EARTH FISSURING IN THE PICACHO AREA
PINAL COUNTY, ARIZONA

by

Dennis E. Peterson

A Thesis Submitted to the Faculty of the

Department of Geology

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1962

STATEMENT BY AUTHOR

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

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

SIGNED: Dennis E. Peterson

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

John Harshbarger
JOHN W. HARSHBARGER
Professor of Geology

August 13, 1962
Date

EARTH FISSURING IN THE PICACHO AREA
PINAL COUNTY, ARIZONA

by

Dennis E. Peterson

ABSTRACT

Earth fissures in the Picacho area appear to be the result of tensile forces related to differential subsidence; the mountains and pediment areas remain stable while the valley alluvium subsides. The subsidence is caused or accelerated by declines in hydraulic heads in confined aquifers composed of fine grained materials. The loss in head increases the effective load on these materials, thereby creating the compacting force.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

EARTH FISSURING IN THE PICACHO AREA, PINAL COUNTY, ARIZONA

1. INTRODUCTION

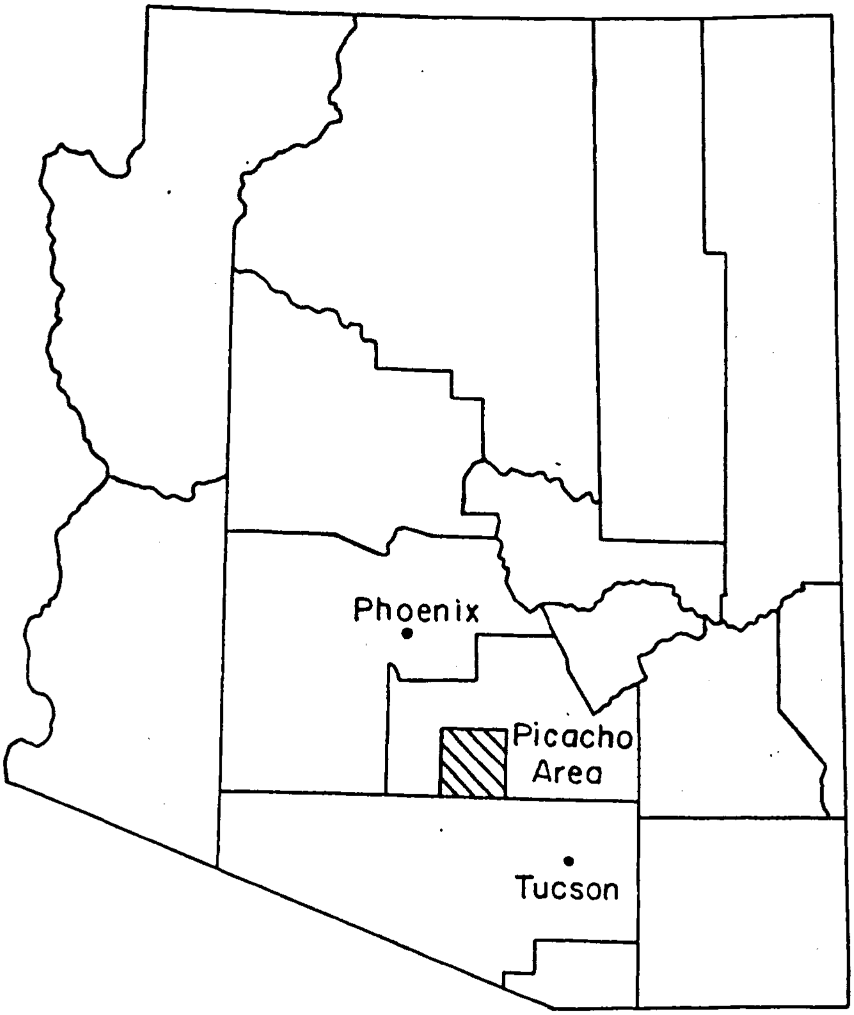
Earth fissuring is known to have occurred in Arizona's alluvial basins as early as 1927. At that time a fissure was reported 3 miles southeast of Picacho; recurring breaks have been noted at irregular intervals to the present time at this particular location. In addition to the Picacho Area occurrences, fissuring has been noted near Chandler Heights, Luke Air Force Base, and Black Canyon in the Phoenix area, near Bowie in Cochise County, near Bouse in Yuma County, and near Chukut Kuk, a Papago Indian settlement in the Tecolote Valley of south-central Pima County.

This thesis considers the Picacho Area only and no further reference will be made to the other locations listed above.

(1.1) Location

The region herein defined as the "Picacho Area" is located in south-central Arizona approximately midway between the cities of Phoenix and Tucson (see figure 1). It lies between latitudes 32° 33' and 32° 53' N, and longitudes 111° 25' and 110° 43' W. The basin is bounded by the Casa Grande and Sawtooth Mountains on the west and by the Picacho Mountains and Picacho Peak on the east.

There are two villages within the area: the town of Eloy, a trading center located midway between the Picacho and Casa Grande Mountains; the hamlet of Picacho lies 3 miles east of Eloy on Arizona



INDEX MAP

FIGURE I

Highway 84 (U. S. Interstate 10).

(1.2) Climate and Vegetation

There are two rainy seasons in the Picacho area: a winter season, when occasional storms from the Pacific Ocean move across the area, and another during the summer occasioned by moist air from the Gulf of Mexico. Total precipitation averages less than 10 inches a year. The summer season receives about 5 inches and approximately 3 inches falls during the winter. May is the driest month of the year and has an average rainfall of 0.09 inches. The heaviest recorded rainfall due to one storm occurred on July 25, 1936 when 4.50 inches fell at Casa Grande Station.

The climate is mild with the daily mean high temperature ranging from 66.2° F in January to 106.9° F in July; the daily mean low ranges from 33.5° F in January to 75.3° F in July. The extremes are 122° F in July 1905 and 15° F in December 1954 (Sellers, 1960).

The natural vegetation consists of the desert scrub and cacti that are typical of the lowlands of southern Arizona (see Plate 8). The natural growth has been replaced in a large part of the Picacho Area by cotton and alfalfa, which are sustained by irrigation.

(1.3) Industry

Agriculture is the principal industry within the basin, with cotton being the main product. Extensive irrigation of cotton began in the area in 1936 using ground water as the source of supply (Smith, 1940). In 1948 the rate of development declined and has since remained at a low level. The 1948 pumping rate was 360,000 acre-feet per year; pumping rates have remained near this level to the present (United States Geological Survey, Open File Records, Tucson, Arizona).

(1.4) Previous Investigations

Comparatively little attention has been paid to the Picacho Area fissures in spite of activity dating to 1927.

Leonard (1929) studied the 1927 occurrence and concluded that a break which appeared suddenly on August 12, after a severe rain storm, was probably caused by an earthquake with an epicenter approximately 120 miles from Picacho.

Fletcher et al (1954) attributed the fissures to a phenomenon called "piping"; the pipes were described as extending from playa-like collection areas to a central drainage way.

Heindl and Feth (1955) in a discussion of the article by Fletcher et al (1954) stated that "..., it seems significant that the fissures become nearly filled in the course of about a year, indicating that there is no ready outlet for lateral flow." From this and the tension break appearance of the fissures they concluded that the Picacho Area fissures could not be attributed to "piping".

Pashley (1961) in his observations on earth cracks near the Casa Grande Mountains concluded that the fissuring was probably the result of shallow differential subsidence due to the application of large quantities of water on poorly consolidated basin fill materials.

(1.5) Purpose and Method of Investigation

The author's original purpose in setting up a research program was to ascertain whether the fissures were caused by seismic disturbances, were related to surface flooding, or were related to a major decline in ground water levels.

A review of the literature on the Picacho Area revealed that, in contrast to Leonard's (1929) observations, succeeding occurrences of earth fissuring could not be correlated with seismic disturbances. However, one feature associated with the 1927 break has apparently recurred each time the fissures have suddenly appeared; this feature is the coincidence of torrential rainfall or the application of large quantities of irrigation water with the appearance of the earth cracks.

These items plus preliminary field observations led to the following 5 steps that were taken as an approach to the analysis of the fissuring:

1. The local fissures were located and mapped.

2. A check of seismic information at the Tucson Magnetic Observatory of the United States Coast & Geodetic Survey was made to determine if seismic disturbances could be correlated with specific occurrences of earth fissuring.

3. An investigation was made of changes in elevation from data furnished by the United States Coast & Geodetic Survey.

4. Changes in water levels were investigated from data available at the United States Geological Survey Office at Tucson, Arizona.

5. A gravity survey was made to determine the nature of the

geologic basement configuration.

It is the object of this thesis to interrelate these steps in presenting a general view of the causes of earth fissuring in the Picacho Area.

(1.6) Acknowledgments

The writer is indebted to Dr. J. H. Harshbarger who suggested the problem and was instrumental, along with Dr. W. D. Pye, in obtaining a Worden Gravimeter for the Geology Department of the University of Arizona; this instrument was used to obtain the gravity data which has been analysed in this thesis. Appreciation is also due Mr. H. E. Skibitzke of the United States Geological Survey, Phoenix, Arizona under whose direction this study was continued during 1961; and to Dr. W. C. Lacy, who made several helpful suggestions during the course of the investigation. Special acknowledgment is due my wife Mary, whose direct and indirect help in this study have been of a large magnitude.

2. HYDROGEOLOGIC SYNTHESIS

The author believes that both hydrologic and geologic factors are related to the occurrence and location of the fissures. The purpose of this section is to discuss these factors and their interrelationships.

(2.1) Physiography

The ground surface in the Picacho Basin is a homoclinal plane gently dipping toward the northwest. On the east lies Picacho Peak, which is composed of mafic volcanic rocks and has an elevation of 3382 feet (mean sea level datum of 1927). The Picacho Mountains, which lie to the north of Picacho Peak, have a maximum altitude of 4508 feet at Newman Peak and are composed of granite and granite gneiss. The elevation of the valley ranges from 1750 feet in the pass between Picacho Peak and the Picacho Mountains to 1450 feet on the northeast side of the Casa Grande Mountains. The Casa Grande Mountains form the western boundary of the basin and have a maximum altitude of 2362 feet; these mountains represent a complex of igneous, metamorphic, and sedimentary rocks with a dominant sialic composition. In the northwest part of T7S, R7E there are four small hills composed of granite pegmatite which appear to be structurally a part of the Casa Grande Mountains, being located on a broad pediment extending to the north of the mountains.

The bed of the ephemeral Santa Cruz River forms the main surface drainage in the region; it enters the basin on the south side of Picacho

Peak and flows northwestward past the Casa Grande Mountains.

Picacho Reservoir is located north of Eloy and Picacho. This feature is situated in a natural depression which was first enlarged by embankments during the 1880's in order to store water for irrigation purposes. The stored water was released to the Casa Grande Canal for use in the Casa Grande Area during the summer months. Completion of the Florence-Casa Grande Extension from Coolidge Dam to Picacho Reservoir and Casa Grande in 1930 resulted in a larger and more dependable flow of water to the Casa Grande area. Due to siltation in the reservoir and to lesser quantities of water available from Coolidge Dam, the reservoir and canals are not used as extensively as in the past. Most stored water at present comes from surrounding highlands during the late summer and winter rains.

(2.2) Geologic Setting

The Picacho Basin is located within the Basin and Range Province of the southwestern United States. This region is characterized by rugged mountain ranges fringed by pediments. The pediments slope toward the basins and disappear under the valley alluvium; drill hole data indicate that the pediments drop off rapidly at what are assumed to be boundary faults which define the basin and range structure.

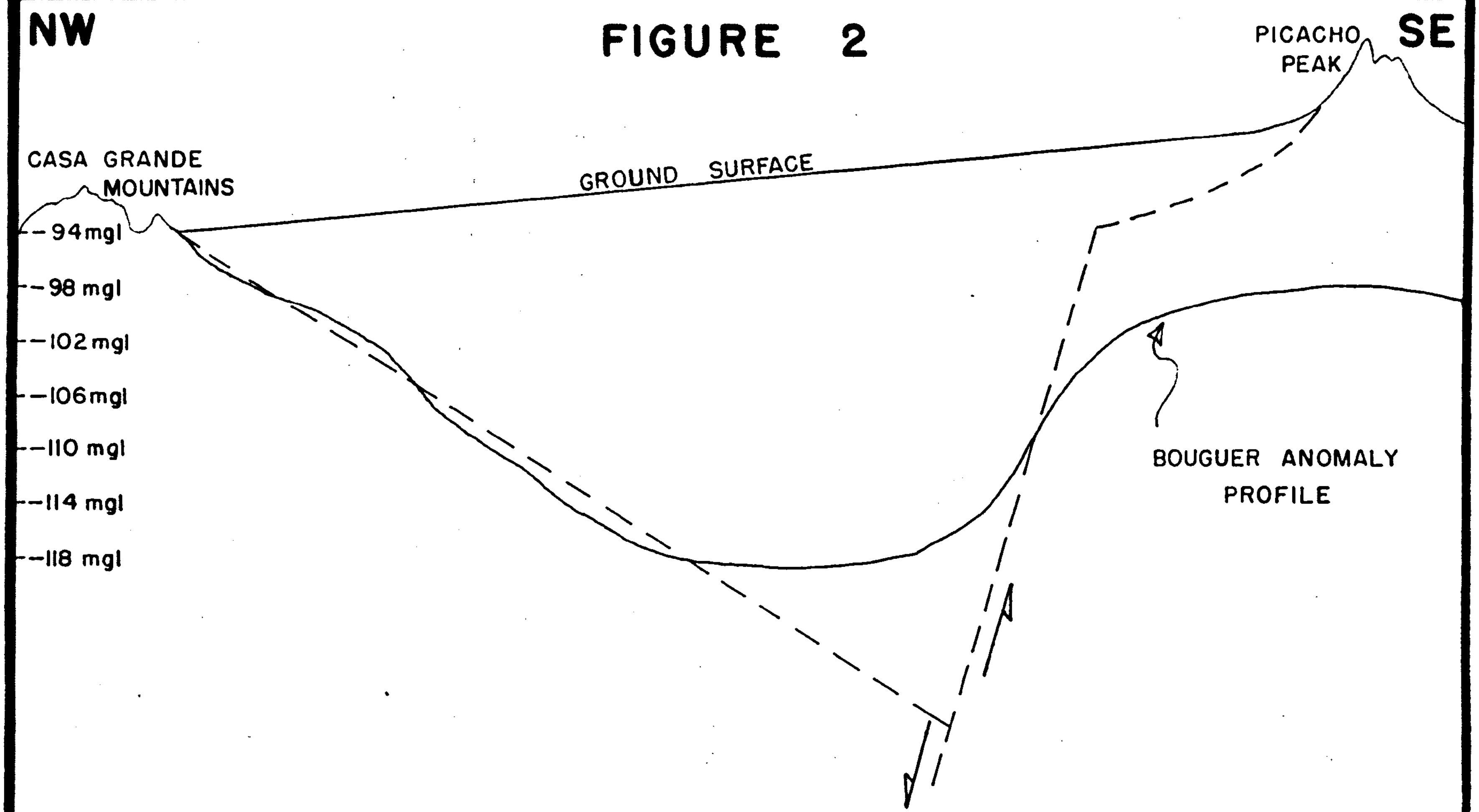
(2.2.1) Stratigraphy

Little information has been published to date on the detailed stratigraphy of the Picacho Area. Halpenny et al (1952) state that the mountainous masses are largely volcanic rocks of Cretaceous, Tertiary and Quaternary age, and crystalline and metamorphic rocks of Precambrian and later ages. In the basin proper Halpenny et al (1952) state that lenses of sand and gravel are present to depths of 500 to 700 feet below the surface. Below these lenses, to about 1100 feet, silt and clay lenses increase in thickness and number, while the sand and gravel lenses diminish in frequency and size. Between 1100 and 1500 feet fine grained, poorly sorted deposits, often called lake beds, predominate. Below 1500 feet subsurface lithologic information is scanty. R. E. Cattany of the United States Geological Survey, Tucson, Arizona, who has made extensive studies of the well logs in the Picacho Basin, has indicated that a conglomerate overlies the basement rock (personal communication, 1961).

(2.2.2) Structure

Two theories are available to explain the relationship between the mountains and valleys in the Basin and Range Province. One postulate is that there are two boundary fault zones with a resulting symmetrical valley trough; the other suggests that there is only one boundary fault with an asymmetrical trough. From gravity anomaly patterns (see section 2.3.2) the author believes the Picacho Basin to be asymmetrical with a north-trending boundary fault on the east flank of the basin. Figure 2 shows a gravity profile from the Picacho Mountains to the Casa Grande Mountains, and the author's concept of the basin structure based on the gravity anomalies.

FIGURE 2



IDEALIZED STRUCTURAL CROSS SECTION
BASED ON GRAVITY ANOMALIES
PICACHO AREA, PINAL COUNTY, ARIZONA

(2.3) Gravity Data Analysis

As the configuration of the basement rock is largely concealed in most alluvial basins, it was hoped that a gravity survey might produce a general picture of the basin boundaries.

(2.3.1) Coverage and Reliability of the Data

Two hundred and five gravity stations were established over an area of approximately 400 square miles in the Picacho Basin. These stations were commonly located on section corners with the exception of one line along Arizona Highway 84.

Readings were taken with a Worden gravimeter, Model 113, Number 461, having a dial constant of 0.4994 milligal per scale division. Meter drift was minor in spite of the fact that most readings were taken above the recommended maximum operating temperature of 90° F. A maximum deviation of 0.15 milligal, after drift correction, was obtained for repeat readings at any station in the network.

The network was set up to include 3 base stations; AHD BM 3812+60 1950, located at Red Rock; USC & GS BM F69 1934, located at Eloy; USC & GS BM C278 1948, located at Casa Grande. These base stations were established on an absolute basis by coordinating them with a gravity pendulum station, USC & GS BM A, located at the Tucson Magnetic Observatory; ties were made by means of looping with the Worden gravimeter. The reading sequence (ordered stations, 1,2,3,...) in the method of looping is 1,2,1,3,2,4,3,5,4,...,n,n-1,n+1,n,n+1,1.

BM	G	Elevation
A	979.2429 gals	2545.5
3812+60	979.3074 gals	1865.4
F69	979.3408 gals	1561.5
C278	979.3847 gals	1398.4

The looping method was not used within the general network itself, but reading ties were made several times a day to insure reasonable control of drift. Each day's readings were tied to the base stations by means of a closed traverse.

The most difficult problem faced in establishing Bouguer anomaly values for any station was elevation control. United States Coast & Geodetic Survey first and second order bench marks were used wherever possible, but often the control consisted only of topographic maps which could be used for interpolation purposes; due to subsidence in parts of the area it was necessary in some cases to adjust topographic control. In general, elevation control was significantly better than ±5 feet. An exception to this was the area around Picacho Reservoir where variations as great as 10 feet were possible. A 10 foot deviation would affect the final Bouguer anomaly by 0.66 milligal.

(2.3.2) Reduction of Data

The Bouguer gravity anomaly map (Figure 3) is derived from the following relationship; Observed gravity + Free air correction - Bouguer correction - Latitude correction = Bouguer anomaly. A combined Free air and Bouguer correction factor of 0.06599h milligal, h in feet, was used assuming an average density of 2.2 for all alluvium and rock above mean sea level datum of 1927. Theoretical gravity (latitude correction) was computed from the International formula $g = 978.0490(1 + 0.005288\sin^2\phi - 0.0000059\sin^2 2\phi)$, where ϕ is in degrees latitude. The gravity network was laid out to avoid abrupt changes in topography, therefore no topographic corrections were considered necessary in the calculations.

The point values from which Figure 3 is contoured should be reliable to the nearest milligal. Minor deviations in the contours may be expected from a denser pattern of gravity stations, but major changes are unlikely since trends were followed out after a basic gridwork had been established.

(2.3.3) Interpretations

It is assumed that the density differential causing the gravity anomalies is due to a contrast between the basin fill and the igneous-metamorphic basement complex. Under this assumption the gravity contours indicate the relative configuration of the hard rock and thus establish a large segment of the ground water boundary conditions within the basin.

The following is a list of wells which aid in the interpretation of the relative gravity highs and lows as shown in Figure 3 (Halpenny et al, 1952):

Location	Depth	Driller's Remarks
T8S, R7E, Sec. 12	2700 ft.	Bottomed in fine grained sediments.
T6S, R7E, Sec. 25	4742 ft.	Oil test; bottomed in granite; sediment-granite contact between 2619 and 4742 foot depth.

Location	Depth	Driller's Remarks
T9S, R9E, Sec. 10	220 ft.	Lava at 210 ft.
T10S,R9E, Sec. 21	405 ft.	Hard rock at 270 ft.
T10S,R9E, Sec. 5	600 ft.	Granite rock at 590 ft.
T7S, R7E, Sec. 8	255 ft.	Granite at 222 ft.

It can be seen from the above data that igneous rock occurs at depths slightly greater than 200 feet below land surface in the gap between Picacho Peak and the Picacho Mountains and between the Casa Grande Mountains and the pegmatite hills in the northwest part of T7S, R7E. Both areas are regions of relative gravity highs. The depth to the hard rock in the two wells in T10S, R9E again show general conformity to the gravity, with the 270 foot contact being a relative gravity high with respect to the well with the 595 foot hard rock contact. The two deepest wells are located in the areas of relative gravity lows.

In terms of geology the author believes that the gravity anomaly configuration on the west side of Picacho Peak represents a buried pediment sloping gently westward to a line approximately 2 miles west of Picacho Peak; this north-south trending line is characterized by a steep gravity gradient and is interpreted to represent the boundary fault separating the mountain mass from the relatively downfaulted basin. Between the villages of Picacho and Eloy the greatest negative anomalies are encountered and probably indicate the greatest thickness of sediments in the basin. A well drilled to 2700 feet of depth in this gravity low was bottomed in fine-grained sediments. From Eloy westward to the Casa Grande Mountains there is a lower gravity gradient than is found on the east slope of the basin, this is interpreted to represent a roughly uniform hard rock slope dipping basinward from the Casa Grande Mountains. The Bouguer anomalies do not suggest the presence of a large boundary fault along the west slope of the basin, although there appears to be a possibility of a lesser boundary feature about 3 miles west of Eloy (see Figure 2).

Between Eloy and Picacho Reservoir a northwest trending gravity high occurs. Due to the presence of several 2000-foot irrigation wells along this high the anomalies probably represent a deeply buried basement ridge with a saddle beneath the central part of T7S, R8E.

(2.4) Residual Drawdown of the Water Table

Irrigation wells were drilled in the Picacho Basin as early as 1914 (Smith, 1940). However, the total cultivated acreage did not exceed 4000 acres until the early 1930's. In 1936 irrigation began between Eloy and Toltec. There has been a continuous, if not progressive, decline in the water levels since the inception of large scale irrigation in the area.

The extensive use of ground water has caused an 180 foot lowering of the water table below static level in the vicinity of Picacho. Figures 4, 5 and 6 show water level changes in the basin for the years of 1915-49, 1915-52 and 1915-60. These residual drawdown or isopachous maps were contoured using a 1915 water level map (Smith, 1940) as a static datum and comparing with 1949, 1952 and 1960 water levels obtained from open files of the United States Geological Survey, Ground Water Branch, Tucson, Arizona.

(2.5) Changes in Surface Elevation

Figure 7 shows changes in surface elevation during irregular intervals of time from 1905 to 1960 along Arizona Highway 84 (U. S. Interstate 10). It is interesting to note that the locus of greatest subsidence has shifted, with time, to the east. A similar pattern is noted for the center of greatest residual drawdown (see Figure 8). From the general similarity of these two trends there appears to be a strong probability that the water level changes have initiated the subsidence or have accelerated consolidation of valley fill which may have been occurring slowly under natural conditions. The 0.066 feet of subsidence occurring between 1905 and 1934 took place during a period when the residual drawdown appears to have been negligible. There are several possible explanations for this small elevation change: 1. The subsidence could result from natural consolidation of the basin fill, a continuation of a process dating to the original deposition of the material. 2. Near surface subsidence of poorly consolidated fine grained materials. This may result when the soil structure collapses due to wetting by irrigation water. In the Picacho Area the sparse rainfall may have prevented thorough wetting of the soils except in drainage ways. 3. Subsidence originating near the water table due to the dessicating effect on clays of seasonal lowering of the water table. An increase in the effective loading on clay due to the removal of the buoyant effect of the water would also contribute to compaction in this case. The seasonal effect could be significant if the rebound-subsidence ratio was less than 1.1 with respect to full recovery of the water level. 4. The subsidence could result from a combination of the above factors.

It does not appear that there has been any significant subsidence of the hard rock basement which could have caused the surface elevation changes. There are several reports of well casing in the vicinity of 11 Mile Corner (11 miles east of Casa Grande) which have protruded above the ground, resulting in the elevation of the pump and concrete platform. This would seem to indicate a shortening of the sedimentary column above the base of the well casing. An inventory of such wells has not been made in the area, therefore the actual number is not known.

3. EARTH FISSURING

It is an interesting aspect of the earth fissures that all known reports of their appearance have made during the period of summer rains, July through September.

(3.1) Description and History of the Picacho Area Fissures

Following the 1927 break (see section 1.4) the next recorded disturbance occurred in 1935 when a crack opened to an extent necessitating repairs in the road bed of the Southern Pacific Railway.

On September 14-15, 1949, again after a heavy rainstorm, a fissure appeared 3 miles southeast of Picacho, creating an opening 3 to 6 inches wide across Highway 84 (Feth, 1951). The Arizona Daily Star, Tucson of September 23, 1949, referred to an earth crack located 1 mile southeast of Picacho, but apparently Feth found or assumed this to be in error since no reference to that location is made by him.

Since the 1949 occurrence, fresh breaks have appeared on several occasions, according to local residents. However, it is difficult to establish the dates of occurrence.

The author first examined the old fissure scars, which were located 3 miles southeast of Picacho, during the fall of 1959 (see Plate 1). At that time the fissure had an inactive, weathered appearance. From 1959 until the latter part of May 1961 there was no new evidence of a break near the old scars; during the last week in May 1961 hairline cracks began to appear and by the end of June a narrow ($\frac{1}{4}$ inch average) fissure was visible along the entire length of the old breaks. This fissure had increased from the 1000 feet observed in 1927 to almost 8 miles by 1961. By July 1, 1961 a bump was noticeable on the highway where the fissure intersected it. The highway, now designated as Interstate 10, had been completed in April 1961; the elevation change causing the bump occurred largely during the month of June. A level line run by the author on August 20, 1961 showed that there was an elevation drop of 0.10 foot in a distance of 2.00 feet where the bump was located; this contrasted with a normal gradient of 1 per cent (0.01 foot per foot) at that point. Plate 2, taken on August 5, 1961, visibly illustrates the elevation change described above. On the morning of August 4, the author again examined the fissure 3 miles southeast of Picacho. The earth crack by this time had widened to slightly less than $\frac{1}{2}$ inch in width. On the afternoon of August 4, a torrential rainstorm occurred in the area, causing ponding of water along the highway and railroad southeast of Picacho. Large quantities of water were noted by observers to have entered fissures at two locations, one 3 miles southeast of Picacho and the other 1 mile southeast. On August 5, the breaks as illustrated in Plates 3 and 4 were from a few inches to several feet in width. Plate 5, which was taken about 10 feet below the ground surface at the large opening shown in the foreground of Plate 4, illustrates the magnitude that the breaks may attain; the opening in the background (overexposed area in photograph) was approximately 4 feet in height.

In addition to the fissures described above there are several others which have occurred since 1950 in the Picacho Basin (see Figure 9). The northwest trending breaks which are located approximately 4 miles north of Picacho first appeared in the mid 1950's. They were first noticed in section 35, T7S, R8E. In 1959 cracks appeared in a cotton field in the sw$\frac{1}{4}$ section 26. Plate 6 was taken in section 26 in 1961. At that time attempts to reclaim the narrow fissured strip through the field had been abandoned after two tries at filling the break with soil. Pre-irrigation water had caused the loss of the fill in both cases due to slumping of the material into the fissure. By August 1961 cracks were visible in the railroad bed a few feet north of a crossroad dividing sections 27 and 22. The railroad tracks at that point had visibly subsided on the north side of the fissure.

Near Picacho Reservoir there appear to be two interfering trends to the fissuring; one trend is to the WSW and the other is N-S. In 1961 a reservoir embankment located at the south-center section line of section 1, T7S, R8E failed where it intersected the N-S fissure trend. Plate 7 illustrates the appearance of a fissure from the air in the vicinity of Picacho Reservoir.

Plate 8 was taken from a prominence on the southeast side of the Casa Grande Mountains. These fissures were studied by Pashley (1961).

It is apparent from observing the development of fissures in the Picacho Area that the breaks do not occur suddenly; instead they develop over a period of months, perhaps years, as narrow openings an inch or less in width. The advent of heavy rainfall or the application of irrigation water causes the fissure walls to slough in, thus creating

PLATE 1

OLD FISSURE SCARS

Old scars in earth embankment in the background appear in the same zone with those developed in 1961.

PLATE 1

PLATE 2

ELEVATION CHANGE

Careful scrutiny will reveal an abrupt elevation change near the front wheels of the truck.

PLATE 2

PLATE 3

PICACHO FISSURE #2

A fissure located 1 mile SW of Picacho on Highway 84.

This zone may have been active as early as 1949.

PLATE 3

PLATE 4

LARGE OPENING

Large opening along old fissure zone revealed by linear growth of vegetation. Before a torrential rain flooded the area on August 4, 1961, the crack(s) were less than $\frac{1}{2}$ inch wide.

PLATE 4

PLATE 5

SUBSURFACE OPENING

Photograph taken 10 feet below the surface at the large opening shown in Plate 4. The light area in the background is approximately 4 feet high.

PLATE 5

PLATE 6

COTTON FIELD FISSURE

A fissure which appeared in a cotton field in the late 1950's. Attempts to reclaim the land have failed to date.

PLATE 6

PLATE 7

AERIAL VIEW

Aerial view of a fissure near Picacho Reservoir.

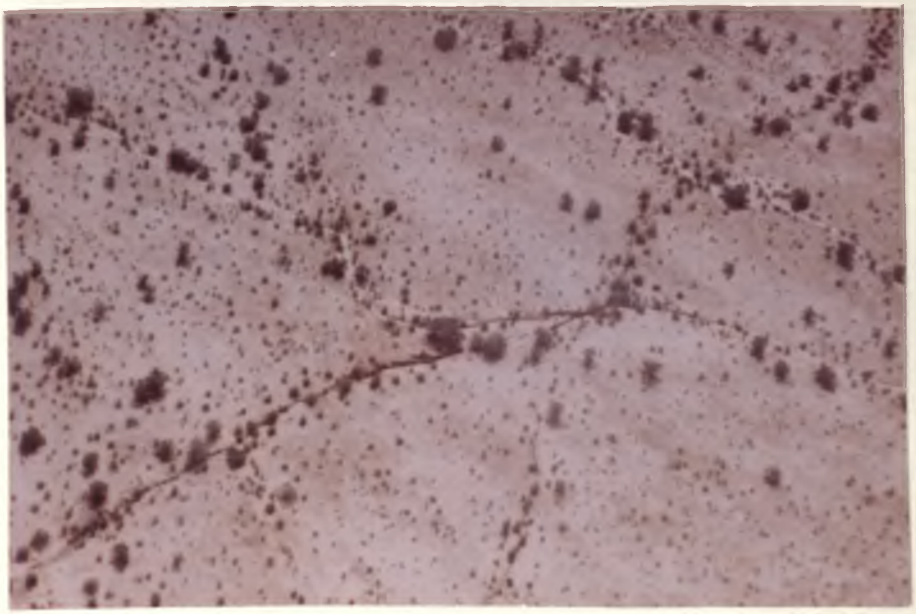


PLATE 7

PLATE 8

NEAR CASA GRANDE MOUNTAINS

View from a prominence on the southeast part of the Casa Grande Mountains. Note the close conformity of the fissures to the mountain front. Gravity anomalies indicate that the basement rock has a shallower slope on this side of the basin.

PLATE 8

the appearance of a cataclysmic event.

(3.2) Possible Causes of Earth Fissuring

Leonard (1929) listed 4 possible causes of earth fissuring:

1. Subsidence or slumping of ground over a cavity. There are no underground mines or evidence of natural openings in the vicinity of the fissures that could support this theory.

2. Fracturing due to readjustment in underlying rock masses. This hypothesis was rejected because of the lack of any reported earth tremors in the area and the apparent relationship between alluvial subsidence and a shortening of the sedimentary column as evidenced by protruding well casings above the ground surface (see section 2.5).

3. Vibrations produced by a distant earthquake. Except for the 1927 break there has been no evidence of any relationship between earth cracks and earthquakes. An investigation of seismic information at the Tucson Magnetic Observatory revealed that no earthquakes occurred in south-central Arizona at times which could be correlated with the 1949 and 1961 earth fissures. No other dates when fissuring occurred are available for verification.

4. A combined effect of seismic vibration and structural strain in partially consolidated basin fill material. This theory, which Leonard (1929) believed best explained the appearance of earth cracks, must still be considered a possibility in that there could be a delay time of considerable magnitude between a seismic disturbance transmitted through the hardrock basement and the appearance of the fissures at the surface. The author has found no evidence to support this

theory other than that reported by Leonard (1929).

Pashley (1961) believed that earth fissures in the vicinity of the Casa Grande Mountains were peripheral cracks around an area subsiding due to the application of large quantities of water to poorly consolidated soils. Pashley (1961) cited Poland's (Inter-Agency Committee on Land Subsidence in the San Joaquin Valley, 1958) work on shallow subsidence in the San Joaquin Valley of California as support for his theory. However, several aspects of the shallow subsidence as described by Poland (Inter-Agency Committee on Land Subsidence in the San Joaquin Valley, 1958) do not appear to be similar to the conditions found near the Casa Grande Mountains. The soil materials in areas subjected to shallow subsidence in the San Joaquin Valley were deposited as very poorly consolidated mud flows. The flows are located in the rain shadow of the coastal ranges and as a result have not been thoroughly wetted since the time of deposition. Very irregular, undulating subsidence occurs when these deposits are soaked by irrigation water or by leakage along canals. A test plot exhibited a maximum subsidence of 9.4 feet in 16 months of operation. In contrast, the soils near the Casa Grande Mountains appear too coarse grained to be characterized as mud flows; the fissures are located in a natural drainage way along which surface runoff usually occurs during rainy seasons; the subsiding areas are saucer shaped and are not irregular and undulating; there is an appreciable difference in the magnitude and rate of subsidence in the two areas. The greatest rate of subsidence that the author has been able to establish in the Picacho Basin occurred at the United States Coast & Geodetic Survey bench mark J304 located 1 mile south of Eloy where a 4.452 foot drop took place between 1952 and 1960; this contrasts with the 9.4 feet of shallow subsidence occurring in the San Joaquin Valley in a period of 16 months. The author believes that the shallow subsidence theory cannot be discarded completely, that it may be a contributing factor to the total subsidence within the basin. The theory is rejected as a major factor since, in addition to the other evidence cited in this thesis against the shallow subsidence theory and for another hypothesis, there is an absence of subsidence in irrigated areas located on the pediment slope to the north of the Casa Grande Mountains. If shallow subsidence were a major factor these areas should be affected by it.

Another possible theory, one that the author first used as a working hypothesis, is that the fissures resulted from differential subsidence in partially consolidated alluvial fill due to dessication and an increase in effective loading with lowering of the water table. Montmorillonite clays would be the material most likely to compact under dessicating conditions. The nature of the sediments, largely sand and gravel to a depth considerably below the water table, seems to eliminate this hypothesis as being of major significance.

A second working theory and one that the author believes more closely fits the field evidence is that the fissures occur near the periphery of a subsiding area (see Figure 7), that the subsidence was due to negative artesian pressures which resulted in compaction of the partially consolidated silts and clays that make up the interbedded aquifers and aquicludes below the 500 to 700 foot depth. In support of this theory is the fact that water well pump tests of short duration indicate an artesian storage coefficient; that the fine grained materials become dominant from 500 feet to 1500 feet of depth; the parallel association of the fissures and gravity highs suggest that deeply buried boundary conditions control the location of the fissures in that subsidence of deep origin is limited by these boundaries.

These items suggest that heavy pumping of deep wells causes a decline in pressure in the fine grained materials, thus lowering the hydraulic head below that of the water table. The result is an increase in pressure on the fine grained sediments, materials that are the most responsive to compacting forces. Long term changes in artesian head would be revealed by changes in the water table in that there would be downward flow from the water to equalize the hydraulic heads.

(3.3) Conclusions

The conclusions drawn here are based on the following summary formulated from field observations and from analysis of data:

1. Subsidence within the basin is related to the residual drawdown of water levels (see section 2.5).

2. Water occurring below the 500 to 700 foot depth (see section 2.2.1) is under artesian conditions when considered on a short term basis, but due to leaky aquicludes long term effects are revealed by the free water table.

3. The earth fissures are the result of differential subsidence within the basin and lie on the periphery of the subsiding area (see Figure 7).

4. The fissures have always appeared suddenly after a torrential

rain or the application of large quantities of irrigation water. The sudden appearance is merely due to the sloughing in of a narrow crack which would not have otherwise been noticed by a casual observer. (see section 3.1).

5. The fissures parallel in general the gravity highs, thus reflecting the affects of basements boundary conditions (see section 2.3.3).

The author believes that the fissures are formed on the periphery of a subsiding area, that the subsidence is caused or accelerated by losses in artesian head in fine grained deposits below the 500 to 700 foot depth, and that the basement boundary conditions adjacent to the compacting artesian zones control the location of the cracks instead of the location being controlled by obvious mountainous masses.

4. IMPLICATIONS OF EARTH FISSURING

Earth cracks to many people appear to be merely a scientific curiosity; however, examination of the cracks and their associated phenomena suggest that property damage may be extensive.

(4.1) Economic Implications

The economic damage associated with earth cracks is obvious when one notices where fissures have broken a highway surface, transected a cultivated area or caused the failure of water storage embankments. Less noticeable, but more costly, are other features resulting from the subsidence associated with the fissures; these include: releveling bench marks at intervals of time in order to maintain the elevation controls necessary for construction purposes; regrading irrigable acreage in order to maintain the necessary drainage slope; reconstruction of irrigation and drainage ditches due to changes in gradient; changes in natural drainage which require the addition or relocation of highway culverts; highway planning requiring expensive, last minute field investigations. Another item would be the collapse of well casings due to horizontal shear in areas of differential subsidence.

(4.2) Downcutting

In recent years arroyo cutting has appeared to be on the increase in southern Arizona. Subsidence due to lowering of water levels in areas previously in a state of equilibrium could be a partial explanation of the activity.

SELECTED REFERENCES

Arizona Daily Star, Tucson, 1949, v. 108, no. 266.

Feth, J.H., 1951, Structural Reconnaissance of the Red Rock Quadrangle, Arizona: Open file report at the United States Geological Survey Office, Tucson, Arizona.

Fletcher, J. E., Harris, Karl, Peterson, H. B. and Chandler, V. N., 1954, Symposium of land erosion "piping": American Geophysical Union Transactions, v. 35, p. 258-262.

Halpenny, L. C., et al, 1952, Ground Water In The Gila River Basin And Adjacent Areas, Arizona - A Summary: Open file report at the United States Geological Survey Office, Tucson, Arizona, p. 115-136.

Heindl, L. A. and Feth, J. H., 1955, Piping and Earthcracks - A Discussion: American Geophysical Union Transactions, v. 36, p. 342-345.

Heiskanen, W. A. and Vening Meinesz, F. A., 1958, The Earth and Its Gravity Field: McGraw Hill Book Company, Inc., New York.

Inter-Agency Committee on Land Subsidence in the San Joaquin Valley, 1958: Progress report on land-subsidence investigations in the San Joaquin Valley, California, through 1957, Sacramento.

Leonard, R. J., 1929, An Earth Fissure in Southern Arizona: Journal of Geology, v. 37, no. 8, p. 765-774.

Nettleton, L. L., 1940, Geophysical Prospecting For Oil: McGraw Hill Book Company, Inc., New York.

Pashley, E. F., Jr., 1961, Subsidence Cracks in Alluvium near Casa Grande, Arizona: Arizona Geological Society Digest, v. 4, p. 95-101.

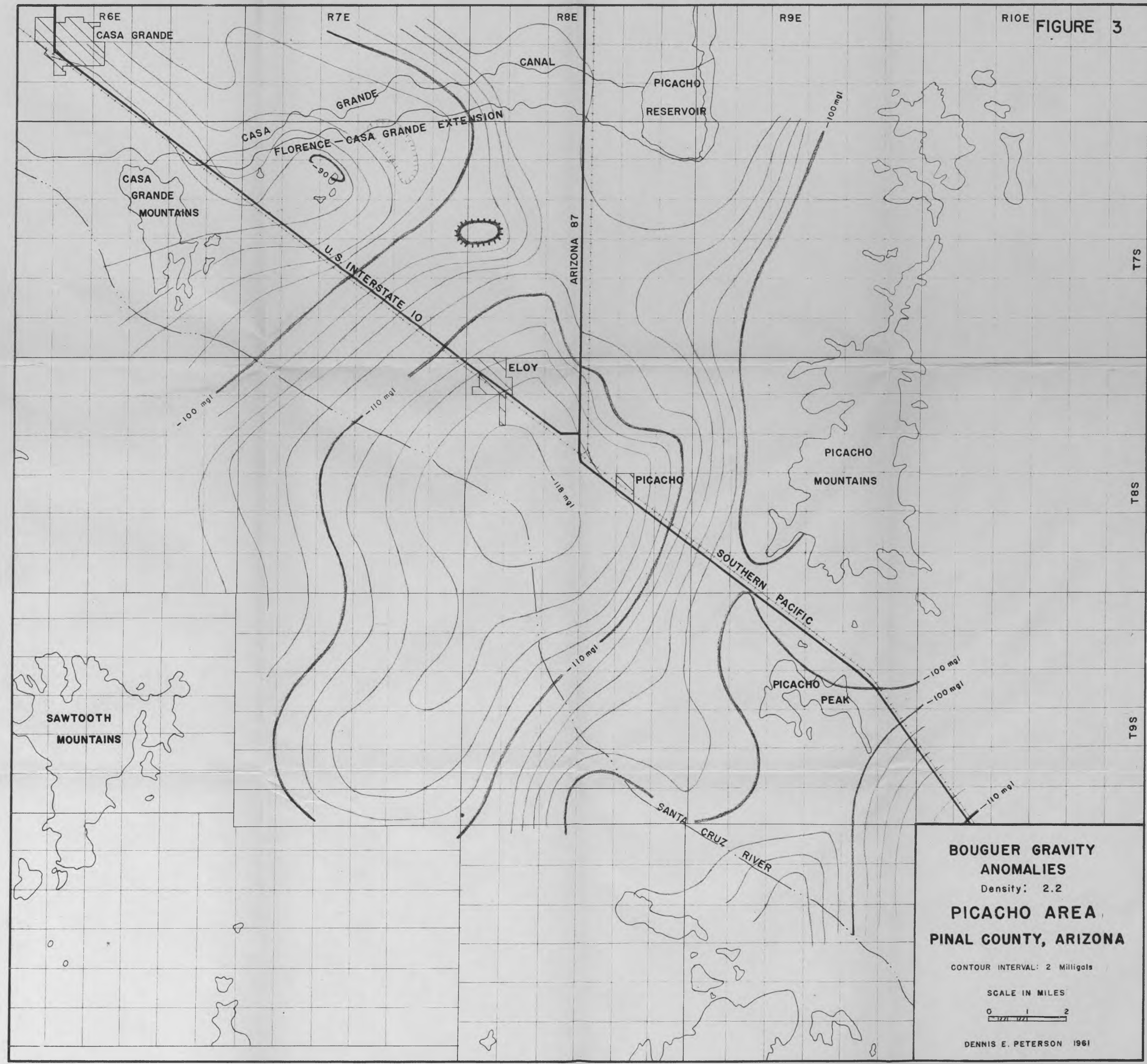
Sellers, W. D., ed., 1960, Arizona Climate: University of Arizona Press, Tucson.

Smith, G. E. P., 1940, The Groundwater Supply of the Eloy District in Pinal County, Arizona: University of Arizona Technical Bulletin no. 87, Tucson.

Tucson Daily Citizen, 1961, v. 89, no. 186.

White, N. D., Stulik, R. S., Morse, E. K., et al, 1961, Annual Report on Ground Water in Arizona Spring 1960 to Spring 1961: Arizona State Land Department, Water Resources Bulletin no. 10, p. 76-80.

7Figures



E9791
1962
15B
FIGURE 3
R6E
R7E
R8E
R9E
R10E
CASA GRANDE
CANAL
CASA
GRANDE
FLORENCE — CASA GRANDE EXTENSION
PICACHO
RESERVOIR
CASA
GRANDE
MOUNTAINS
-90
U.S. INTERSTATE 10
ARIZONA 87
-100 mgl
ELOY
-110 mgl
-118 mgl
PICACHO
PICACHO
MOUNTAINS
SOUTHERN PACIFIC
T7S
T8S
T9S
-110 mgl
PICACHO
PEAK
-100 mgl
-100 mgl
-110 mgl
SAWTOOTH
MOUNTAINS
SANTA CRUZ RIVER
BOUGUER GRAVITY
ANOMALIES
Density: 2.2
PICACHO AREA
PINAL COUNTY, ARIZONA
CONTOUR INTERVAL: 2 Milligals
SCALE IN MILES
0 1 2
DENNIS E. PETERSON 1961

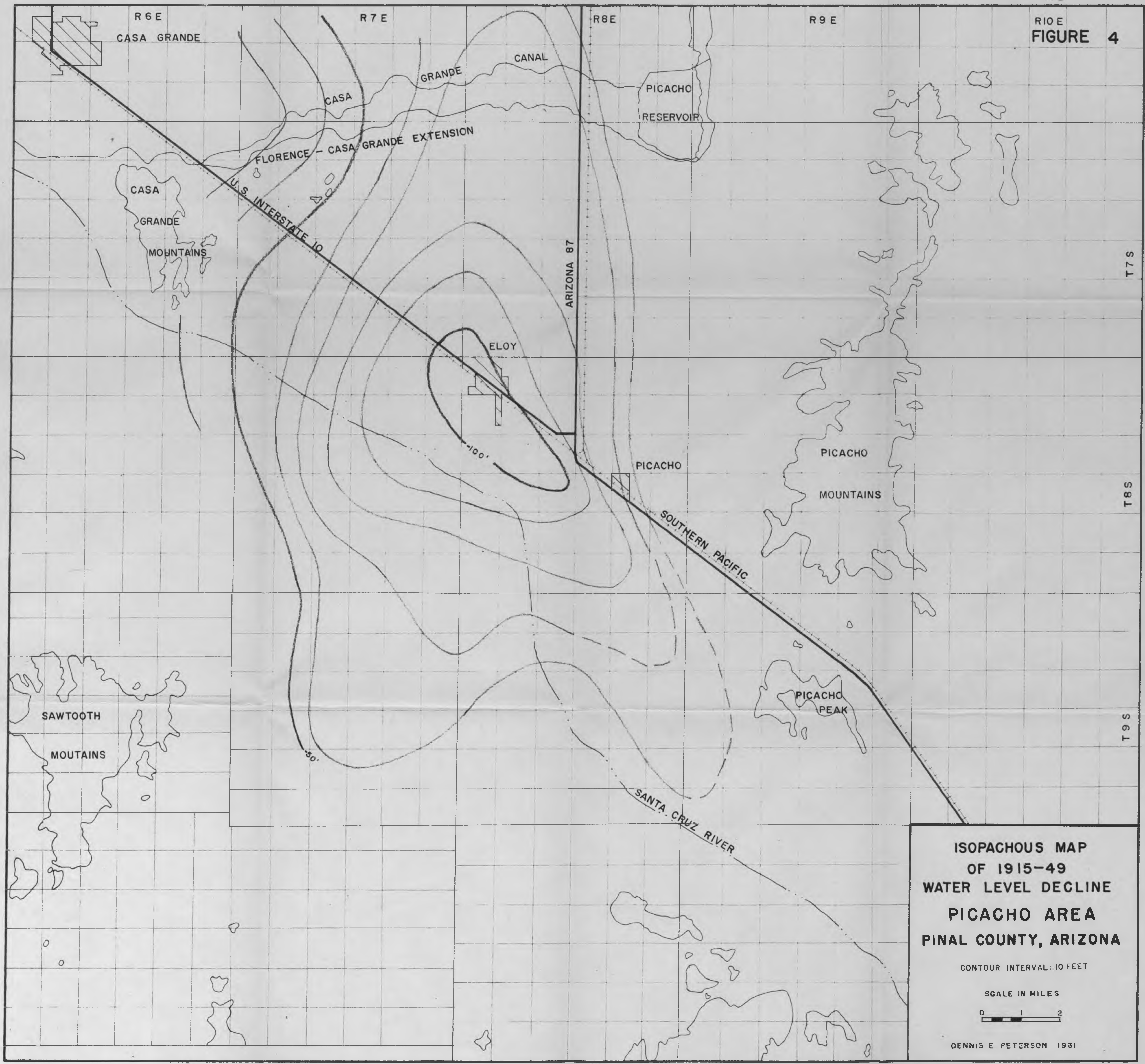


FIGURE 4

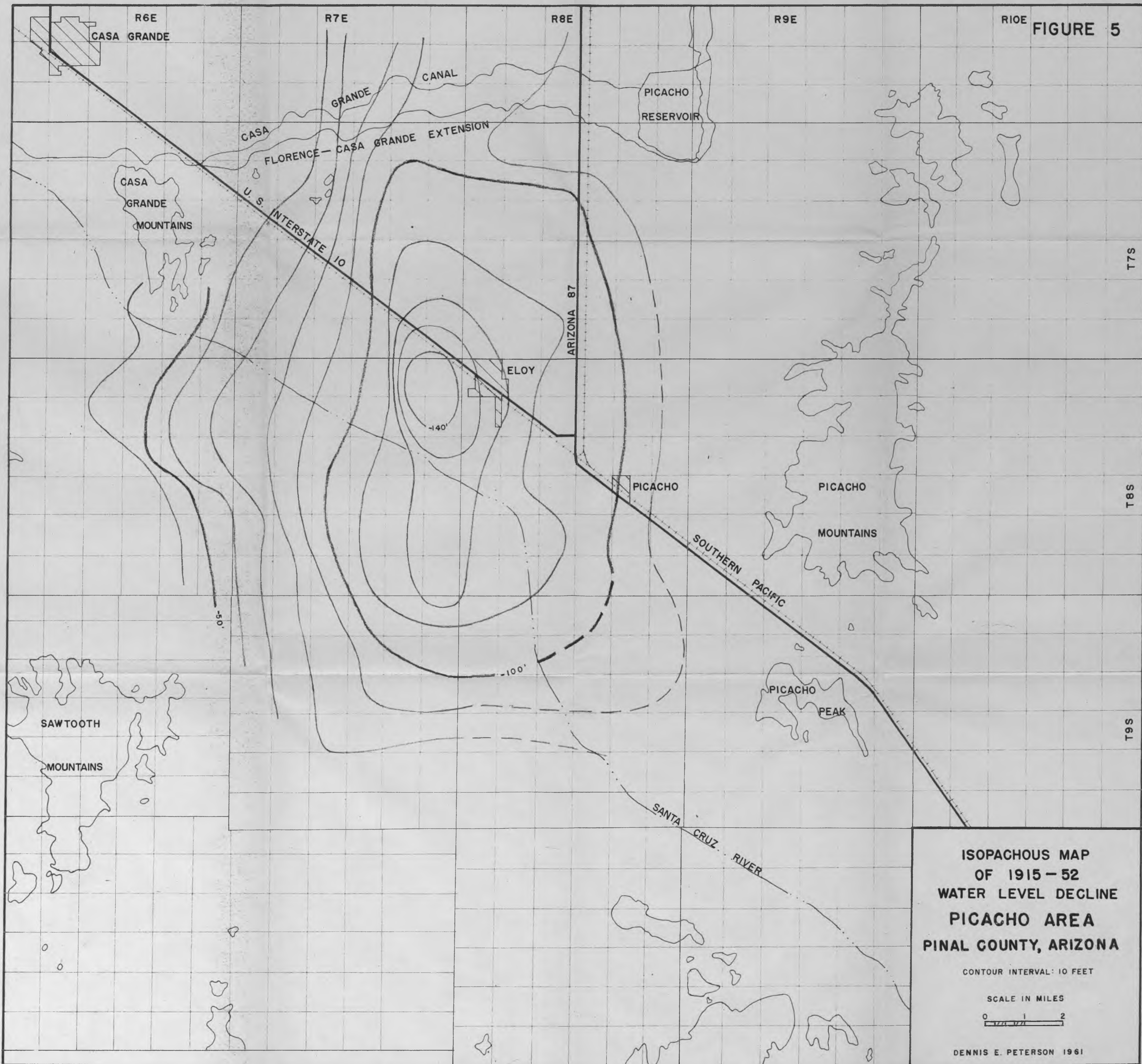
ISOPACHOUS MAP
OF 1915–49
WATER LEVEL DECLINE

PICACHO AREA
PINAL COUNTY, ARIZONA

CONTOUR INTERVAL: 10 FEET

DENNIS E PETERSON 1961

FIGURE 5



ISOPACHOUS MAP
OF 1915 — 52
WATER LEVEL DECLINE
PICACHO AREA
PINAL COUNTY, ARIZONA

CONTOUR INTERVAL: 10 FEET

DENNIS E. PETERSON 1961

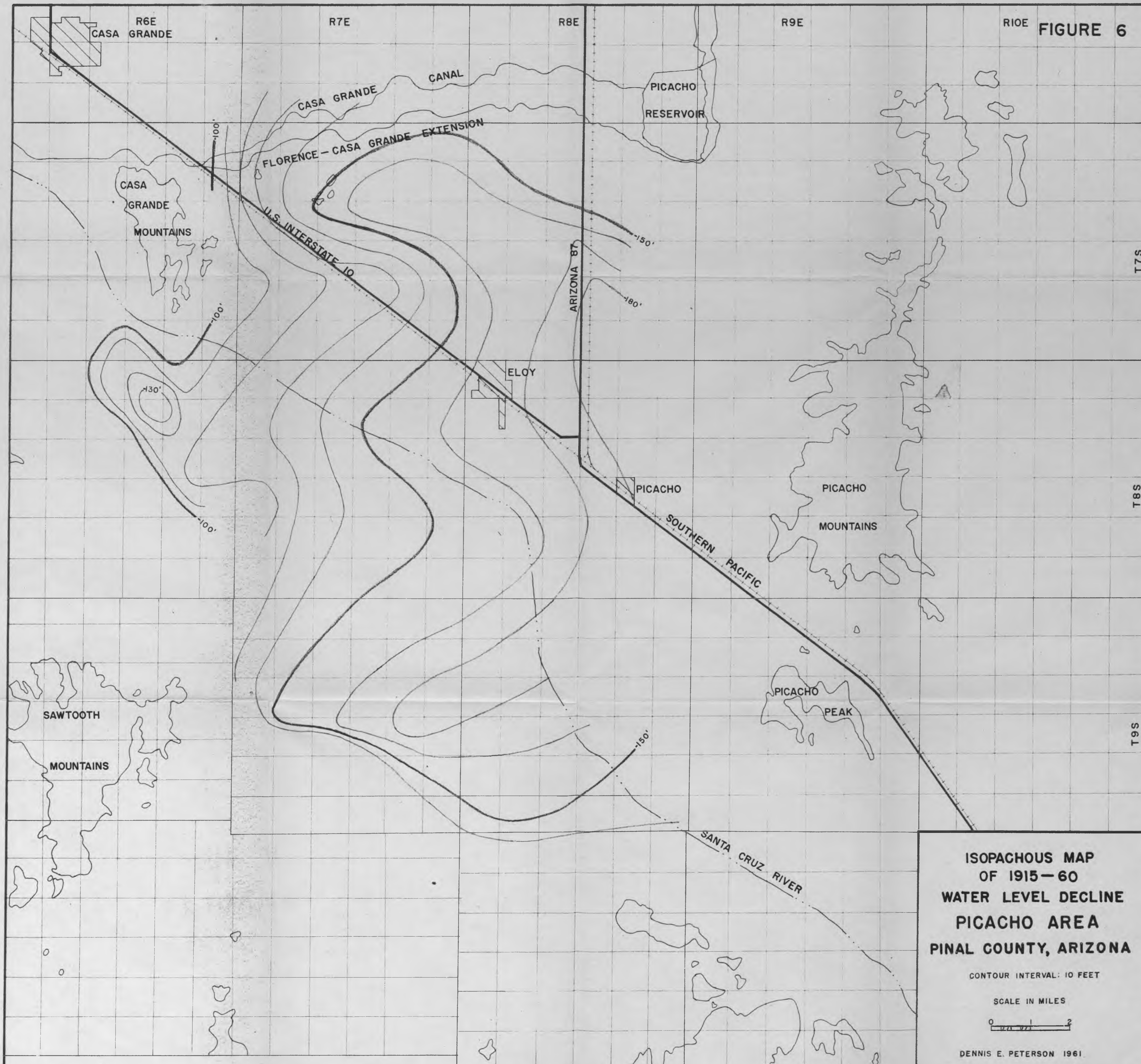
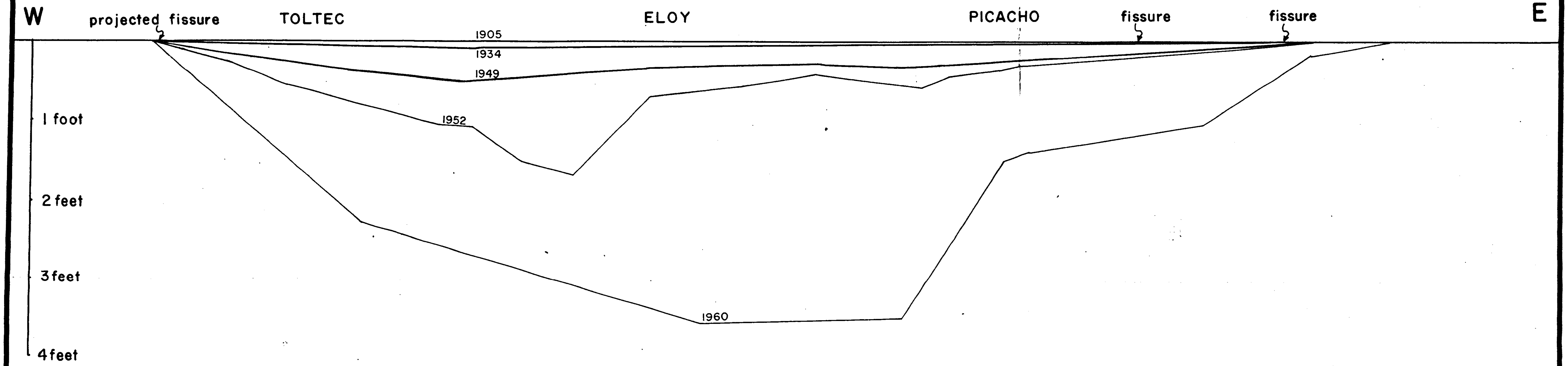


FIGURE 6
R6E
R7E
R8E
R9E
R10E
T7S
T8S
T9S
CASA GRANDE
CASA GRANDE CANAL
FLORENCE — CASA GRANDE EXTENSION
PICACHO RESERVOIR
CASA GRANDE MOUNTAINS
U.S. INTERSTATE 10
ARIZONA 87
100'
130'
150'
180'
ELOY
PICACHO
PICACHO MOUNTAINS
SOUTHERN PACIFIC
PICACHO PEAK
SAWTOOTH MOUNTAINS
SANTA CRUZ RIVER
ISOPACHOUS MAP
OF 1915—60
WATER LEVEL DECLINE
PICACHO AREA
PINAL COUNTY, ARIZONA
CONTOUR INTERVAL: 10 FEET
SCALE IN MILES
0 1 2
DENNIS E. PETERSON 1961

FIGURE 7



CHANGE IN LAND SURFACE PROFILE, ALONG U. S. HIGHWAY INTERSTATE 10 (ARIZONA 84)

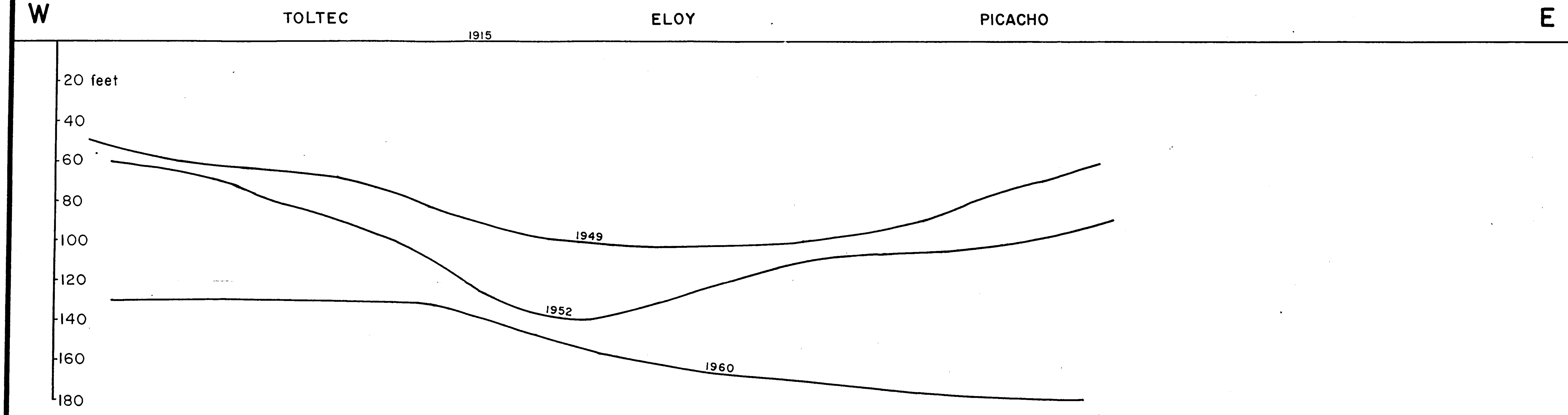
PICACHO AREA, PINAL COUNTY, ARIZONA

SCALE IN MILES:

0 1 2

E9791
1962
158

FIGURE 8



WATER LEVEL PROFILES, ALONG U. S. HIGHWAY INTERSTATE 10 (ARIZONA 84)

PICACHO AREA, PINAL COUNTY, ARIZONA

SCALE IN MILES

0 1 2

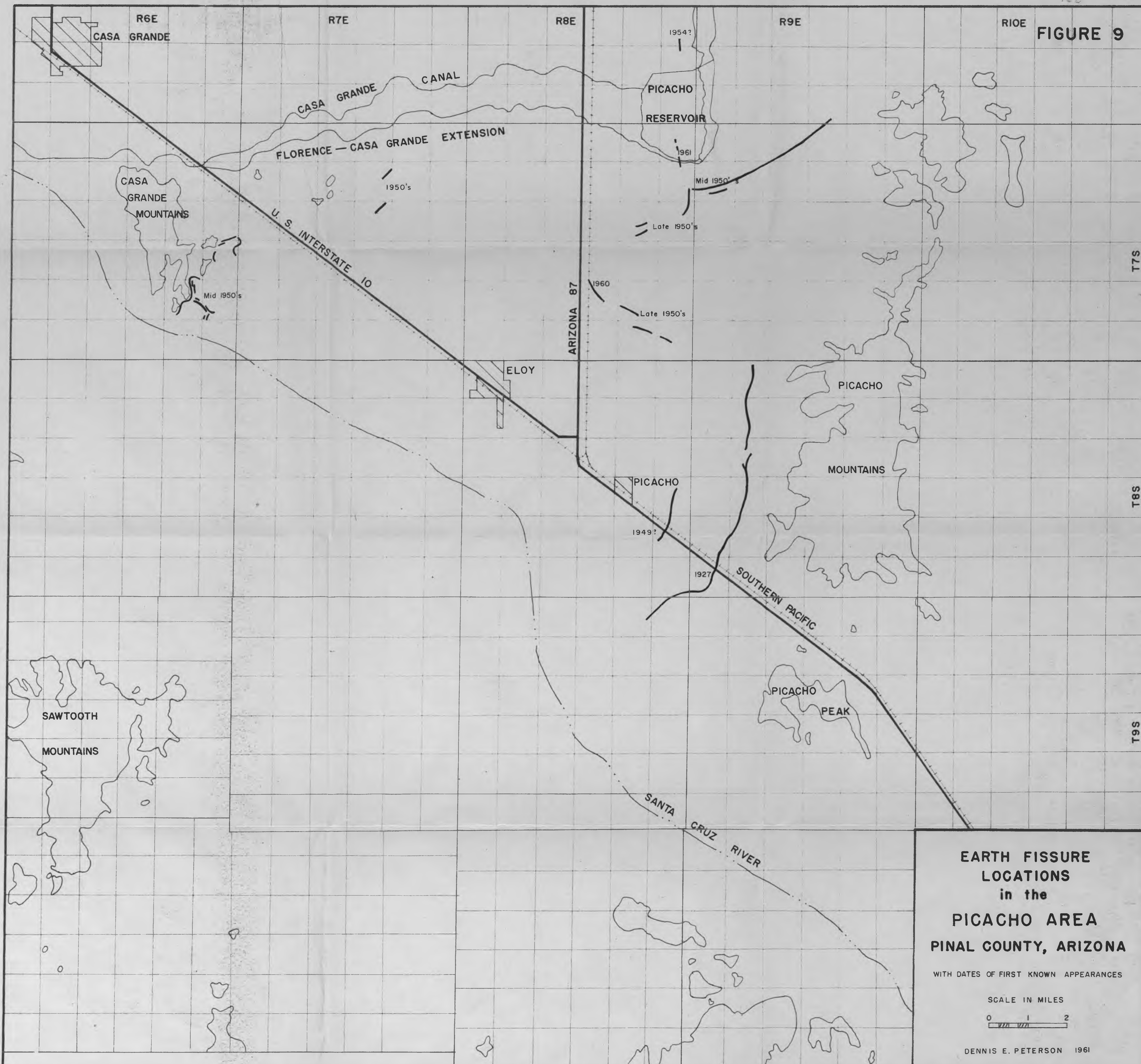


FIGURE 9
R6E
R7E
R8E
R9E
RIOE
T7S
T8S
T9S
CASA GRANDE
CASA GRANDE CANAL
FLORENCE — CASA GRANDE EXTENSION
PICACHO RESERVOIR
1954?
1961
Mid 1950's
Late 1950's
1950's
CASA GRANDE MOUNTAINS
Mid 1950's
U. S. INTERSTATE 10
ARIZONA 87
1960
Late 1950's
ELOY
PICACHO
MOUNTAINS
PICACHO
1949?
1927
SOUTHERN PACIFIC
PICACHO PEAK
SAWTOOTH MOUNTAINS
SANTA CRUZ RIVER
EARTH FISSURE LOCATIONS in the PICACHO AREA
PINAL COUNTY, ARIZONA
WITH DATES OF FIRST KNOWN APPEARANCES
SCALE IN MILES
0 1 2
DENNIS E. PETERSON 1961