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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Denver, Colorado 80225

GEOLOGY AND HYDROLOGY OF THE TATUM SALT DOME, LAMAR COUNTY, MISSISSIPPI

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By

E. J. Harvey and R. V. Chafin

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ABSTRACT

Tatum salt dome, a subsurface feature in southwestern Lamar County, Miss., was formed by a salt stock, about 1 mile in diameter at the top, that has protruded through rocks as young as early Miocene in age. The salt stock is the medium in which an experiment using nuclear devices is proposed. The top surface of the salt stock, which has very little relief, is about 1,500 feet below land surface. Overlying the salt is an anhydrite caprock 400 feet thick which in turn is overlain by calcite caprock 50-150 feet thick. The sediments surrounding and overlying the dome have a regional dip to the southwest of about 40 feet per mile except where modified by Tatum dome and other structures.

The Cook Mountain Limestone, at a depth of approximately 2,600 feet at Tatum dome, is the shallowest aquifer (designated aquifer 5) that contains brine. This aquifer is used for the disposal of brine in the vicinity of the Baxterville oil field, a few miles southwest of Tatum dome. The injection of brine has caused a rise in head in this aquifer at Tatum dome and apparently has reversed the flow of brine to the northeast. The aquifer probably can be used for disposal of salt mined at Tatum dome as part of the construction effort associated with the proposed experiment. Such use will result in a further rise in head. Thick intervening clay beds, however, probably will prevent much movement of brine into overlying fresh-water aquifers.

The deepest fresh-water aquifer (designated aquifer 4) is in limestone beds in the Vicksburg Group, at a depth of about 2,000 feet in the vicinity of Tatum dome. The yield of the aquifer is small and the aquifer is not now utilized for water supply probably because large yields can be obtained from wells in shallower sands. This aquifer is discontinuous over Tatum dome but may be hydraulically connected with the caprock.

The overlying sandstone and clay beds of Oligocene(?) and Miocene age contain several sand units that will yield large amounts of water to wells. In the Tatum dome area the principal sandstone units have been designated aquifers 1, 2, and 3; the deepest one is aquifer 3.

These principal aquifers in turn have been subdivided into a and b units. Aquifer 2a has the highest permeability. These sands, in a general way, form one hydrologic system that is extensive over the general region. Large-scale regional pumping from this hydrologic system has altered the original regional hydraulic gradient, which was south-southwest, and has affected the hydraulic gradient in the vicinity of Tatum dome. The result has been to make the hydraulic gradient more gentle in the vicinity of Tatum dome, but there is evidence to suggest the direction of movement of water has been reversed in some of the sandstone units.

Surficial sand and gravel deposits blanket most of the region. The deposits are thick enough and the infiltration rate is high enough that the water discharged from this hydrologic system into adjacent drainage maintains a high base flow in perennial streams. The aquifer is utilized intensively for domestic water supply in the rural area.

On the remote chance that radioactivity might escape from the salt stock in which the nuclear tests are proposed, the activity would most likely enter the caprock, the overlying sands of aquifer 3, or aquifers 4 and 5 on the flank. Computed values of the rate of movement of water in aquifers 3, 4, and 5 indicate that the movement will be less than 10 feet per year. This slow rate of movement coupled with the high exchange capacity of the material constituting the aquifers lead to the conclusion that the offsite contamination potential is small to nil. The highest rate of movement, about 160 feet per year, was computed for aquifer 2a. It is unlikely that radioactivity would be released into this aquifer, which is several hundred feet above the caprock.

INTRODUCTION

This report briefly describes the geologic structure and stratigraphy of the Tatum salt dome area and discusses in some detail the hydrologic conditions of the principal aquifers. Emphasis is placed on the direction and rate of movement of water in each of five different aquifers, the deepest of which lies at a depth of 2,600 feet below land surface in the vicinity of Tatum dome. This information on movement of ground water is needed for pretest and postshot evaluation of the contamination potential associated with the testing of nuclear devices in the salt of the Tatum dome.

Source of data

Data used herein were derived from electric logs of exploratory holes drilled by oil and sulfur companies, from seismic exploration and from recent exploratory drilling on the dome by the Atomic Energy Commission. Hydrologic data were collected by personnel of the U.S. Geological Survey under the general supervision of J. W. Lang. The geologic section used in this report was prepared mostly from studies of D. H. Eargle and R. V. Chafin. Test data related to the disposal of brine by injection wells in the Cook Mountain Limestone were obtained from the U.S. Bureau of Mines.

GEOGRAPHIC SETTING

The approximate geographic center of the Tatum salt dome, Lamar County, Miss., is at coordinates N. 537,000 and E. 269,000 (Mississippi State grid coordinates). The top of the salt stock of the Tatum dome is at a depth of 1,500 feet and underlies parts of secs. 11, 12, 13, and 14, T. 2 N., R. 16 W. (fig. 1). This area consists of moderately dissected terrain with narrow ridges rising about 100 feet above the valleys. Elevations above mean sea level range from 230 feet along the streams to 350 feet on the hills along the lease border.

Half Moon and Grantham Creeks drain the 1,400-acre AEC lease centered on the dome. Small springs and seeps are common along exposed contacts of the Miocene clays and the overlying permeable surficial deposits. The ground water discharged from these seeps maintains the high base flow of streams in the area.

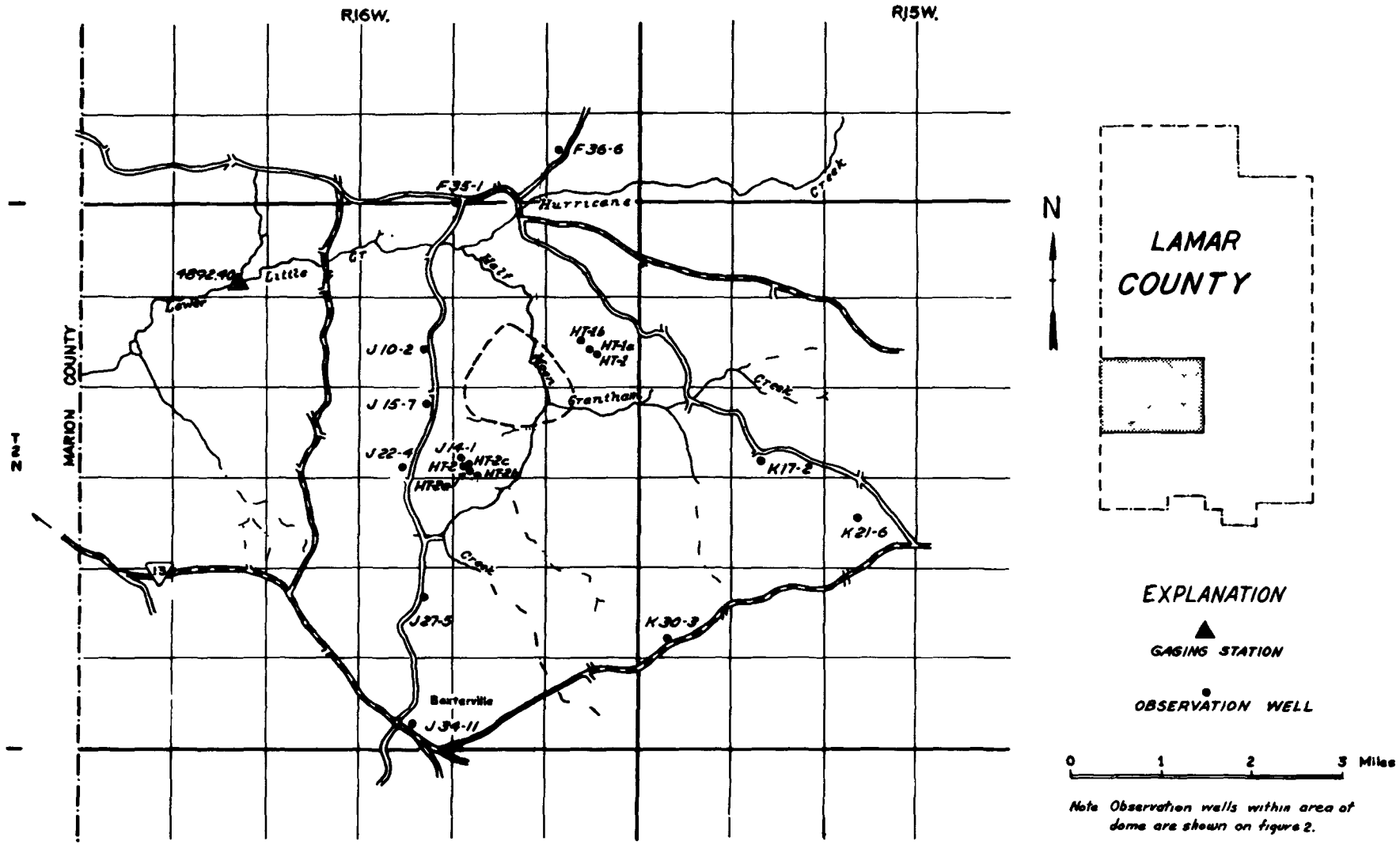

Figure 1.--Map of Tatum dome and vicinity, Lamar County, Miss., showing locations of observation wells.

The climate of southern Mississippi is subtropical. Long-term climatological records are not available for the immediate Tatum dome locality. However, at Hattiesburg, about 20 miles northeast of the dome, the mean annual precipitation is about 60 inches and the mean annual temperature about 67°F. December has a mean temperature of 51.8°F, and July has a mean temperature of 81.6°F. Precipitation is well distributed through the year. July and March are the wettest months of the year, having nearly the same amount of rainfall (6.85 and 6.83 inches, respectively). October is the driest month with an average of 2.29 inches.

GEOLOGIC SETTING

Tatum dome is a large buried salt stock that has pierced sedimentary deposits of Early Cretaceous to early Miocene age. Sediments of later Miocene age surround and overlie the dome but are thinner over the dome than in the surrounding area. Rocks of Eocene and Oligocene age are absent on the crest of the dome. The sedimentary deposits of Tertiary age have a regional strike of approximately N. 75° W. and dip southwest about 40 feet per mile except where modified by Tatum dome or other local structural features.

Stratigraphy, lithology, and identification of aquifers

The stratigraphic section for southeastern Mississippi has been described by Eargle (1971). Presented here is a resumé of the stratigraphic section, a brief description of the lithology of the

formations, and the identification of the aquifers in the dome area. Figure 2, a cross section through Tatum dome shows diagrammatically, the geology and the position of the aquifers and aquicludes overlying and adjacent to the dome. Formations and aquifers at depths below the Cook Mountain Limestone are not of particular concern to the safety aspects of Project Dribble and therefore will not be described.

With the possible exception of aquifer 4, all aquifers on the down-dip or southwest side of the dome apparently are 20-40 feet thicker than on the up-dip side. Aquifers 1-5 in Hydrologic Test Well 2, southwest of the dome, are found at depths ranging from 30 to 190 feet deeper than in Hydrologic Test Well 1, which is on the up-dip side of the dome. Where the aquifers overlie the dome they are thinner and tend to be lenticular and discontinuous. Tentative correlations between wells is possible only by electric logs because of the general lack of physical correlative criteria in the deposits of Miocene age.

The lack of uniformity in thickness of the Miocene beds is explained by their fluviatile origin. The thinning of some beds over the dome, while others show little change in thickness, is related to the rate of deposition as compared to the rate of subsidence in the rim syncline and the rate of rise of the salt core.

Cook Mountain Limestone

The Cook Mountain Limestone, designated aquifer 5, has been pierced by the salt stock and therefore does not overlie the dome.

This limestone is underlain by the Sparta Sand and Zilpha Clay (undifferentiated) and overlain by the Cockfield Formation, which contain no known aquifers in the vicinity of the dome. From the northeast side to the southwest side of the dome aquifer 5 ranges from 160 to 180 feet in thickness. It is composed primarily of fine- to coarse-grained marly limestone interbedded with greenish-gray to dark-brown and black calcareous glauconitic clay and shale. Aquifer 5 contains saline water.

Vicksburg Group

In ascending order, the next aquifer of importance (aquifer 4) lies within the Vicksburg Group and is separated from aquifer 5 by about 340 feet of pre-Vicksburg clays and soft marly limestone. This clay and marly limestone zone is made up of the following geologic units: Cockfield Formation, Moodys Branch Limestone, Yazoo Clay, and Red Bluff Clay. Aquifer 4, in its lower part, consists of limestones of the Vicksburg Group undifferentiated and, in its upper part, sand of the upper part of the Byram Formation. This aquifer, as well as aquifer 3, may possibly have a hydraulic connection with the caprock overlying the salt stock. Aquifer 4 and the overlying sandstones contain fresh water.

Catahoula Sandstone and Hattiesburg and Pascagoula Formations

The Catahoula Sandstone includes aquifers 3b (Tatum Limestone Member) and 3a (upper part of Catahoula Sandstone), and is separated from the underlying Vicksburg Group by relatively impermeable beds possibly correlative with the Chickasawhay Limestone.

For purposes of correlation and differentiation of aquifers and aquicludes, the top of the Catahoula is placed at the clay and shale zone immediately beneath aquifer 2b. No definite contact of significant areal extent has been identified between the Catahoula and Hattiesburg Formations or between the Hattiesburg and Pascagoula Formations. For the purpose of correlation between wells, arbitrary points on electric logs have been picked. In some sections of Pascagoula, Hattiesburg, and Catahoula deposits, similar contacts have been picked on the basis of heavy-mineral distribution (Brown and Guyton, 1943), but this is not to be considered an unequivocal method of classification and correlation over large distances.

There is a possibility of a hydraulic connection and lithologic correlation with the "false cap," which immediately overlies the calcite caprock. Aquifer 3b, recognized only off the flanks of the dome, lies within what was previously called the Heterostegina Assemblage Zone now called the Tatum Limestone Member of the Catahoula Sandstone. This member of questionable Oligocene and Miocene age is made up of thin-bedded limestone and sandy limestone interbedded with calcareous sandstone and clay. Over the dome, aquifer 3b is apparently interrupted by the caprock.

Aquifer 3a is in the upper part of the Catahoula Sandstone. This sandstone, found overlying as well as adjacent to the dome, contains material that ranges in size from silt to coarse sand and pebbles. Clay and shale partings are found throughout aquifer 3a, and it is calcareous, pyritic, and lignitic.

Aquifers 3a, 2b, 2a, 1, and the "local" aquifer all occur within the Miocene Series. Correlation of individual sandstone beds of Miocene age across the dome and in adjacent areas is problematical. The beds are lenticular, and correlatable marine beds such as those found between aquifers in the Eocene Series are absent. In setting up the original nomenclature of the Miocene aquifers, the most extensive units were numbered from 1 to 3 in descending order as shown on figure 2. Aquifer 3 was previously discussed as the Catahoula Sandstone. Where a lenticular aquifer splits into two sand beds separated by a clay unit the upper bed is designated "a" and the lower "b." Aquifer 2, even though it seems to be consistent, divides into two units in some areas. Aquifers 2b, 2a, 1, and the "local" aquifer are grouped together lithologically for the sake of brevity as there is no significant lithologic variance in grain size, sorting, shape, or sand content within individual aquifers. The section composed of the above numbered aquifers may be described in general as Pascagoula and Hattiesburg Formations undifferentiated, and is composed of greenish-gray to light-gray, silty calcareous clay and fine to very coarse sand with some pebbles.

Citronelle Formation, terrace deposits, and alluvium

The Pliocene Citronelle Formation, Pleistocene terrace deposits, and Holocene alluvium form a blanket or surface veneer of sand and gravel over most of southern Mississippi. In the Tatum dome area the deposits range from 0 to 130 feet thick, with the thicker sections

located on the terraces and gentle slope of the ridges. In a few places along some steep ridges and in the deeper stream valleys where the streams have eroded down to the Miocene clays these surficial deposits are absent. This permeable veneer of sand and gravel forms an extensive water-table aquifer overlying the deposits of Miocene age and is an excellent environment for ready recharge to the underlying aquifers.

Caprock

The caprock, which overlies the salt stock, consists of a thick lower unit of anhydrite and an upper thinner unit called the calcite caprock. The high point, altitude -617 feet, recorded on the calcite caprock horizon (fig. 2), is at Freeport Sulphur Co. No. 4 well. The lowest altitude at which the top of the calcite caprock was penetrated was -1,499 feet in the Freeport Sulphur Co. No. 2.

The highest point of the anhydrite horizon (fig. 2) is at an altitude of -765 feet in the Freeport Sulphur Co. No. 4 well. The lowest altitude at which the top of the anhydrite was penetrated was -1,507 feet in the Freeport Sulphur Co. No. 2.

The greatest thickness of caprock is at exploratory test hole E-6, where it is 602 feet thick. The next greatest thickness of caprock, 590 feet, was found in test hole E-7. At test hole E-7 the top of the caprock is at 905 feet and the salt is 1,495 feet below the land surface. Cores taken from the interval 1,020 feet to 1,156 feet include fractured and brecciated sandstone with lignite

and pyrite; conglomerate consisting of calcite fragments, fine to coarse sand, and quartz and black chert gravel. These cores are believed to be of Miocene sedimentary rocks filling a fracture in the caprock. The depth at which this material was found below the top of the calcite caprock indicates a vertical displacement of not less than 251 feet; however, there are no other factors to substantiate a fault of such magnitude. The displacement may be explained by assuming that during the structural evolution of the dome, a system of fractures within the caprock was developed to such an extent that the Miocene sediments were able to migrate downward and fill the open fractures. This would also explain the 136-foot section of brecciated material found in test hole E-7. The unusual thickening of calcite and a corresponding thinning of anhydrite shown on figure 2 for test hole E-7 is based entirely on drill cuttings and coring information.

The structure section (fig. 2) shows a surface of very low relief on top of the salt. The dome surface within the bounds of the exploratory wells 1-6 (within a 2,000-foot radius of the geographic center of the dome) has a total relief of only 27 feet. The known points of highest altitude are at Freeport Sulphur Co. No. 6 (well 14 on inset map, fig. 2) which lies near the southwest perimeter of the dome and at test hole E-2, near the southern perimeter. A shallow trough between these two points extends N. 10° W. toward Freeport Sulphur Co. No. 3 (well 13 on inset map, fig. 2), and from a point just west of that well, N. 42° W. This trough is thought to be the result of possible faulting in the salt plug during the time of its

uneven upward movement. It appears likely that this uneven upward movement contributed to the high degree of fracturing which has been encountered by drilling in the caprock. It also seems probable that these fractures would extend from the salt-caprock contact to the sedimentary deposits overlying the calcite caprock and the "false cap".

Driller logs and electric logs both indicate that there is a porous "mushy" zone at the salt-anhydrite contact. This is a soft, mucky, gypsiferous material that probably includes the less soluble materials released from the salt by the dissolving action of water migrating downward through the fractured caprock and then moving laterally along the salt-anhydrite contact zone.

It is possible that the caprock evolved by this method during the numerous stages of upward movement of the salt. The muck and less soluble minerals were compressed and consolidated by the upward growth of the salt stock. During stationary periods or very slow movement the downward-migrating ground waters dissolved the salt leaving the less soluble residue, and the process of consolidation was repeated. Therefore, it is assumed that the fracturing of the caprock continued and, as a result, the fractures extend throughout the caprock from top to bottom.

As shown in figure 2, there appears to be a good probability that aquifer 3 and(or) aquifer 4 are hydrologically connected with the calcite caprock aquifer. If the fracture porosity of the caprock was developed by the upward movement of the salt stock it is not

unreasonable to expect that the fractures are in direct contact with the sands of aquifers 3 and 4. The solution-enlarged fractures and the moderately fresh water imply that water is circulating through the caprock. Aquifers 3 or 4, therefore, would have to be hydrologically connected to the caprock to facilitate such circulation.

HYDROLOGIC SETTING

Water is one of the more important natural resources in the vicinity of Tatum dome. Abundant precipitation and a favorable geologic environment make large quantities of water of good quality readily available from both surface and underground sources.

Aquifers containing fresh water extend from near surface to depths of about 2,000 feet in the vicinity of Tatum dome. The aquifers are areally extensive. The shallower aquifers are developed primarily for use as domestic supplies. The deeper aquifers are utilized for municipal and industrial supplies in the general area. Aquifers below a depth of 2,000 feet in the Tatum dome area contain saline water.

Aquifer 5

The shallowest saline-water aquifer in the vicinity of Tatum dome is within the Cook Mountain Limestone (aquifer 5). The water from this aquifer is not utilized in the general area so the aquifer is used for brine disposal. Brine disposal into this aquifer also is being considered at Tatum dome for disposal of the salt produced from the mining operations associated with Project Dribble.

The introduction of brine into the Cook Mountain Limestone in the vicinity of Baxterville oil field, a few miles southwest of Tatum dome, has been continuous for more than 10 years. The quantity of brine introduced over the years has been enough to raise the head in the aquifer an appreciable amount over a rather large area. In the vicinity of Tatum dome the head in this aquifer now stands 25-30 feet above water levels in wells in the overlying fresh-water sandy artesian aquifers. When a water-level correction for density of the brine is made, the difference in head is more than 75 feet. The head differential would be markedly greater if the aquifer were to be used locally for disposal of brine. Little movement of brine into the overlying fresh-water aquifers is likely to occur over the region because of the thick intervening clay beds. However, there is the possibility that brine might move upward locally along the flanks of the salt dome.

Aquifer 4

The deepest fresh-water aquifer in the Tatum dome area (aquifer 4) is in the limestone beds of the Vicksburg Group. The aquifer overlies the saline-water aquifer in the Cook Mountain Limestone and underlies the aquifers in sandstones of Oligocene(?) and Miocene age. The observed head in aquifer 4 is intermediate between the head in the Cook Mountain Limestone and the aquifers in the overlying sandstone. Aquifer 4, in the vicinity of Tatum dome, does contain water having slightly more dissolved solids than the water in the overlying sandstone. This condition suggests the possibility that some movement

of brine from the Cook Mountain Limestone into aquifer 4 is taking place. The regional movement of water in aquifer 4 is probably similar to that in the overlying sandstone; that is, to the south or southwest. Aquifer 4 has a low permeability in comparison to some of the overlying sandstone and inasmuch as adequate water supplies can be developed from the shallower sandstone, water-supply wells have not utilized this aquifer in the vicinity of Tatum dome.

Aquifers 1, 2, and 3 and related aquifers

Aquifers in the Catahoula Sandstone and the Hattiesburg and Pascagoula Formations are the source of water for a small number of the domestic wells in the vicinity of Tatum dome, for the large-capacity municipal wells in Hattiesburg and other towns, and for several industrial wells in the region. Water in these aquifers is confined by clay beds which separate these aquifers from the aquifers in the surficial sand and gravel. Farther north and east from Tatum dome, water-table conditions exist in the aquifers where the water-bearing units are exposed or directly underlie the terrace deposits. At the Tatum dome site, artesian conditions exist in all the aquifers (aquifers 1, 2, and 3) in the sandstone of Oligocene(?) and Miocene age.

Several years ago, in the region of Tatum dome, the direction of ground-water movement in all sandstone of Miocene age (upper part of the Catahoula Sandstone and the Hattiesburg and Pascagoula Formations) was south-southwest. Today, however, the effect of

withdrawal of water from the sandstone by pumping, particularly northeast and east of the dome, has modified the movement of ground water in these aquifers. In some units the hydraulic gradient may have been reversed or, at least if the movement continues to be to the south and southwest, the gradient has become more gentle.

Pumpage at Hattiesburg, 20 miles northeast of the dome, and at the Pontiac-Eastern Refinery, 11 miles east, is large enough (10 mgd) to effect water-level declines at Tatum dome, but not large enough as yet to reverse the direction of water movement. Lesser pumpage at other nearby towns has no detectable effect on the regional movement of water. The closest large-scale pumpage south of the dome is at Bogalusa, La. (8.3 mgd).

At Hattiesburg, in 1907, the water level stood about 175 feet above sea level. In 1963 water levels average about 140 feet above sea level. Municipal pumpage at Hattiesburg, which dates back at least to 1894, has grown from an average rate of less than 50 gpm to a present-day average of 3,000 gpm (4.3 mgd). In addition, industrial pumpage totals about 2.2 mgd. It is estimated that the total pumpage at Hattiesburg over the years has lowered the water level in the Miocene aquifers at Tatum dome several feet. Similarly, pumps which were installed at Pontiac-Eastern Refinery in 1957 probably have lowered water levels at the dome a somewhat greater amount. Although pumpage at the refinery has not been active for as long a period of time, the yearly amount has been almost as large as at Hattiesburg and the distance from the dome to the refinery is

only about one-half as great. Consequently, refinery pumpage effect on the water level is greater. Offsetting somewhat the pumpage to the east of the dome is the pumpage at Bogalusa, La.--the only other nearby large-scale pumpage. The influence of pumpage at Bogalusa is also felt at Tatum dome and has the effect of preserving the southerly gradient of the piezometric surface. However, because of its greater distance (32.5 miles) the effect is less than from wells at the Pontiac-Eastern Refinery and from municipal and industrial wells at Hattiesburg.

Figure 3 shows the generalized configuration of the piezometric surface of the aquifers in Miocene rocks. The wells at Sumrall, Columbia, Hattiesburg, Pontiac-Eastern Refinery, Purvis, Tatum dome, Lumberton, Miss., and at Bogalusa, La., are not necessarily screened in the same sandstone, but the sandstones are interconnected to form a single aquifer system so that the water-level contours for the system indicate a southerly flow of water. Water-level contours on the map are based on water-level data obtained between 1961 and 1963. The water level in wells at the Pontiac-Eastern Refinery were at an average altitude of 155 feet when the plant was built in 1957. Figure 3 shows water-level contours for these wells based on water-level measurements made in June and July 1962. Measurements at the refinery were made in each well while the other two wells were pumping. Therefore, the water levels of 135, 136, and 137 feet above sea level in each of the unpumped wells indicate a local decline of 18-20 feet between 1957 and 1962.

The regional slope of the piezometric surface of this aquifer is 3.2 feet per mile measured from Sumrall to Tatum dome. Pumping during recent years at Pontiac-Eastern Refinery has altered, to some extent, the direction of flow of water in these formations in the vicinity of the refinery and probably has had the effect of decreasing the ground-water gradient over the dome.

Near-surface aquifers

A blanket or veneer of sands and gravels covers the hills and terraces bordering the stream valleys in the region. This porous veneer readily absorbs precipitation and then slowly discharges the water as seeps and springs. In the vicinity of Tatum dome the discharge from these deposits provides the large base flow to the streams draining the Tatum site. Most of the domestic wells in southern Mississippi, including the Tatum dome area, are completed in those shallow deposits.

The aquifer in the caprock

The calcite caprock contains numerous open water-filled fractures that probably have been enlarged by solution. In nearly all test holes drilled through the calcite caprock, lost circulation has been a major problem in drilling. When drilling fluid is lost from a hole being drilled through the caprock, the loss is reflected almost immediately as a rise in water levels in an observation well along the east margin of the calcite caprock. These conditions suggest that the calcite caprock has a high permeability.

The aquifer in the caprock may be in hydraulic continuity with the overlying aquifer 3. It may also have continuity with aquifer 4 along the flank of the dome. Preliminary information on the head of the water in the caprock suggests that it is somewhat higher than that in the overlying sandstone and somewhat lower than the head in aquifer 4. Intensive pumping tests planned for the aquifer in the caprock may show by means of observations in wells finished in aquifers 3 and 4 the hydrologic connection between the aquifers.

QUALITY OF WATER

Water occurring in all aquifers above the Yazoo Clay is fresh. Within this fresh-water zone, the water in the limestones and sandstones of the Vicksburg Group contains more dissolved solids than the water in the overlying aquifers of Oligocene(?) and Miocene age aquifers. Waters in aquifers below the Yazoo Clay are very salty, indicating that the principal change in water quality occurs at the Yazoo Clay, which does not extend across the top of the dome.

Water from the Cook Mountain Limestone (aquifer 5) is very saline. The total dissolved solids content of the water on the northeast side of the dome is 18,600 ppm and on the southwest side of the dome, 31,100 ppm.

Water from the Vicksburg Group (aquifer 4) is a mixture of sodium-bicarbonate and sodium-chloride types with a total dissolved solids content of 1,320-1,480 ppm. Water temperature averages 93°F. Water from the Vicksburg Group northeast and southwest of the dome is similar in character.

The aquifers in the sandstone of Oligocene(?) and Miocene age (aquifers 3, 2, and 1) contain very soft to moderately hard water of the sodium-bicarbonate type. Total dissolved solids range from 26 to 1,420 ppm. Total iron ranges from 0 to 10 ppm. Temperature ranges from 71° to 84°F.

Inasmuch as the water in the calcite caprock on top of the dome is fresh (table 1) a hydrologic connection between the caprock and the saline aquifers on the flank of the dome is not indicated. However, this conclusion is based on only one analysis of water from the caprock. Subsequent samples may show the quality of water in the caprock near the flank of the dome to be more highly mineralized than that over the central part of the dome.

Soft water occurs in the Citronelle Formation, the terrace deposits, and the alluvium. Total dissolved solids normally range from 19 to 100 ppm. The total iron content of the water ranges from 0.02 to 8.5 ppm. In places the excessive iron content of the water is caused by the low pH of the water and its corrosive effect on casings and screens.

Pollution is more common in the shallow-bored wells that derive water from the terrace deposits than in deeper small-bore wells, because of unsatisfactory well construction practices. Water from wells for which water analyses show the chloride content exceeds the normal value of 10 ppm or less, and in which the nitrate content is relatively high, probably is contaminated. All wells drawing water from the terrace deposits in which the water had a high nitrate

Table 1.--Chemical analysis of water sample from well HT-3, the calcite caprock, in March 1963

Constituents	Parts per million
Silica (SiO_2)	16
Iron (Fe)	.26
Total iron (Fe)	.79
Calcium (Ca)	150
Magnesium (Mg)	1.3
Sodium (Na)	301
Potassium (K)	2.8
Bicarbonate (HCO_3)	279
Carbonate (CO_3)	0
Sulfate (SO_4)	485
Chloride (Cl)	221
Fluoride (F)	2.6
Nitrate (NO_3)	.4
Dissolved solids, calculated	1,320
Hardness as $CaCO_3$	380
Noncarbonate hardness	151
Residue on evaporation at 180°C, mg/1	1,400
Specific conductance, micromhos at 25°C	2,050
pH	7.0
Color	40
Temperature °F	90

content also contained more than the normal amount of chloride, that is, more than 10 ppm. Nine additional water analyses of terrace wells show an abnormal amount of chloride but the nitrate content is not given. These nine wells are also suspected to be contaminated.

RATE AND DIRECTION OF MOVEMENT OF GROUND WATER IN THE TATUM DOME AREA

An estimate of the average rate of movement of ground water in an aquifer can be made if the coefficient of permeability, the porosity, and the hydraulic gradient are known. Values for the coefficient of permeability for five of the principal aquifers in the vicinity of the Tatum dome were obtained by means of pumping tests. The porosity of the water-bearing sands is known in a general way, but estimates of the porosity of the limestone aquifers are more difficult to make. The hydraulic gradient usually can be determined to a satisfactory degree by means of measurements of water levels in observation wells finished in the aquifer of concern.

Permeability of aquifers 1-5

Values listed below for the coefficient of permeability of aquifers 1-5 were computed from values of the coefficient of transmissibility and the estimated effective thickness of the aquifer. Several thin clay beds within the various aquifers were not subtracted from the thickness of the overall producing section, so the computed values for the coefficients of permeability probably are lower than the actual permeability. Nevertheless, the values obtained are

probably close to the real values and are used in the computation of the rate of movement of water in aquifers 1-5.

Aquifer	Coefficient of permeability gpd/ft^2
1	20
2	700-1,000+
3	70
4	30
5	10

A value of 300 gpd/ft^2 was assigned as the coefficient of permeability of the shallow aquifer in the vicinity of Tatum dome and when used with the aquifer thickness and gradients appeared to correlate well with the observed discharge from the aquifer into Lower Little Creek.

Porosity of aquifers

As no simple field procedure for determining the porosity in situ is available it is necessary to revert to laboratory procedures. Laboratory procedures require undisturbed samples, however, which are difficult to obtain, even with modern day technology. The porosities listed below for the five aquifers under study were derived by averaging numerous samples collected from many horizons in each of the aquifers penetrated by wells HT-1 and HT-2.

Total porosity of aquifers

Aquifer	Number of samples	Total porosity, in percent		
		High	Low	Average
1	15	38	29	35
2	20	40	28	33
3	13	41	21	31
4	13	37	25	30
5	20	44	23	38

The total porosity as given above is larger than the effective porosity, which is a parameter in hydrological problems. This is particularly true in carbonate aquifers, such as aquifers 4 and 5, where effective porosity can be much less than the total porosity. The effective porosity for aquifers 4 and 5 is estimated to be about 25 percent, and that for the overlying sandstone about 30 percent.

Water-level fluctuations, hydraulic gradients, and direction of ground-water movement

Recording gages have been maintained on several of the observation wells at Tatum dome since the summer of 1961. Periodic measurements of water level have been made in several shallow wells in the area surrounding the dome. These records form much of the basis for the discussion of water-level fluctuations in the various aquifers in the vicinity of Tatum dome and provide much of the basic data for determination of hydraulic gradients and direction of ground-water movement.

At Tatum dome only two observation wells are available for measurement of gradient in a number of the aquifers. Thus, theoretically, from the two observation points a wide range of gradients would be possible and the direction of movement could vary in direction over nearly a 180° arc. However, taking into account the regional movement of water, the more probable gradients and direction of movement can be inferred. At Tatum dome, because the aquifers on which observations were made extend to depths of as much as 2,600 feet and because the heads in the aquifers stand near land surface, the well bores contain a long water column. Consideration had to be given, for comparative purposes, to correction in head in the water columns caused by water of differing density from well to well. Different density of the water columns could be caused by dissolved gases, dissolved solids, temperature, or solids in suspension. Solids in suspension were eliminated by pumping the well until clear water of uniform quality was obtained. Temperature profiles for the various wells were similar enough to eliminate the necessity for a temperature correction. In most of the fresh-water aquifers the dissolved solids were low enough so that no correction for density differences was required. Corrections for dissolved solids were required for comparison of heads in the brine aquifer. Gas was observed to be discharged along with the water from some of the wells, but the amount of dissolved gas was not determined. Further, while gases coming out of solution would make the water column lighter for a short period, gas bubbles would finally bleed

off leaving only a minor amount of gas in solution. A correction in density of the water column for dissolved gases was not made, but there is some evidence that such a correction should be made, if possible, for the water column in some wells.

Aquifer 5

Hydrographs for wells HT-1 and HT-2 are shown on figure 4. The long-time trends of the water level in these two wells are very similar despite the erratic fluctuation in well HT-2. From July 1961 to March 1963 the water level in HT-1 rose about 7 feet while the level in HT-2 rose about 6 feet.

Injectivity tests were made on well HT-2 on two different occasions. The first test, in October 1961, resulted in displaced water level, owing to the difference in density of the formational water and the injected fluid. In November this condition was altered by pumping the well until the well bore was filled with formational water. The injectivity test in March 1962 caused a repeat of this phenomenon, which persisted until the well was pumped in February 1963. From March 1962 to February 1963 the water level appeared to be slowly declining.

The water levels measured in tubing open to aquifer 5 in wells HT-1 and HT-2 in July 1961 and again in March 1963, after both wells had been pumped intensively, suggest a south or west gradient of the piezometric surface in the aquifer between the two wells. Actually,

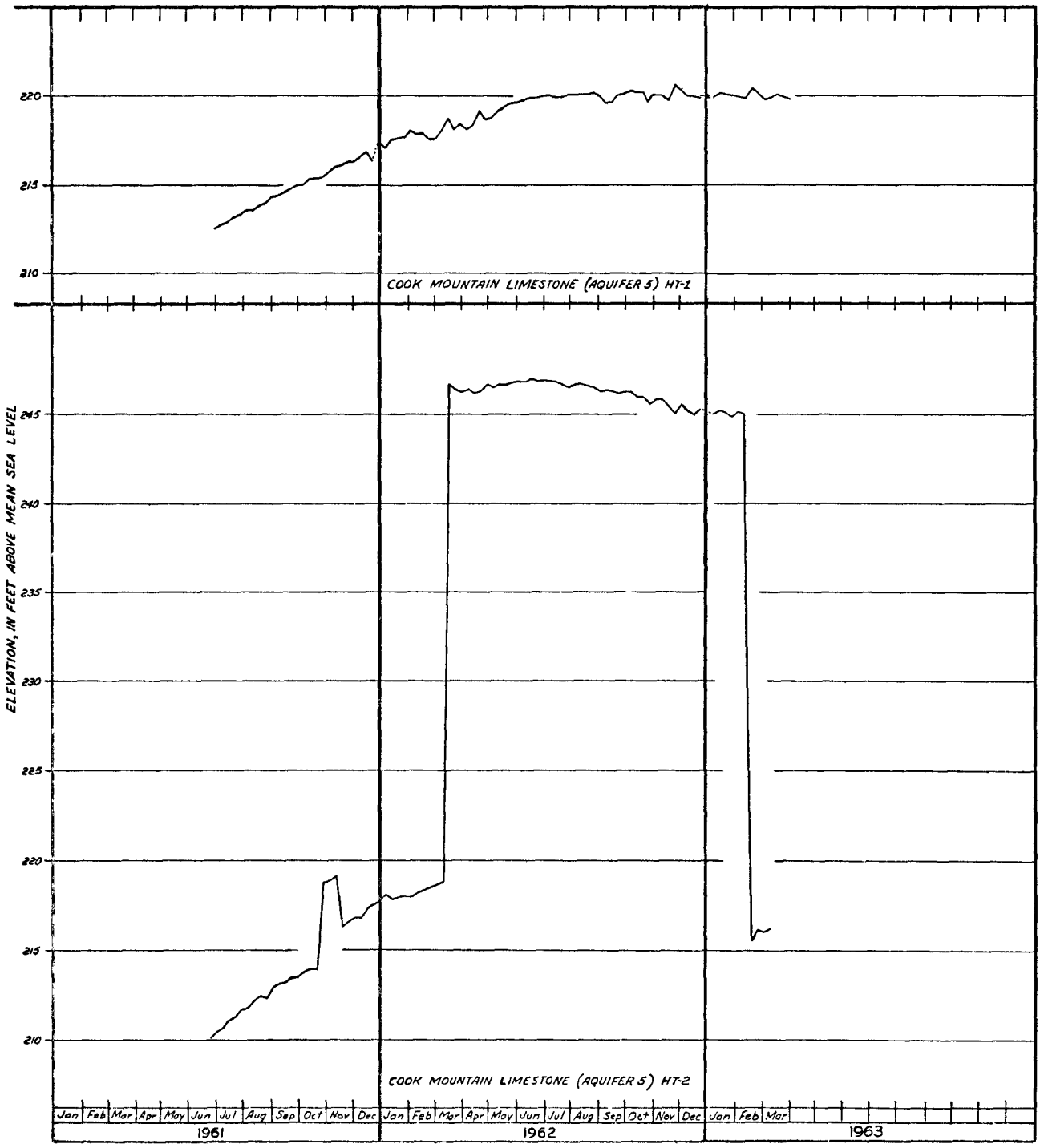

Figure 4.--Hydrographs for wells HT-1 and HT-2 in the Cook Mountain Limestone (aquifer 5)

with only the two control points the piezometric surface could slope through a range of directions from northwest to southeast.

However, as the water columns in the two wells contain water of different quality, a density correction is required before the water-level elevations in the two wells can be compared. The water in well HT-2 is more saline than in well HT-1. After a density correction is applied, the head in well HT-2 is higher by 17 feet than the head in well HT-1.(see fig. 8). Thus the piezometric surface for aquifer 5 has a north or east component between wells HT-2 and HT-1. The more probable direction of the slope of the piezometric surface is to the north-northeast. Such a slope is different from the expected direction of movement of the brine under natural conditions but is not surprising when the probable effect of injection of brine into the aquifer in the vicinity of Baxterville is taken into consideration. Assuming that the gradient is to the north-northeast, the magnitude of the gradient is about 7 feet per mile or 0.001 foot per foot.

Aquifer 4

Hydrographs for wells tapping aquifer 4 in the Vicksburg Group are given in figure 5. Following the original pump test of HT-1 in this aquifer, the water level continued to rise. This rise may have been due in part to a continuing change in density of the water column caused by the settling of materials suspended in the water. As the solids settled out, changing the water density, the water level rose. The abnormal fluctuation of water in this well may also have been due

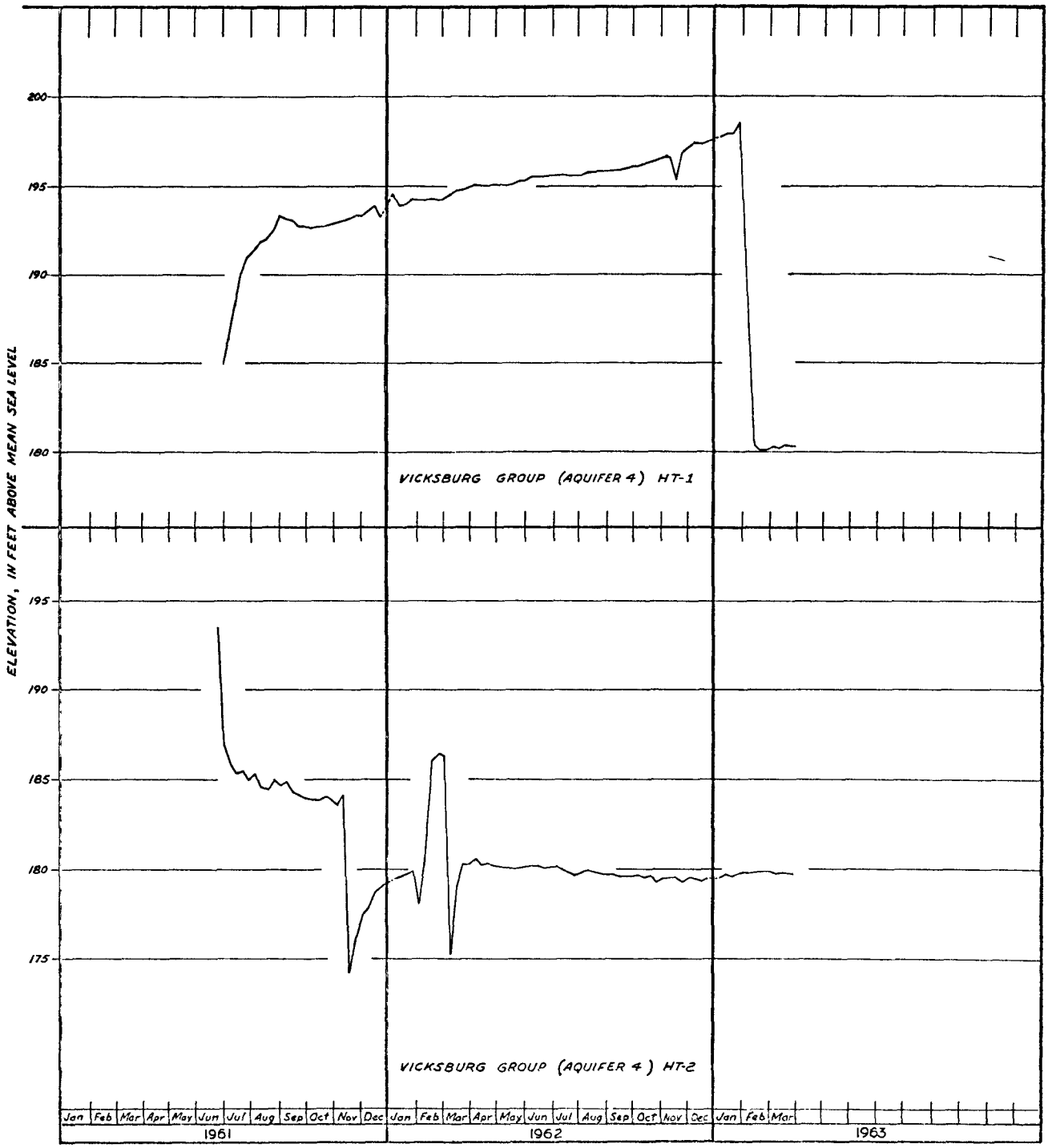

Figure 5.--Hydrographs for wells HT-1 and HT-2 in the Vicksburg Group (aquifer 4)

to the perforated section of the casing being partially blocked by sand. An indication of such a blockage was noted in the short low-yield pumping test made in January 1963. In that test the water level was drawn down 127 feet while pumping the well at a rate of only 0.4 gpm. Following the low-yield test the water level recovered to about 180 feet above sea level, which was about 18 feet below the water level measured before the test. It is now believed that the true water level in HT-1 is in the range of 180-182 feet above sea level.

The water level in HT-2 following the original pump test rose to about 193 feet above sea level then declined until it stabilized at about 180 feet above sea level. A low-yield test made on the well in February 1963 pumped 2,900 gallons of water from the well completely changing the water column. Subsequent water-level measurements show no marked change in the elevation of the water level. Therefore, it is believed that the normal water level in HT-2 is about 180 feet above mean sea level. The water in aquifer 4 is similar in temperature and chemical character in wells HT-1 and HT-2; thus, a density correction is not needed. Therefore, if the water level in HT-1 is about 182 feet above sea level and if we assume a southwest gradient, the indicated hydraulic gradient in aquifer 4 has a magnitude between HT-1 and HT-2 of about 1 foot per mile or 0.0002 foot per foot.

Aquifers 1, 2, and 3

Well HT-1 was perforated adjacent to both aquifers, 3a and 3b, of the Catahoula Sandstone; however, it was reported that the Tatum Limestone Member, aquifer 3b, contributed little water to well HT-1. Well HT-2 was perforated only adjacent to the upper aquifer, 3a.

Elevations of water level in wells HT-1 and HT-2 indicate that movement of water in the Catahoula Sandstone is easterly. When hydrographs of wells HT-1 and HT-2 are compared (fig. 6 and 8), the water level in HT-2 always stands higher than it does in HT-1, although variations of fluctuation in the water levels of HT-2 are considerable. The reasons for large fluctuations in well HT-2 are unknown. Following the pump test on HT-2 in May 1961, the water rose to a very high level (174 feet above sea level). After completion of the test, however, the water level declined to an elevation comparable to the water level of well HT-1. In March 1962 the U.S. Bureau of Mines pumped well HT-2, which resulted in the changing of the water in the pump column and a reduction in the density of the water. In February 1963 a low-yield pump test was made on the well during which 14,000 gallons of water was pumped. Weekly measurements made after the test indicate that the hydrograph from March 1962 to March 1963 is a true representation of the water level.

In January 1963 about 8,000 gallons of water was pumped from HT-1 in a low-yield test. A rise of 3 feet in water level occurred following the test and the hydrograph (fig. 6) shows that this higher level has been maintained.

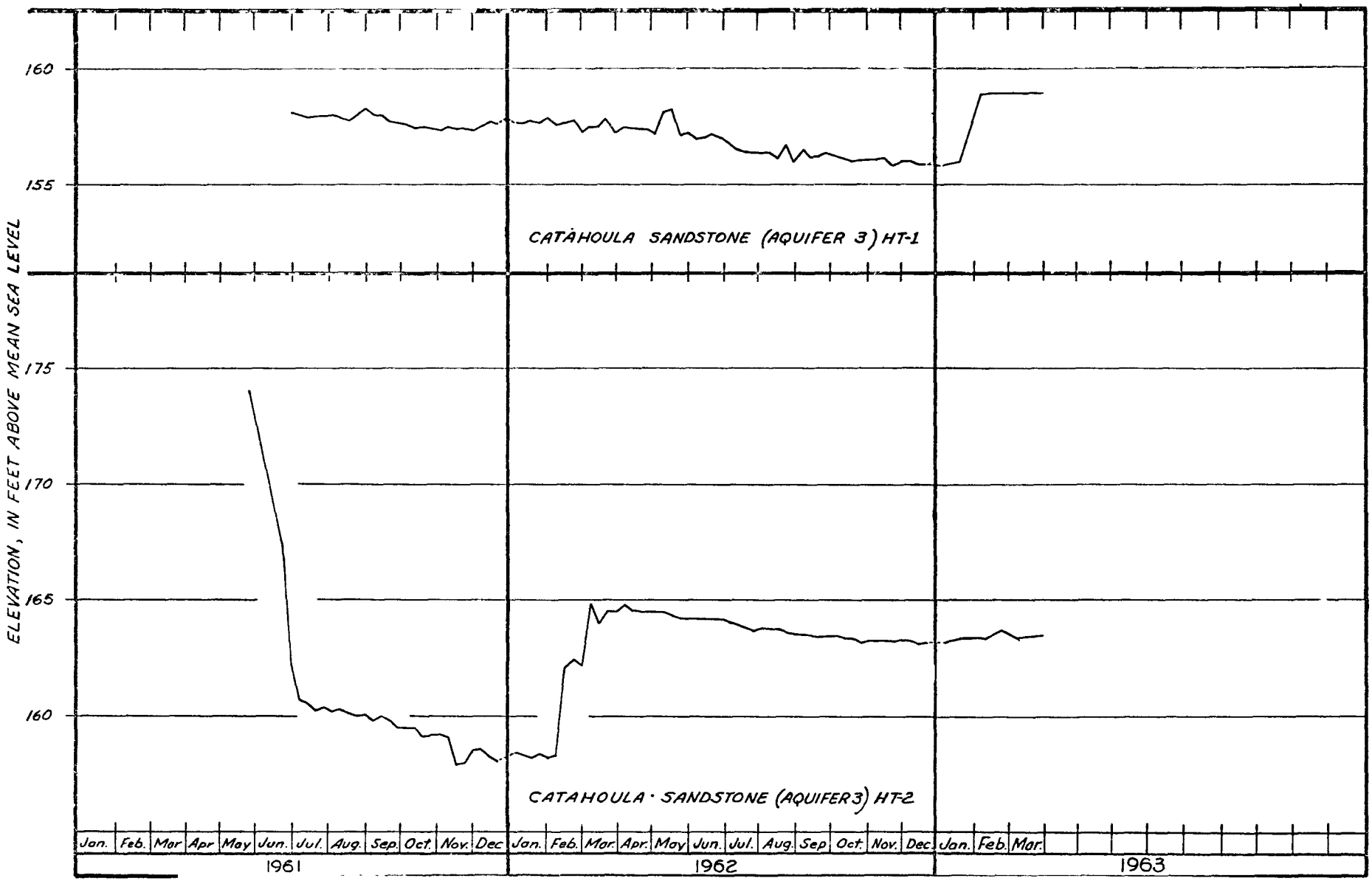

Figure 6.--Hydrographs for wells HT-1 and HT-2 in the Catahoula Sandstone (aquifer 3)

From water levels obtained after the 1963 low-yield test in well HT-1, it is believed that a head difference of about 4 feet exists between HT-1 and HT-2. Therefore, the apparent hydraulic gradient between well HT-2 and well HT-1 is about 2.2 feet per mile (0.0004 foot per foot) if the movement is to the northeast, or about 3 feet per mile (0.0006 foot per foot) if the movement is to the east.

On the basis of available analyses, water from HT-2 contains 1,420 ppm total dissolved solids, and water from HT-1 contains only 420 ppm. The correction for difference in water density, if applied, would increase the velocity by 0.003 foot per day or 1.1 feet per year giving a calculated velocity of 8.4 feet per year. However, specific-conductance determinations, which were made during the low-yield test on well HT-2 and which average 160 micromhos, indicate that the mineral content of the water in HT-2 is much lower than the 1961 chemical analysis would indicate and that no density correction would be necessary.

Hydrographs of wells finished in the sandstone of Miocene age in the Tatum dome area are presented in figure 7. Whereas no long-trend decline or rise in water level normally would be evident in hydrographs of wells in terrace deposits, a decline is apparent in hydrographs of wells in the sandstone of Miocene age. Similar declines are evident in most sections of the State where the use of water from artesian aquifers is increasing. The water-level decline in the State ranges from less than 0.5 foot to more than 2 feet per year depending on aquifer characteristics and pumpage.

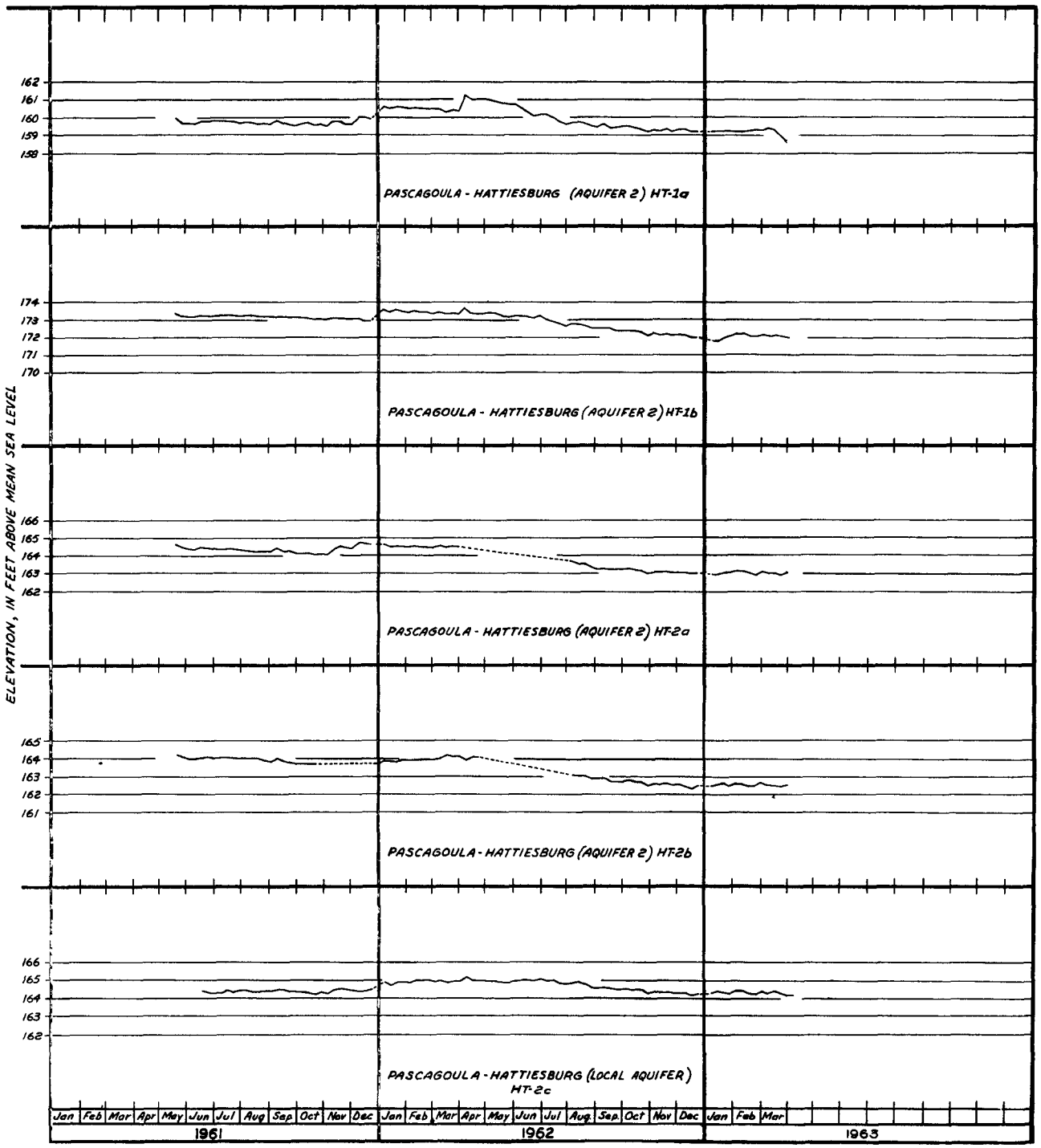

Figure 7.--Hydrographs for wells HT-1a, HT-1b, HT-2a, HT-2b, and HT-2c in sandstone of Miocene age (aquifer 2 and local aquifers)

Although the elevation of the water level in well HT-2c (fig. 7) stands at nearly the same elevation as the water level in the deeper Miocene aquifers, its hydrograph does not show the annual decline exhibited by the deeper aquifers. This is due to only minor withdrawals of water from the aquifer, closer proximity of recharge area, and the presence of a considerable thickness of clay or silt between the aquifer and the deeper Miocene sandstone. However, it is also an artesian aquifer, like the deeper Miocene aquifers, and as such does not show the seasonal fluctuation characteristic of water-table wells of the terrace deposits. If the isolated high water level recorded in HT-1b on the northeast side of the dome is disregarded, the water level in HT-2 that taps aquifer 2 on the southwest side of the dome stands about 4 feet higher than the water level in HT-1 that taps aquifer 2, and is indicative of an easterly or possibly northeasterly movement. If the movement is eastward, the inferred gradient is about 3 feet per mile (0.0006 foot per foot); if the movement is to the northeast, the gradient is about 2.2 feet per mile (0.0004 foot per foot).

The water level in HT-1b stands about 13 feet higher than does the water level in nearby HT-1a (fig. 8). HT-1a is completed in aquifers 2a and 2b, whereas observation well HT-1b is completed only in aquifer 2a. However, it is believed that the screen section in well HT-1a through aquifer 2a may not have been open, because no fluctuations were observed in observation well HT-1a when observation well HT-1b was pumped. It is presumed, therefore, that the water

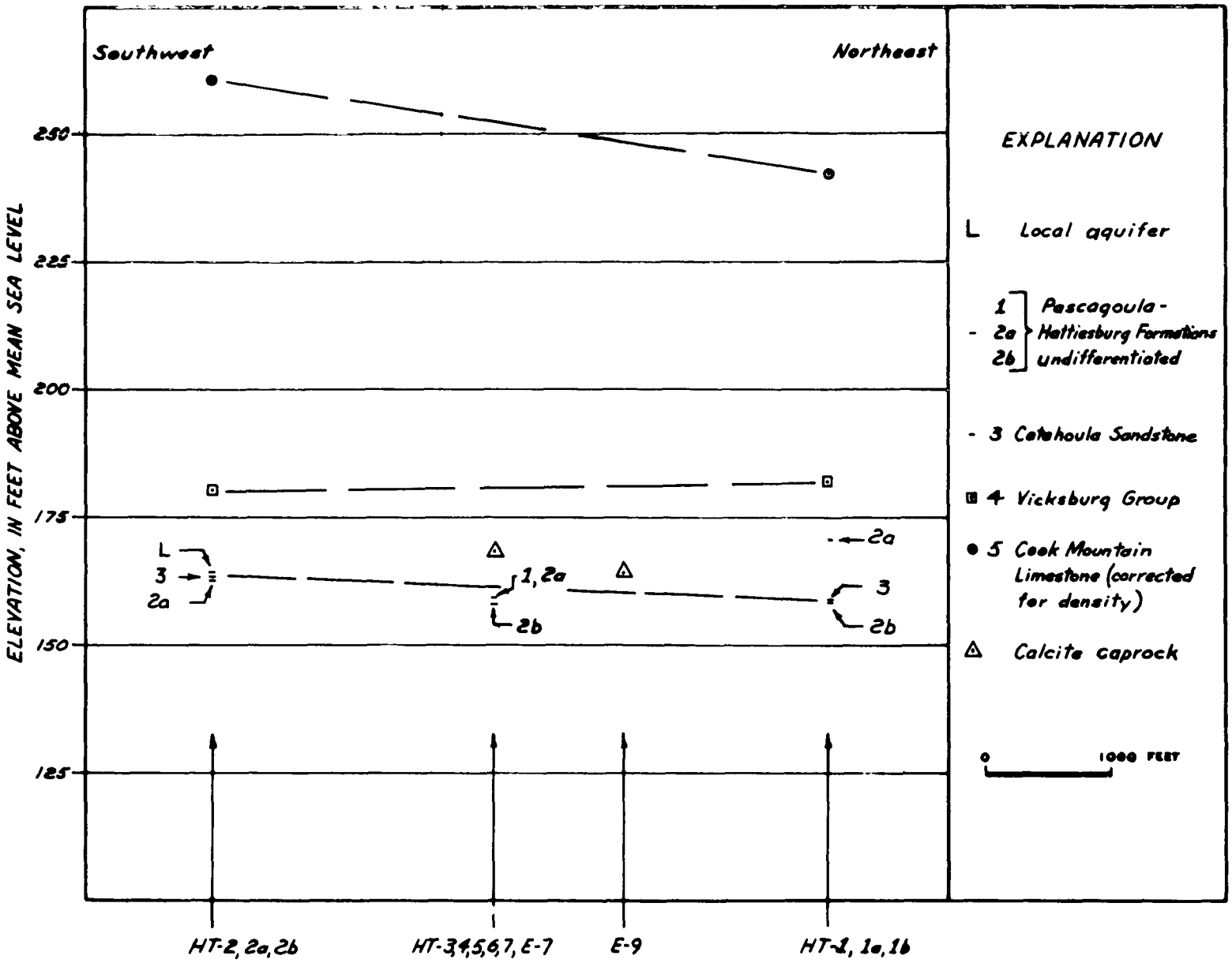

Figure 8.--Section across Tatum dome showing relation of water levels in the principal aquifers.

level in HT-1b could be representative of aquifer 2a. The elevation of the water level in HT-1, which was perforated in 2a and 2b, corresponds with the elevation of the water level in HT-1a and not with that in HT-1b--a further indication of the lack of interconnection between well HT-1b and aquifer 2a. As the water levels in observation wells HT-2a and HT-2b stand at an average elevation of 162.70 feet above sea level and the water level in observation well HT-1b stands 172 feet above sea level, the possibility exists of southwestward movement of water in aquifer 2a and northeastward movement of water in aquifer 2b. If the gradient in aquifer 2a is toward the southwest, the magnitude of the gradient is about 5 feet per mile or 0.0001 foot per foot.

Water levels in all aquifers tested, including the local aquifer at a depth of 361 feet and the Catahoula Sandstone (aquifer 3) at a depth of 1,400 feet on the southwest side of the dome, stand within 1.7 feet of the same elevation. It seems unlikely that the water level in aquifer 2b, if measured at the HT-2 site, would stand at a level much different than it does in the local aquifer, aquifer 2a, and aquifer 3. On this premise it is believed that the water level in observation well HT-1b screened in aquifer 2a is not truly representative of head in aquifer 2a on the northeast side of the dome. The water level may be standing higher for some reason not as yet ascertained. Further, the water level in aquifers 2b and 3 on the northeast side of the dome stand at nearly the same elevation above sea level. The piezometric surface of aquifer 3 slopes in an

easterly direction, and it is believed that the piezometric surfaces of aquifers 2a and 2b (or aquifer 2 as a unit) would slope in the same direction.

Initial water levels measured in hydrologic test wells currently being completed at sites HT-3, 4, 5, 6, and 7 almost midway between HT-1 and HT-2 indicate that water levels in aquifers 1, 2a, and 2b are very near the same elevation. When these water levels are plotted on the section (fig. 8) to compare with the water levels in HT-1 and HT-2, it appears that the piezometric surface slopes from well HT-2 to well HT-3-7. From wells HT-3-7 to HT-1 the slope appears to be negligible. Future measurements that will be made after the new wells are developed may clarify the apparent change in slope.

No observation wells were preserved in aquifer 1 in the vicinity of the Tatum dome. Measurements made at the time pumping tests were conducted on wells HT-1 and HT-2 (Armstrong and others, 1971a; 1971b) when the wells were open only to aquifer 1, indicate that the head in aquifer 1 was about 9 feet higher in well HT-1 on the northeast side of the dome than the head in well HT-2 on the southwest side. However, the water level for aquifer 1 in well HT-2 is about 5 feet lower than the water level recorded over a period of time in the local aquifer above, and in aquifer 2a below. This lower measured water level may have resulted from having a muddy water column. It is estimated that the maximum head difference is about 4 feet. The inferred direction of movement in aquifer 1 is to the south-southwest, and the gradient is about 2 feet per mile or 0.0004 foot per foot.

Near-surface aquifers

Water is under water-table conditions and near the land surface in the alluvium, terrace deposits, and Citronelle Formation. For this reason water levels in wells tapping these aquifers rise and decline with seasonal variation in rainfall and temperature, as shown by the hydrographs in figures 9 and 10. The magnitude of these fluctuations depends largely on the topographic situation of the observation wells. The well hydrograph reflects change in water storage in these deposits as stream discharge in the summer and fall months, evapotranspiration loss during the growing season, and recharge to the deposits from precipitation in the winter months.

The amplitude of the fluctuation in water level in wells located on topographic divides is normally larger than that noted in wells located in low areas. The hydrograph for J34-11, located on a divide, is smooth with no apparent effect of rainstorms, whereas the hydrograph for J14-1, located in the lowlands, does reflect rainfall. In wells located near creeks, whether near the upland divides or at lower levels, the effect of rainfall is apparent. (See hydrographs for wells K-21-6, fig. 10 and J-14-1, fig. 9).

Shapes of recession curves of well hydrographs indicate the location of the well with respect to a stream. Those wells at or near divides have recession curves that are convex upward while recession curves for wells near creeks are convex downward. The recession curve of a well near a stream is similar to the recession curve of the stream hydrograph. Well K-21-6 (fig. 10), located on

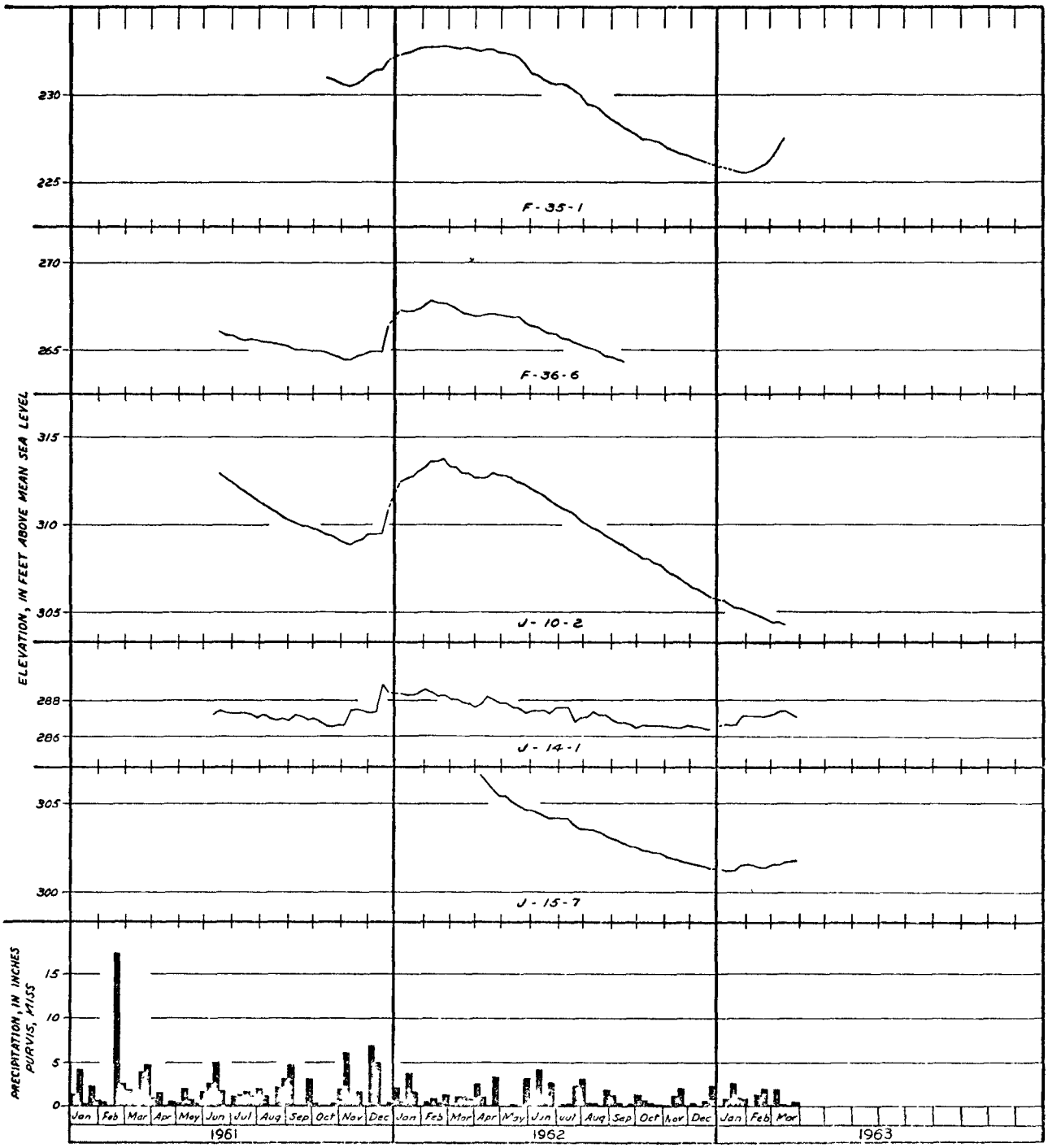

Figure 9.--Hydrographs for selected wells in the terrace deposits and bargraph of precipitation at Purvis, Mississippi

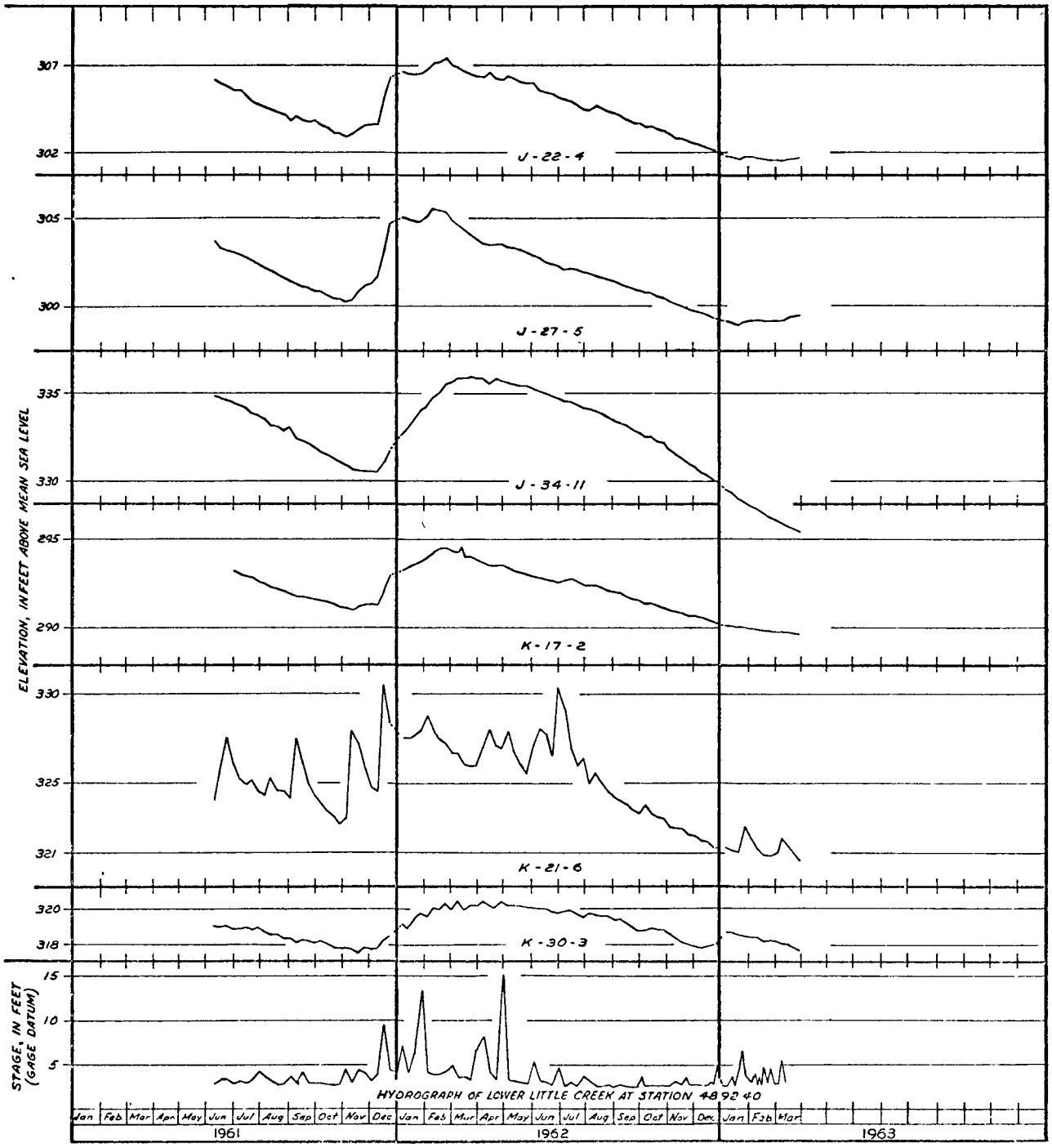

Figure 10.--Hydrographs for selected wells in the terrace deposits and Lower Little Creek

the bank of a small upland tributary of Little Black Creek east of the dome, was completed in low-lying terrace deposits adjacent to the stream channel. Water-level response to rainfall and streamflow is marked when compared to water-level changes in other wells located away from the streams. From a comparison of hydrographs it is evident that the seasonal change in water level may be large or small depending on topographic situation. However, a definite seasonal cycle is always present in water-table wells.

Water levels in wells in the terrace deposits were considerably higher in the spring months of 1961 and 1962 than in the spring of 1963, owing to a precipitation deficiency following the summer of 1962. A comparison of water levels between March 16, 1962, and March 16, 1963, in 11 observation wells screened in the terrace deposits shows that the mean decline was 4.6 feet. Until substantial precipitation occurs, water levels, although they may rise in the spring months, will continue to show increased difference between 1963 and the previous year. It is probable that water levels will be much lower before the end of 1963 and yields of many wells will diminish markedly until the winter of 1963-64.

The configuration of the water table in these shallow water-bearing deposits is similar to but has less relief than the land surface. Even so, locally, the gradient of the water table may be steep (more than 50 feet per mile) compared to that observed in the deeper aquifers. The direction of ground-water movement in the shallow aquifers differs markedly from place to place.

The aquifer in the caprock

Water levels measured in three observation wells in the calcite caprock stand at elevations ranging from 164 to 168 feet above sea level. The higher water level was measured in HT-3, a well completed in March 1963 specifically for hydrologic studies of the caprock. The two other wells are reclaimed exploratory holes E-7 and E-9. The water developed in HT-3 is clear but has a total dissolved solids content of 1,400 ppm (residue at 100°C). A distinct odor of hydrogen sulphide was noted during swabbing operations in the development of all three caprock observation wells.

Inasmuch as the water from HT-3 is chemically fresh, the high static water level in the caprock, as compared with water levels in the adjacent Miocene aquifers, may be explained by the presence of gas in the water. However, the difference in water level between test hole E-9 and well HT-3 remains unexplained.

During development of test hole E-7, specific-conductance measurements were made of the water periodically as it was swabbed from the well. After about 20 hours of swabbing, the specific conductance of the water had declined from a high of 20,000 micromhos and had leveled off at about 6,000 micromhos. It is presumed that the specific conductance of the water that finally constituted the water column in the well must have been about 6,000 micromhos. Water levels were measured at the end of the well development and on the 3 days following. These measurements indicated that the water level recovered and stabilized at 165 feet above sea level. The measurements were then

corrected for the density of the water giving a corrected elevation of the water level of 167 feet above sea level, 1 foot lower than that in HT-3.

Differences in elevation of the water level in the caprock probably result from several factors, among which are varying degrees of mineralization of the water and varying amount of dissolved gases. In any event, the adjusted water level in the calcite caprock will probably stand somewhat higher than that in the overlying sandstone of Miocene age.

Computed rates of movement and inferred direction of movement of ground water

Table 2 lists the values for the coefficient of permeability, the effective porosity, and the hydraulic gradient used to compute the rate of movement of water in each of the five principal aquifers. There is considerable doubt about the precise direction of movement of the water in a few aquifers and in these cases more than one direction and more than one value for the computed rate of movement is listed. Data are not available from which an estimate can be made of the rate of movement of water through the calcite caprock.

The computed rates of movement are believed to be correct within an order of magnitude and possibly within a factor of 2.

On the remote chance that radioactivity might escape from the salt stock in which the nuclear tests are proposed, the activity would most likely enter the caprock, the overlying sandstone of aquifer 3, or aquifers 4 and 5 on the flank. Computed values of the

Table 2.--Computed rate and inferred direction of movement of ground water in five of the principal aquifers in the Tatum dome area

Aquifer	Coefficient of permeability gpd/ft^2	Effective porosity	Hydraulic gradient ft/ft	Computed average rate of movement ft/day	ft/year	Inferred direction of movement
1	20	0.30	0.0004	0.004	1	south-southwest
2a	1,000+	.30	.0005 .001	.2 .4	80 160	east-northeast south-southwest
2b	700	.30	.0006 .0004	.2 .1	80 40	east northeast
3	70	.30	.0006 .0004	.02 .01	7 4	east? northeast
4	30	.25	.0002	.003	1	south-southwest
5	10	.25	.001	.01	3	north-northeast

rate of movement of water in aquifers 3, 4, and 5 indicate that the movement will be less than 10 feet per year. This slow rate of movement coupled with the high exchange capacity of the material composing the aquifers lead to the conclusion that the offsite contamination potential is small to nil. The highest rate of movement, about 160 feet per year, was computed for aquifer 2a. It is unlikely that radioactivity would be released into this aquifer, several hundred feet above the caprock.

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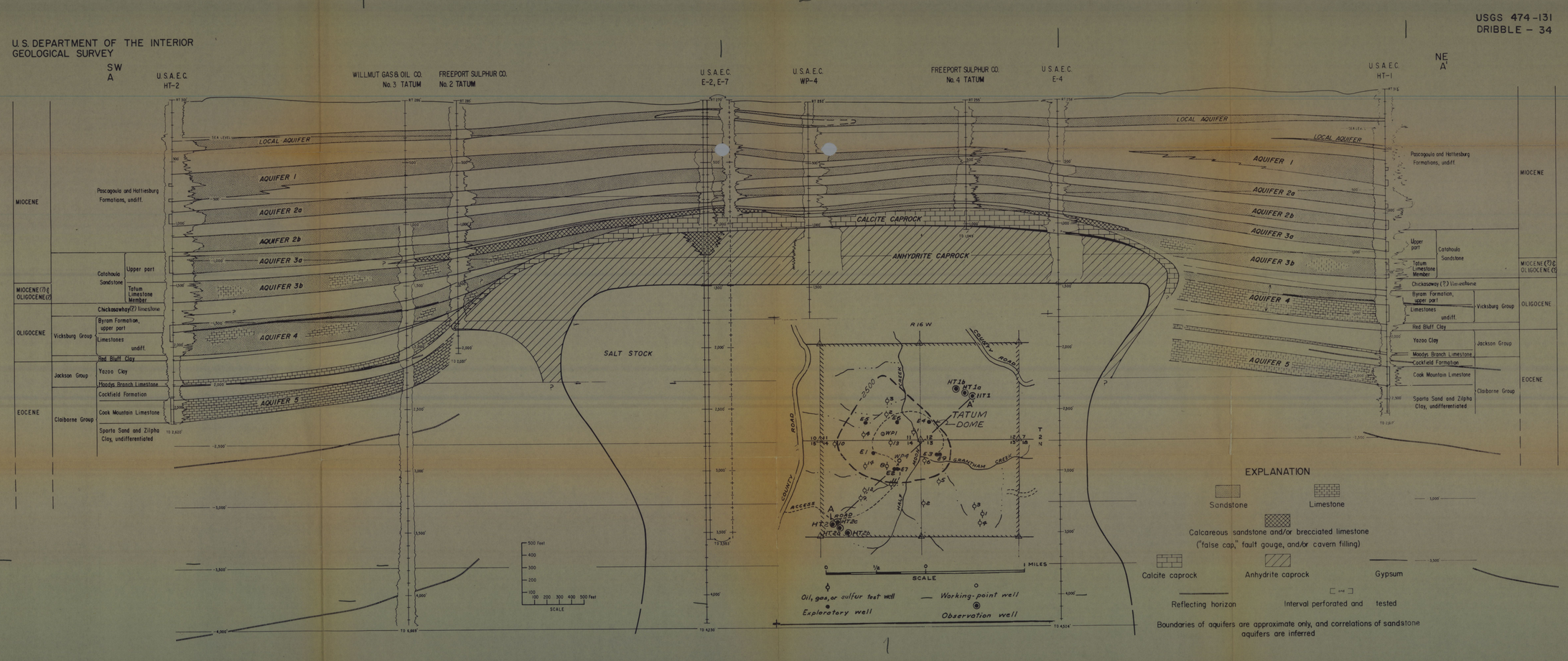

Figure 2.– SOUTHWEST–NORTHEAST SECTION THROUGH TATUM DOME.

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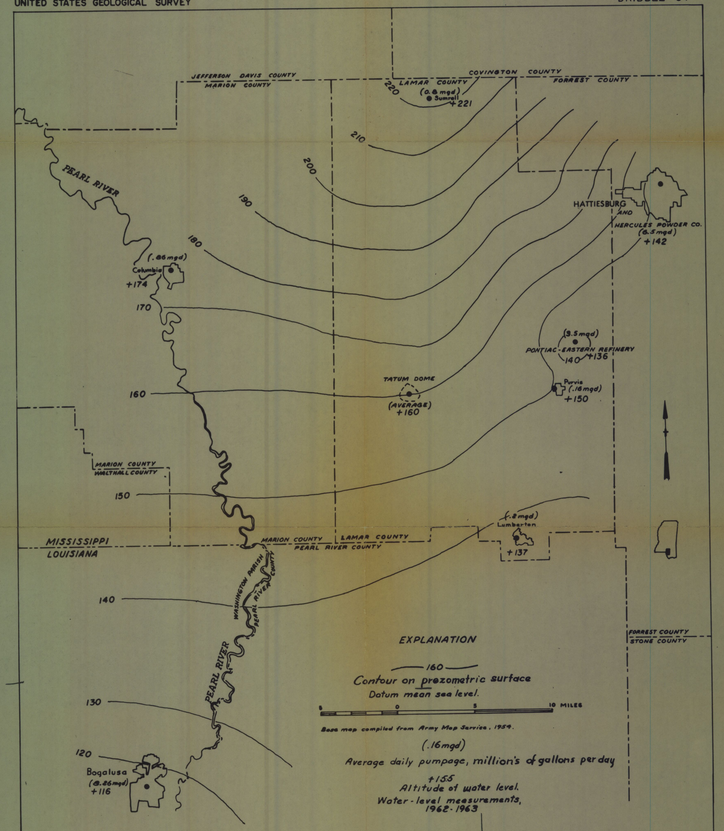

Figure 3.--Map of Tatum dome and vicinity showing generalized Piezometric surface for aquifers in sandstone of Miocene age.