent of the aquifer at this point in the basin. The 2300 foot contours (1947 and 1964) begin to show the municipal location and demand for water. Contributing to this displacement are the fine grained sediments extending into this area (Plate II-C).

The 2400 foot contours (1947 and 1964) demonstrate the zones of maximum displacement and dewatering across the basin. In the northeastern part of the basin, in an area of relatively clean coarse basin-fill sediments, well density is high and water withdrawal has been large. As more water is removed from these sediments, the impermeable (negative) boundary which is present in the subsurface will be exerting more influence on the dewatering. In the southeastern portion of the city, dewatering has been controlled primarily by the presence of the fine grained sediments. Increased pumping in recent years has intensified this problem. The excessive water demand by the Tucson Gas and Electric Company operations south of Tucson is responsible for the dewatering in this area. Lack of displacement of the 2400 foot contour west of the Tucson Gas and Electric Company wells can be attributed to the sparce population and well development. Along the Santa Cruz River large displacements are caused by the high capacity wells of that area.

The 2500 foot contours (1947 and 1964) begin to suggest a basin constriction and a radius of influence of the city's pumping. This area shows prominently on the 1964 water table map, where a close spacing of contours is evident (Plate III-A). The radius of influence of the city's pumping does not appear to be the entire cause. Several explanations of this anomaly have been suggested and one or more may be present. It has been suggested that beginning along this semi-circular pattern of contours and extending outward across the basin, a low permeability or fine grained bed is present within the alluvium and the resulting water table lowering across this bed has caused the close spacing of the contours. From drillers' logs this fine grained bed has not been precisely defined. The almost stationary nature of these close contours for a number of years does not substantiate either the radius of influence of pumping or the fine grained bed explanations. Also postulated as a cause of this contour pattern is the possibility of a zone of restricted flow. This zone would be coincident with and may be caused by the horst block described under Structure and shown on Plate I, cross-section A-A'. If the more permeable alluvial beds were deposited across a slightly higher, less permeable rock (Pliocene clays and silts), then as dewatering to the north of this block takes place, the net inflow of groundwater from the south across to the vertically restricted zone would result in a velocity and gradient increase if the lateral permeability remains constant. This would be similar to the increased velocity of surface flow over a submerged object. The lithologic distribution diagrams do not indicate any sedimentation controls that would cause this water table contour pattern.

In the northeastern portion of the basin, the water table contours show a close spacing that has intensified since 1947, but has not moved laterally. It is believed that this is due to the impermeable (dike or fault) feature indicated by the gravimetric survey mentioned under Structure. Because the 2470 foot contour in this area appears to be the lowest contour unaffected by the dewatering in the basin, the impermeable feature probably rises to this elevation. No wells have been drilled in the exact location of this barrier, however some of the surrounding wells have reported encountering granitic type rock at shallow depths. As there are no city wells with pump tests northeast of this feature, it is difficult to predict the areal yield and transmissibility of the sediments. Privately owned wells in the areas of these sediments are generally of low capacity.

The lithologic distribution diagram shows a high correlation with the isospecific capacity map which was discussed in an earlier section. High specific capacity values can be seen to coincide with the coarse, generally clean, facies, while the finer grained facies are correlative with the lower specific capacity values. The channeling in the central portion of the area, interpreted from the distribution diagram, is borne out by the specific capacity correlation and configuration. The extension of this channel to the south by additional drilling should outline a belt of relatively good water production.

A program of recompleting wells by gravel packing and/or deepening is currently being carried out by the City of Tucson Water Department. Preliminary indications are that, in areas of coarse grained sediments, the gravel packing or deepening of a well has been successful in increasing the production and specific capacity. In the areas of fine grained sediments, recompletion attempts have generally resulted in insignificant changes in the production and specific capacity.

Though it has been easy to discuss the basin sediment distribution of the geologic past and correlate this with areas of known good or poor production, it is hoped that this study may indicate areas of future water development or well deepening where good results may be expected and those areas where future development should be approached with caution.

CONCLUSIONS

Certain lithologic and structural controls of the Tucson Basin combined with man's intervention have caused the water table of the area to decline in the last twenty years in a somewhat unpredictable manner. A recognition of these natural and man made controls on the system is necessary to explain the anomalous water table response.

In heterogeneous sediments of the type found in the Tucson Basin, the methodology used in this study has been successful in determining the areas of large scale lithologic variations. It is believed that direct correlation of well logs from well to well is often too laborious and too interpretive to be of practical value in a study of this type.

The lithologic distributions of the sediments of the water table aquifer from the selected interval, +2100 - 2500 feet, show definite areas of coarse, fine, and mixed sediments. The overall distribution of this 400 foot interval reveals an unexpected vertical consistency which indicates that a definite drainage pattern, instead of a continually shifting undefined pattern, existed throughout much of the time of basin-fill sedimentation.

The exceptionally good correlations of the dewatered and iso-specific capacity zones with the lithologic distributions demonstrate that in a basin-fill deposition of this type, a careful study of the sediment size distribution could outline areas of relative groundwater yields.

If artificial recharge in the Tucson Basin is undertaken on a large scale, those areas of coarse, clean sediments, outlined in this study, should be selected as the receiving areas. It is especially advantageous that the natural areas of recharge to the basin, the Santa Cruz River and Rillito Creek, are regions of basin-fill sediments of good permeabilities. Detention of rainfall runoff in either of these areas should be effective in increasing the natural recharge to the basin.

The population and water demands of the Tucson area are expected to increase remarkably in future years. To provide a sufficient supply for the future water demand, continual successful exploration for and development of the groundwater reserves is a necessity. Perhaps a formulative approach, of the type used in this study to determine the controlling factors--geologic, hydrologic, and man made-- would assist in the exploration for extended groundwater reserves.

BIBLIOGRAPHY

Blissenbach, E. B. K. (1957). "The Geology of Alluvial Fans in Arizona." Master's thesis, University of Arizona.

Brennan, D. J. (1957). "Geological Reconnaissance of Cienega Gap, Pima County, Arizona." Ph. D. dissertation, University of Arizona.

Bryan, Kirk (1925). "Date of Channel Trenching (Arroyo Cutting) in the Arid Southwest." Science, vol. 62 (Oct. 16, 1925).

Cooley, M. E. and E. S. Davidson (1963). "The Mogollon Highlands--Their Influence on Mesozoic and Cenozoic Erosion and Sedimentation." Arizona Geological Society Digest, vol. VI, 7-36.

Coulson, O. B. (1950). "Geology of the Sweetwater Drive Area and Correlations of Santa Cruz Valley Gravels." Master's thesis, University of Arizona.

Damon, Paul E. and M. Bikerman (1964). Contribution No. 104, University of Arizona Geochronology Laboratories.

Fenneman, N. M. (1931). Physiography of the Western United States. New York: McGraw-Hill Book Co., Inc.

Heindl, L. D. (1959). "Geology of the San Xavier Indian Reservation, Arizona." Southern Arizona Guidebook II. Arizona Geological Society, 153-159.

Kidwai, G. E. (1957). "The Relationship of Groundwater to Alluvium in the Tucson Area, Arizona." Master's thesis, University of Arizona.

Maddox, G. E. (1960). "Subsurface Geology Along Northwest Rillito Creek." Master's thesis, University of Arizona.

Moore, L. M., C. F. Tolman, B. S. Butler, and R. M. Hernon (1941). "Geology of the Tucson Quadrangle." U. S. Geological Survey open-file report. (On file at the U. S. Geological Survey office, Tucson, Arizona.)

Schwalen, H. C. and R. J. Shaw (1957). "Groundwater Supplies of the Santa Cruz Valley of Southern Arizona between Rillito Station and the International Boundary." University of Arizona Agricultural Experimental Station Bulletin 288.

Schwalen, H. C. and R. J. Shaw (1961). "Progress Report on Study of Water in the Santa Cruz Valley, Arizona." University of Arizona Agricultural Experimental Station Report 205.

Smith, G. E. P. (1910). "Groundwater Supply and Irrigation in the Rillito Valley." University of Arizona Agricultural Experimental Station Bulletin 64.

__________ (1938). "The Physiography of Arizona Valleys and the Occurrence of Ground Water." University of Arizona Agricultural Experimental Station Bulletin 77.

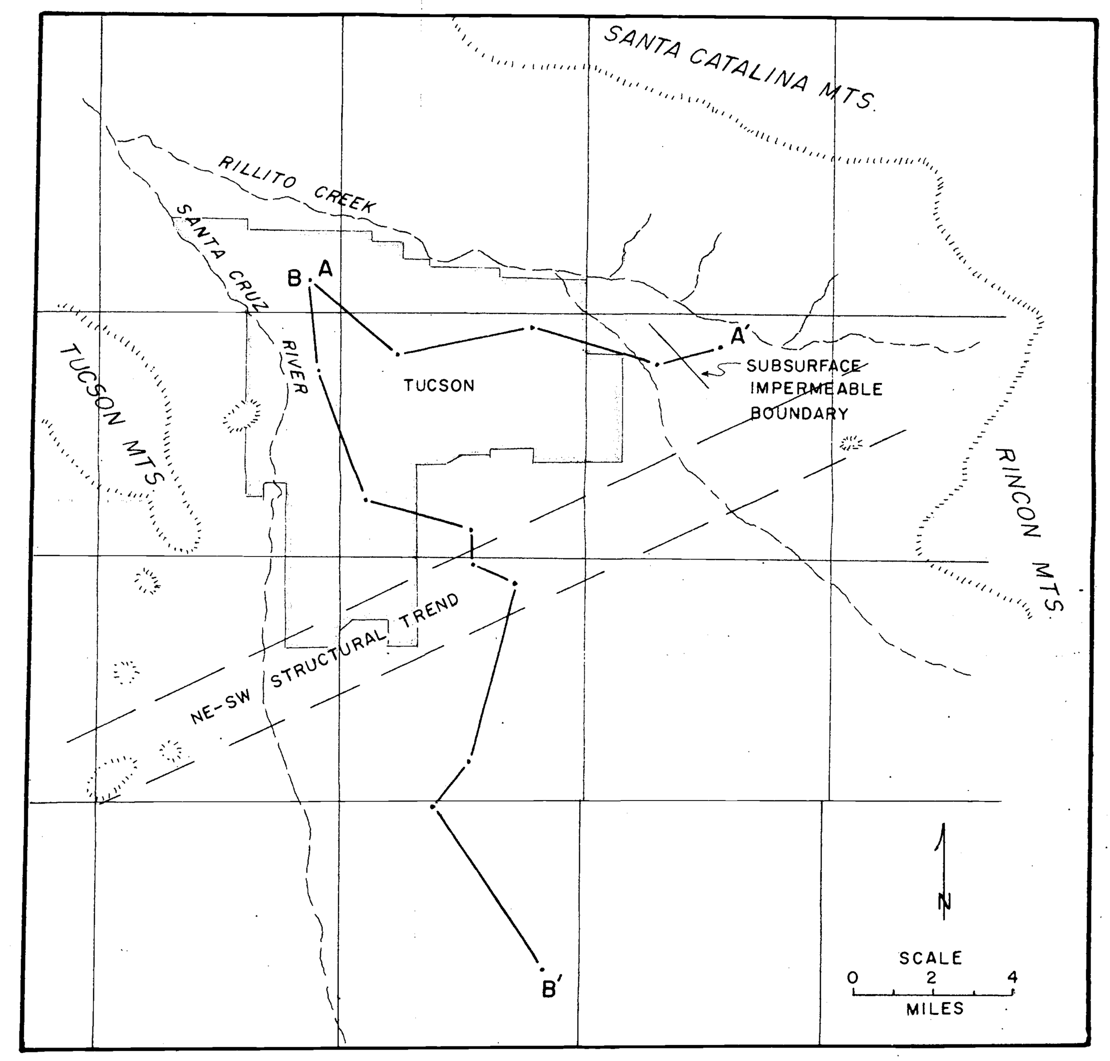
Streitz, R. K. (1962). "Subsurface Stratigraphy and Hydrology of the Rillito Creek-Tanque Verde Wash Area, Tucson, Arizona." Master's thesis, University of Arizona.

Todd, David K. (1960). Ground Water Hydrology. New York: John Wiley & Sons, Inc.

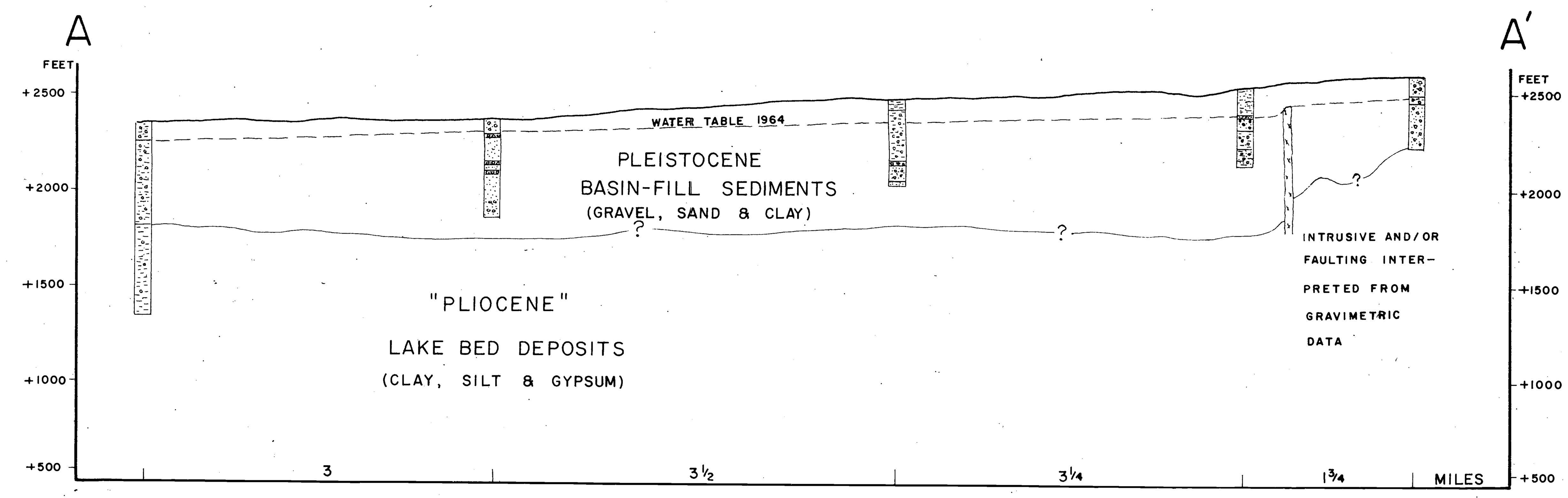
Turner, S. F., and others (1943). "Groundwater Resources of the Santa Cruz Basin, Arizona." U. S. Geological Survey open-file report.

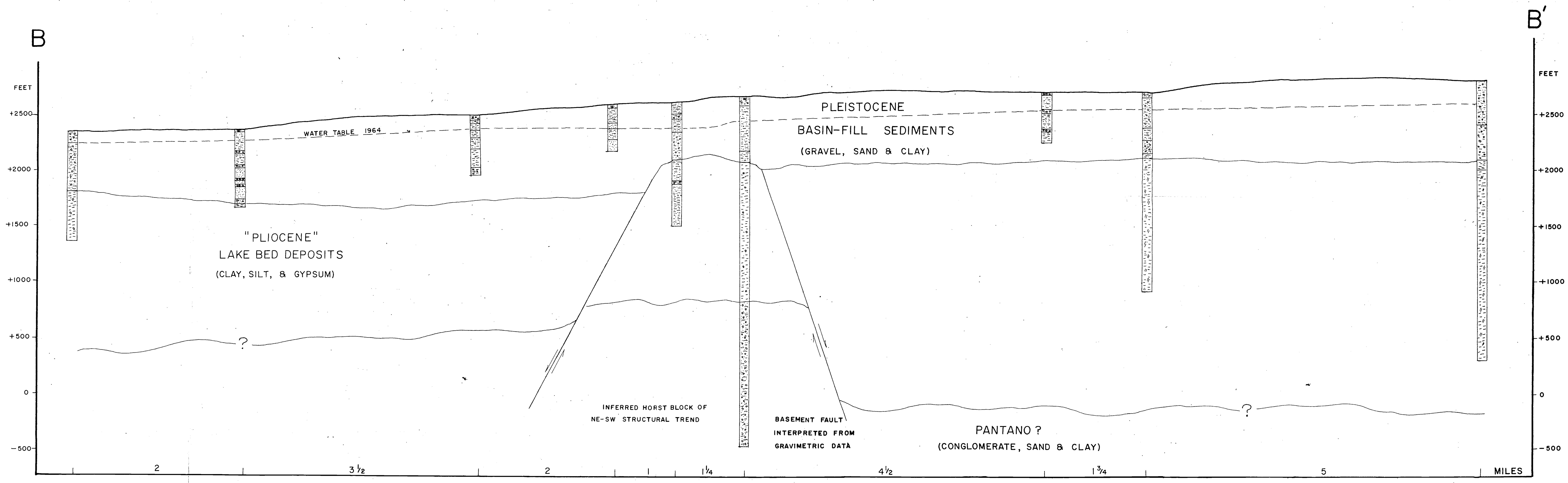
Voelger, K. (1953). "Cenozoic Deposits in the Southern Foothills of the Santa Catalina Mountains near Tucson, Arizona." Master's thesis, University of Arizona.

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.)



LOCATION MAP





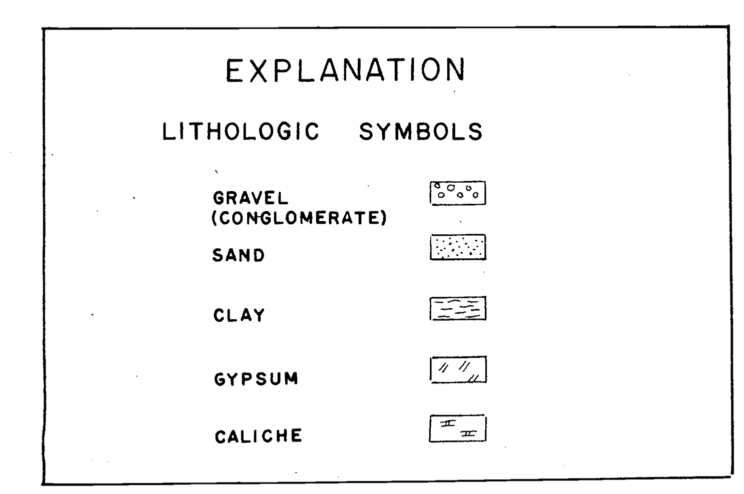
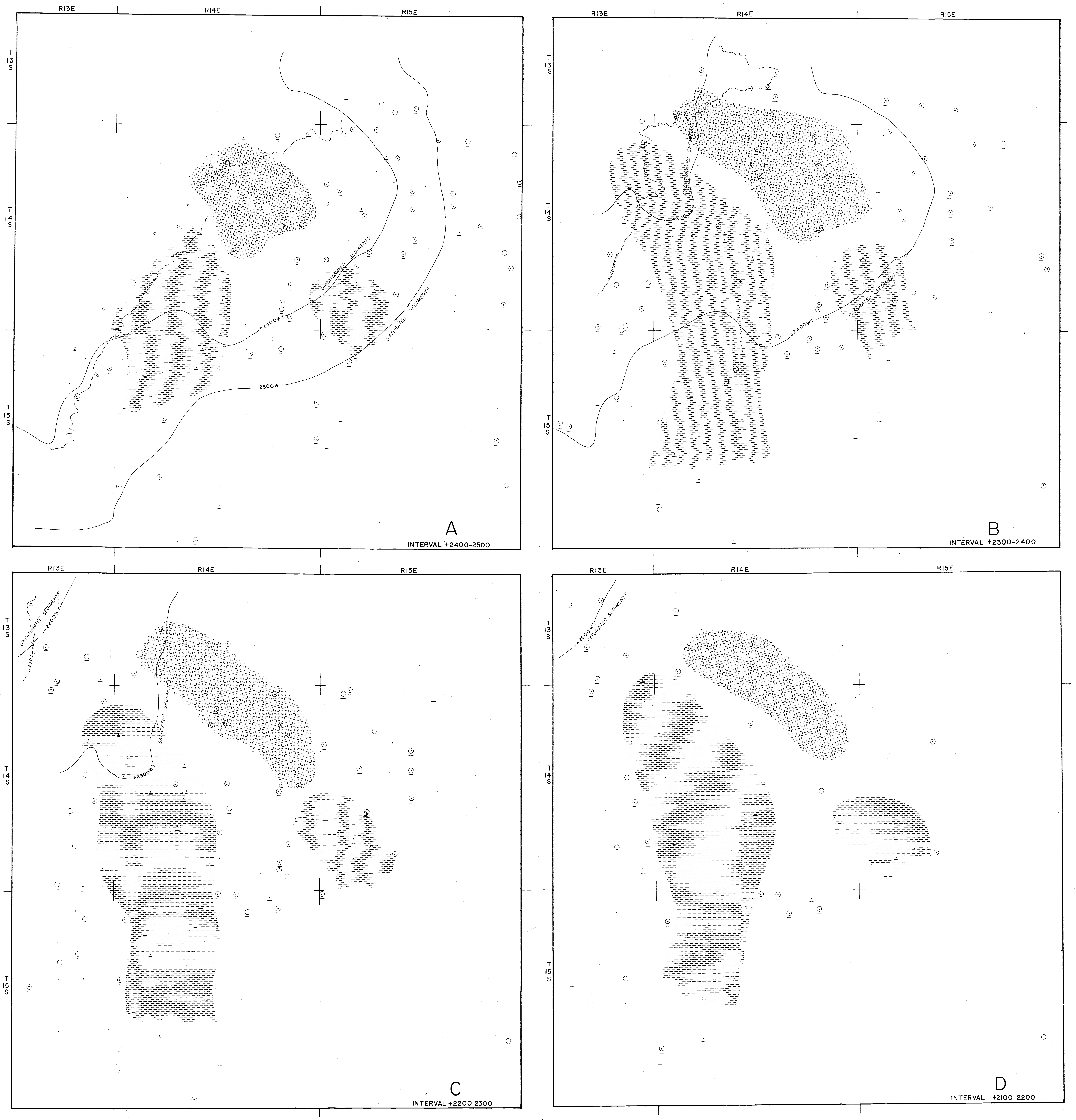


PLATE I. HYDROGEOLOGIC SECTIONS OF THE TUCSON BASIN A-A' & B-B'

W J GANUS 6-65



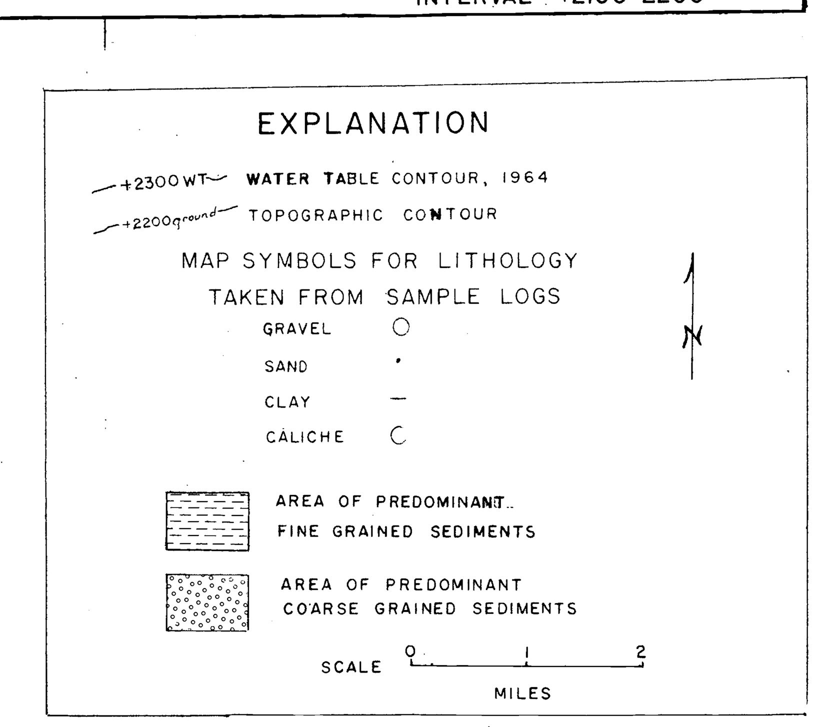


PLATE II. MAPS SHOWING THE LITHOLOGIC DISTRIBUTIONS OF THE TUCSON BASIN WATER TABLE AQUIFER SEDIMENTS, +2100 to +2500

W J GANUS 6-65

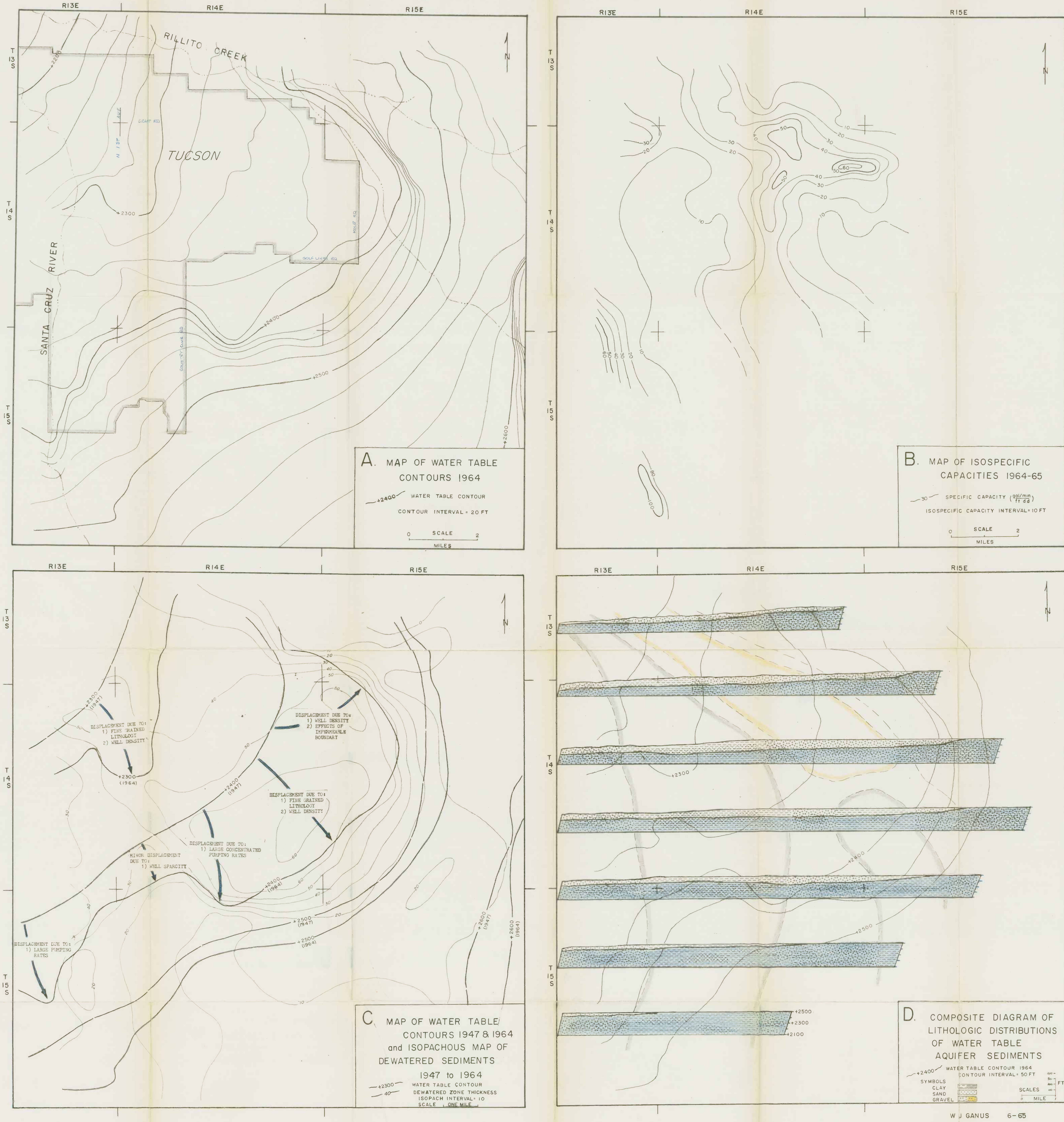


PLATE III. MAPS SHOWING HYDROGEOLOGIC FEATURES OF THE WATER TABLE AQUIFER OF THE TUCSON BASIN