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UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey

GROUND-WATER FIELD TRIP, TUCSON TO NOGALES, ARIZONA

By

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Tucson, Arizona
April 1954

FOREWORD

By L. C. Halpenny

A field excursion following the route described herein was conducted as a part of the curriculum of the 6th Ground Water Short Course, which was held by the Geological Survey at the University of Arizona in April 1954. The route log and descriptive text were designed to provide a general background of the ground-water situation in the Upper Santa Cruz Basin, a few of the geologic features that affect the occurrence of ground water, and some of the historical highlights of the region.

HISTORICAL HIGHLIGHTS OF THE UPPER SANTA CRUZ BASIN

By D. R. Coates

The history of the Upper Santa Cruz area can be divided into three separate periods of development: (1) The epoch of Spanish exploration and missionary activity from 1539 to 1823; (2) the interval of Mexican control from 1823 to 1853; (3) the present era of American occupation and administration. Prior to 1539 the Upper Santa Cruz area had been a no-mans-land and a battleground separating the peaceful, agrarian Papagos and Pimas on the west from the hostile, warlike Apaches on the east. Under Spanish, Mexican, Confederate, or Union flag, many people have left indelible marks on the pages of Arizona history: Indians, priests, soldiers, prospectors, miners, desperados, ranchers, farmers, healthseekers, and businessmen.

The famous march of Coronado into Arizona in 1540 completely overshadows the earlier travels in 1539 of Marcos de Niza, a Franciscan friar. The fabulous tales of powerful villages to the north, with many-storied houses, inhabited by a superior race of Indians, climaxed by de Niza's report of the Seven Golden Cities of Cibola, inspired Coronado to organize an expedition. His force consisted of about 250 Spanish cavalry, 75 troops, 300 Indian allies, and over 1,000 Indian and Negro servants. Although the exact itinerary is not known, they moved up through southern Arizona into the northern part of the State, and discovered that the wondrously imaginative stories of the gold and silver cities and their inhabitants were fiction.

No one has made a greater contribution to the history of Arizona than Father Eusebio Francisco Kino, a Jesuit priest. His first entry into the Upper Santa Cruz area was in 1691. From this date until his death, 30 years later, Kino pursued with ceaseless energy and zeal his ministry among the Indians. By 1694 he had established the first three missions in Arizona, at Guevavi, Tumacacori, and San Xavier del Bac. In 1697 he brought from Mexico cattle, sheep, goats, and mares for the more than 800 Indians living at San Xavier. This was the beginning of the cattle industry in Arizona; the early Indians did not even have beasts of burden. Kino also made the first map of southwestern Arizona, established many rancherias and cattle ranches , introduced new food plants and encouraged agriculture, and made 14 extensive journeys throughout the State. His energy was prodigious -- he once covered as much as 1,500 miles in 53 days.

After the death of Kino the Spanish influence languished and, goaded by unnecessary cruelties, the Pima Indians revolted in 1751 and plundered the San Xavier Mission. During this short rebellion Tubac was garrisoned with Spanish troops, making it the northernmost fort in Arizona. The Apache depredations were also increasing in fury and by 1776 it became necessary for strategic reasons to move the Tubac troops north to Tucson. The name Tucson, from the Papago means "at the foot of a black hill," and the first settlement was on the west bank of the Santa Cruz River. The early scenery at Tucson would not be recognizable today. There were large areas of malaria-infested swamplands and lagoons. Grass was reported to have been horse-high, and the Santa Cruz River is said to have had a perennial flow of water.

The period from 1790 to 1820 was one of relative peace in the Upper Santa Cruz area. At the end of this interval, however, a period of decay and abandonment of the missions set in and Tumacacori was partly destroyed by Apaches.

The short-lived domination of the area by the Republic of Mexico began in 1823. Private American explorations into Arizona began in 1825. Although the Apaches hated the other Indians, the Spanish, and the Mexicans, they lived peacefully with the American pioneers until 1836, when some malcontents killed a chief in order to collect the scalp bounty offered by the Mexican government. From that time on the Apaches, when not actively on the warpath, were an ever-present menace and a sinister deterrent to the development of the region. The war with Mexico began in 1846. It ended with the Treaty of Guadalupe-Hidalgo in 1848, by which the Upper Santa Cruz area still remained under Mexican control. Not until the Gadsden Purchase of 1853 did the area come into the possession of the United States.

The American period of colonization started with gold and silver prospecting near Tubac and the development of several successful mines in the Santa Rita and Patagonia Mountains. Dr. Thomas Antisell, geologist, was a member of an expedition to locate a southern railroad route in 1855, and he made the first systematic geologic description of southern Arizona. About this time Tucson and Tubac were given troops. Fort Buchanan was built on Sonoita Creek to give protection to the prospectors and miners who were arriving in increasing numbers, many of them failures of the 1849 California gold rush. In 1857 the semiweekly Butterfield stage line from San Antonio, Tex., via Tucson to Sandiego, Calif., was started. This important service was a tremendous stimulant to settlement and development of the area and, in fact, of the entire Southwest.

During the Civil War mining progress ceased, mail stages were discontinued, troops were withdrawn, and the Apaches filled the void with murder and depredations. The atrocities of the Apaches increased in fury after an act of unmitigated treachery committed under Army orders during a flag of truce. Friends and some of the family of Cochise, greatest of the

Apache chiefs, were killed by soldiers commanded by an inexperienced junior officer. In revenge, Cochise's warriors began a blood bath that lasted about 10 years.

The Confederates, in 1862, were the first troops to occupy Tucson during the Civil War. Two years later they were evacuated as a result of news that Union forces from California were approaching. In the confusion of these times Arizona was created as a separate territory in 1863. After the arrival of the California militia, mining again began to fluorish and more immigrants moved in. By 1867 Tucson was the center of a western cattle industry and the capital of the territory. The first federal census in 1870 showed Tucson to be the largest town in the region, with a population of 3, 200, predominantly Mexican. The ever-present Apache menace subsided somewhat in 1872, when Captain Jeffords and General Howard persuaded Cochise to abandon hostilities and to live peacefully on the newly created Chiricahua Reservation. However, several renegade Apache bands, the most notorious being those led by Victorio and Geronimo, continued to harass, plunder, and kill until 1886 when all outlaw Apaches were captured and sent to Florida. For the first time, after almost 300 years, the white man had domination of Arizona.

The completion of the Southern Pacific transcontinental railraod in 1879 and that of the Atlantic and Pacific in 1886 were necessary and important factors in bringing people and capital to the territory. New mines were opened, and those that had previously been submarginal could now afford to ship their ores at a profit. The number of cattle and the number and size of the ranches increased many fold. The medical profession began to recommend the dry, sunny climate for its therapeutic value, thus persuading many healthseekers to move in. The water table was at shallow depths, pumps were becoming available, and the drilling of wells was becoming less costly. By 1903 there were approximately 10, 000 acres of land under irrigation from surface and ground water in the entire Santa Cruz basin. Thus, prior to 1910 the economy of the four "c's"-- cattle, climate, copper, and cotton -- that was to build southern Arizona had already been established. In 1912 Arizona was admitted to the Union as the 48th State.

PRINCIPAL GEOLOGIC FEATURES OF THE UPPER SANTA CRUZ BASIN

By D. R. Coates

Location and Extent

Arizona can be broadly divided into three physiographic regions: (1) The plateau region, a part of the Colorado Plateau in the northern part of the State; (2) the mountain region, a comparatively narrow belt of mountains along the southwest margin of the plateau; and (3) the desert, or Basin and Range region, in southern Arizona. The Upper Santa Cruz basin is a part of the desert region, an area characterized by rugged mountains rising from broad, irregular plains. The drainage area of the basin is about 3, 500 square miles, of which 380 square miles is in Mexico. The maximum width of the basin is 47 miles. The length is 80 miles from the Mexican border northward to Rillito, where there is a hard-rock narrows that separates the Upper from the Lower Santa Cruz basin.

Land Forms and Drainage

The Santa Cruz River provides the major drainage of the basin. It is an intermittent stream with a source in the San Rafael Valley in Arizona (see map). The river flows south into Mexico, makes a 35-mile arc to the west and north, and re-enters Arizona 6 miles east of Nogales. Most of the important tributaries enter from the east; including Sonoita Creek, Rillito Creek, and Canada del Oro. Sopori Wash is the only important large tributary that enters from the west. Nogales Wash flows northward and joins the Santa Cruz about 8 miles north of Nogales. It is common for the smaller stream channels issuing from the mountains to disappear completely before reaching the valley trough.

The gradient of the Santa Cruz River ranges from about 40 feet per mile in the San Rafael Valley to about 15 feet per mile at Rillito. In relief, the altitude ranges from 9, 445 feet, on Miller Peak in the Huachuca Mountains, to 2, 060 feet, at Rillito. When first seen by white men the Santa Cruz River was reported to be permanent stream through much of its course. Since about 1890 the Santa Cruz River has cut a continuous channel through the basin and become incised to depths ranging from a few feet to more than 25 feet. With a lowering of ground-water levels the stream has become influent.

The Santa Cruz River does not follow the axis of the basin; instead the stream has been pushed westward because of the greater deposition of alluvial sediments from the east. The mountains on the east are much higher than those on the west and consequently receive heavier precipitation -- an annual average of about 22 inches compared with about 14 inches for the mountains on the west. Bedrock surfaces in the mountains comprise more than 30 percent of the drainage area in the basin.

Principal Mountain Ranges and Elevations of Highest Peaks

Mountain range	Elevation of highest peak (feet above sea level)
Atascosa	6,440
Canelo Hills	6,100
Cerro Colorado	5,000
Empire	5,500
Huachuca	9,445
Patagonia	7,200
Rincon	8,590
Santa Catalina	9,185
San Cayetano	5,990
Santa Rita	9,432
Sierrita	6,206
Tanque Verde	7,030
Tortolita	4,645
Tucson	4,687
Tumacacori	5,724
Whetstone	7,684

The three principal geomorphic elements of the present landscape are (1) the mountains, (2) the transverse alluvial slopes, and (3) the flood plain of the Santa Cruz River. Some mountains, such as the Huachuca, have a youthful aspect with linear features and serrate or sierra-type crestlines. Others, such as the Sierrita and Whetstone Mountains, are maturely dissected, with well-established and integrated radial drainages. The mountains of the Upper Santa Cruz basin are not as typical of the basin and range type as is generally pictured. Straight rectilinear base lines that endure for long distances are rare; instead, the mountains and the valleys are very irregular, with broad reentrants commonplace throughout the basin. Such irregularity results from an exceedingly complex structural history, variations in physiographic age, and unusual distribution of rock types. An interesting feature of the weathering-erosion regimen of the mountain slopes is that bouldery talus deposits are almost non-existent because the comminution cycle is exceedingly active.

A sharp break is present at the contact of the mountain slope with the transverse slope of alluviation. This break is attributed to headward retreat of the mountain fronts, which were originally fault controlled. The long transverse alluvial slopes often include a pediment or eroded bedrock surface near the mountains which passes imperceptibly into an alluvial zone of deposition. Alluvial fans occur in a few of the ranges, including the Santa Rita Mountains, where mountain streams have deposited much of their load on the shallower gradients of the alluvial slopes. Many of these fans have been incised by recent degradation.

The width of the flood plain of the Santa Cruz River ranges from a few hundred feet in the headwaters to more than half a mile in the northern part of the basin. South of Tubac at least three well-developed terrace levels occur along the present course of the Santa Cruz River.

Rock Sequence

Rocks of early pre-Cambrian time are represented by the Pinal schist, some gneiss, and granite. The later pre-Cambrian rocks belong to the Apache group, consisting of mudstone and shale, orthoquartzites and conglomerate, and limestone. The thickness of this group is less than 1,000 feet.

The Paleozoic deposits of the Upper Santa Cruz basin are largely marine limestone and reworked detrital sediments of shelf areas that extended northward from a Sonoran geosyncline. There is no sharp line of demarcation separating the rocks of the Apache group from those of the Paleozoic era. Typical Paleozoic units include Cambrian orthoquartzite, limestone, and sandstone interbedded with mudstone. From Devonian time to the end of the era the dominant deposits were marine limestone. Rocks of Ordovician and Silurian age are not present in the area. Paleozoic rocks attain a thickness of about 5,000 feet.

As sediments of Triassic and Jurassic age are absent in southern Arizona, the Mesozoic rocks in the basin are restricted to those of the Cretaceous period. Some marine limestones of this age do occur, but the bulk of Cretaceous deposits are continental and consist of much graywacke, and of other sediments ranging from mudstone to conglomerate. The total thickness of Cretaceous deposits has been reported to be as much as 20,000 feet in the vicinity of the Huachuca Mountains.

The igneous and metamorphic rocks of the Upper Santa Cruz basin vary widely in age and composition. The granite and related intrusive rocks are mostly of two ages, pre-Cambrian and Laramide. Thick masses of Paleozoic diabase occur in many areas. Volcanic and eruptive materials are mostly Cretaceous, Tertiary, and Quaternary. The older volcanic flows generally are more acidic in composition and those of later Tertiary and Quaternary age are predominantly basic. Many areas in the basin have been covered with large volumes of tuff and agglomerate, as in the Tumacacori and Atascosa Mountains. The gneiss and associated metamorphic rocks of the Santa Catalina, Tanque Verde, and Rincon Mountains are considered to be of Tertiary age.

The alluvial fill in the Upper Santa Cruz basin can be conveniently divided into "older fill," of Tertiary and Quaternary age, and Recent fill. In addition to the age difference, the two fills vary in thickness, extent, compaction, cementation, and size of materials. The older fill is thicker, more widespread, compacted, and cemented and, in general, consists of finer-grained materials except near the mountains. The total thickness of the fill is unknown, as the deepest well in the basin, 1,480 feet, did not encounter bedrock. Oil test holes in other basins of southern Arizona have proved the fill to be more than 4,000 feet thick in some areas. The thickness of Recent alluvial fill in the basin is not known to exceed 300 feet and is greatest under the Santa Cruz River. This fill provides practically all the ground water used for irrigation, as it is permeable and composed of relatively coarse materials.

The materials of the alluvial fill are unconsolidated to poorly consolidated gravel, sand, silt, clay, occasional boulders, and some caliche. The materials were carried downslope by streams and sheet runoff, the large fragments being deposited nearest the mountain source and the smaller fragments farther away. Thus, there is a gradation in size of particle from coarse to fine toward the valley trough. Other factors are present, however, which upset such a clear-cut classification of sediment size. Variations of storm intensity and shifting of stream channels produced widely fluctuating conditions of deposition and resulted in lens-shaped beds and strata which change rapidly in texture and character both horizontally and vertically. Well logs throughout the basin reflect these conditions and correlation of individual beds is tenuous to impossible. Although there is no thick lake-bed series of clays in the basin, such as is present in some other southern Arizona basins, some suggestion of local ponding can be deduced from well-log information and foreset bedding in some Tertiary sedimentary outcrops.

Structural Geology

The structure of the mountains in the Upper Santa Cruz basin is a complex of large-scale faulting which resulted in the depression of some blocks and the relative uplift of others. Displacement is known to be more than 3,000 feet in some areas. Extensive thrust faulting is present throughout most of the ranges in the northern part of the basin. Of special local interest is the structure, origin, and age of the metamorphic complex that comprises large areas of the Santa Catalina, Tanque Verde, and Rincon Mountains. The gneiss and granite gneiss were emplaced into a host rock already deformed by recumbent and isoclinal folding. This intrusion resulted in a doming of the area. Later the dome was faulted.

PRINCIPAL FEATURES OF THE GROUND-WATER SUPPLY OF THE UPPER SANTA CRUZ BASIN

By L. C. Halpenny

The preceding section on geology has provided a setting for a description of the ground-water supply, so let us follow water through the hydrologic cycle and observe the results.

Recharge

The ultimate source of the water supply of the Upper Santa Cruz basin is, of course, precipitation. As the basin is in a semiarid part of the

United States, precipitation is relatively small and is governed to a large extent by altitude. On the valley floor the mean annual precipitation ranges from about 11 inches near Tucson to about 16 inches near Nogales. The mean annual precipitation in the higher mountains is 25 to 30 inches and, in the lower mountains, 12 to 20 inches.

Precipitation is in two principal seasons. Summer storms, which occur from June through August, are local in extent, have high intensity but short duration, and sometimes result in as much rainfall in the valleys as in the mountains. Winter storms occur generally from December through February. The precipitation in this season is widespread and gentle, and is more intense on the mountains than in the valleys. Winter storms frequently produce accumulations of snow in the mountains, which sometimes last 3 or 4 months.

Runoff from precipitation is a major source of recharge to the ground-water supplies of the alluvial fill in the Upper Santa Cruz basin. Runoff issuing from the mountains is depleted considerably by infiltration as it passes onto the alluvial fill of the valley. The sediment content of the runoff has a direct relation to the infiltration rate. The winter runoff from the gentler rains and snow melt generally carries less sediment load and produces more recharge than the muddy runoff from torrential summer storms.

Several years ago data were obtained on infiltration from runoff in the Santa Cruz basin. Streamflow losses from relatively clear water in the Santa Cruz River and Rillito Creek ranged from 1.1 to 3.8 feet per square foot of wetted area per day, and from silt-laden water, 0.2 to 1.0 foot per day.

Recharge from precipitation falling directly on the desert floor is considered to be negligible, on the basis of soil-moisture tests before and after storms. There are several reasons for this lack of penetration: The surface soil is fine grained and tightly packed under natural conditions; there is a deficiency in soil moisture due to evaporation potential, which is about 80 inches a year, and to use by native desert plants; and relatively impermeable "caliche" zones of calcium carbonate cementation are present.

Some recharge occurs from infiltration of water used for irrigation of cultivated fields. On the basis of experiments in southern Arizona it is estimated that about 10 to 20 percent of the water applied to fields for irrigation becomes recharge in the Upper Santa Cruz basin. The infiltrating waters slowly move downward. The rate of movement varies greatly depending on the distance traveled, type of material and obstructions encountered, and depth to the water table. The downward movement of the percolating water is known to range from less than 0.3 foot to more than 33 feet per day.

Movement

Ground water of the Upper Santa Cruz basin moves from areas of recharge near the mountains toward the axis of the valley. The gradient of the water table is more gentle than the land slopes and is somewhat oblique to the surface contours. The time required for water to move to the axis of the basin from the margin is probably many years. The slow rate of movement is illustrated in the Lower Santa Cruz basin, where a cone of depression, developed to a depth of more than 100 feet during the past 15 years, has not yet spread sufficiently to produce a significant decline at a distance of 5 miles.

Discharge

Under natural conditions, before man began to utilize the water supply of the Upper Santa Cruz basin, discharge of ground water occurred only by surface flow and underflow out of the basin, and by evapotranspiration within the basin. From reports of early explorers, it is deduced that effluent seepage of ground water many years ago was sufficient to sustain perennial flow at several places in the basin. The water table was high enough in the narrows at the lower end of the basin, at San Xavier, and possibly near Tumacacori, for natural discharge by effluent seepage to balance recharge.

In the areas where the water table was shallow, phreatophytes apparently were more plentiful than now, and natural discharge occurred by transpiration through phreatophytes and by evaporation of ground water from wetted sands.

The Spaniards observed that the Indians farmed by irrigation with effluent ground water diverted from the Santa Cruz River. The diversions were crude, and probably washed out in time of flood and were useless in time of drought.

Beginning with the settlement of the area by white men, the ground-water supplies began to be developed. One of the earliest known wells in the region was at Mission San Xavier. Beginning in the present century, withdrawals of ground water became sufficiently great to lower the water table in local areas and thereby reduce or even stop the effluent seepage. The infiltration gallery at the San Xavier road crossing represents an effort to increase the withdrawal of ground water for irrigation.

Throughout the Southwest, in the past 20 years several factors have exerted a tendency to increase the need for irrigation water in general and the utilization of ground water in particular. The period has been one of increasing prices for agricultural products and of guaranteed security against unforeseen losses. Technological improvements have been made in well-drilling methods, design of plants, and availability of cheap power. As a result, withdrawal of ground water by pumping in the Upper Santa Cruz basin is now of predominant importance.

The initial effect of the increasing pumpage of ground water was to reduce and finally stop natural discharge by effluent seepage. Later effects were to reduce underflow out of the basin and losses by evapotranspiration. As withdrawals now exceed recharge, they must be partially supplied from the quantity in storage, with a resulting decline in the water table.

Johnson (in Halpenny and others, 1952, p. 109) presents a tabulation showing the approximate relation of recharge to discharge for the 5-year period 1947-51. The tabulation is printed here.

Estimated annual gains to reservoir	Acre-feet	Estimated annual losses from reservoir		Acre-feet
Infiltration at mountain fronts	65,000	Discharge by pumping:		
		Irrigation	105,000	
		Exported	18,000	
		Public supply) Industrial) all others)	43,000	166,000
Seepage from surface channel runoff	45,000	Underflow out of basin:		
		Rillito narrows	2,500	
		San Rafael Valley	2,000	4,500
Underflow into basin	1,000	Evapotranspiration		12,000
Springs	---	Springs	--	---
Seepage from irrigation	20,000 - 10,000			
Total gains	131,000 - 121,000	Total losses		182,500
or approximately	125,000	Rounded to		182,000
		Total gains		131,000 - 121,000
		Net annual loss from storage		51,000 - 61,000
		or approximately		55,000

The resulting decline of the water table is currently about 3 feet per year in the Tucson area. This decline is persistent and is not offset greatly by sporadic recharge from the Santa Cruz River. Upstream toward Nogales the effect of recharge from occasional floods is more noticeable and offsets the withdrawals to a greater extent. In the more heavily pumped areas of Arizona the declines are as much as 20 feet annually. Total pumpage in the State was approximately 3.7 million acre-feet in 1952, an amount greater than the storage capacity of all the State's surface-water reservoirs.

Quality of Water

A common feature of the quality of the ground-water supply in most of the alluvial basins in southern Arizona is that the water is hard. This is true for the Upper Santa Cruz basin. Water falling as precipitation carries negligible amounts of dissolved mineral matter but begins to become mineralized as soon as it comes in contact with the earth. As runoff, the water is in contact with suspended sediment and, as ground water, it slowly moves past the component rock particles. As it moves, it dissolves soluble material and hence becomes progressively more highly mineralized. The following is quoted from Johnson (in Halpenny and others, 1952, p. 111):

"The ground water of the Upper Santa Cruz basin contains moderate amounts of dissolved solids consisting largely of calcium and bicarbonate (table 21). Concentrations of total dissolved solids range from about 100 to about 950 parts per million, and of hardness range from 75 to about 350 parts per million. Analyses of water sampled for public supply use in the Tucson area range in total dissolved solids from 177 to 484 parts per million and in total hardness from 94 to 220 parts per million. An analysis of a sample of water supplied to Nogales in 1951 showed 333 parts per million of total dissolved solids and a total hardness of 214."

Sources of Data

Bryan, Kirk, 1925, The Papago Country, Ariz.: U. S. Geol. Survey Water-Supply Paper 499, 436 p.

Johnson, P. W., _in_ Halpenny, L. C., and others, 1952, Ground water in the Gila River basin and adjacent areas, Arizona--a summary: U. S. Geol. Survey open-file report, p. 101-115.

Schrader, F. C., with contributions by Hill, J. M., 1915, Mineral deposits of the Santa Rita and Patagonia Mountains, Ariz.: U. S. Geol. Survey Bull. 582.

Turner, S. F., and others, 1943, Ground-water resources of the Santa Cruz basin, Ariz.: U. S. Geol. Survey mimeographed report, 84 p.

ROAD LOG

By

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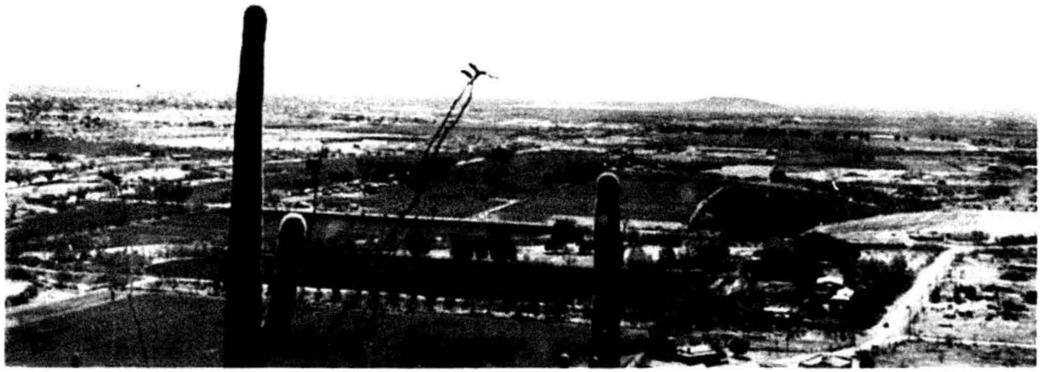
Mileage between observations	Cumulative mileage	
0.0	0.0	Start at University of Ariz. Football Stadium; head west on 6th St. at Cherry Ave.
1.05	1.05	Turn RIGHT (north) on N. 4th Avenue.
.55	1.60	Traffic light at Speedway; turn LEFT (west).
.20	1.80	6th Ave. traffic light, continue west.
.20	2.00	Stone Ave. traffic light, continue west.
.40	2.40	STOP sign at 12th Ave., continue west.
.20	2.60	SLOW for railroad crossing.
.15	2.75	STOP sign at Freeway, continue west.
.10	2.85	Cross Santa Cruz River.
.30	3.15	Grande Ave., turn LEFT (south). State School for Deaf and Blind at 3 o'clock just before making turn.
.40	3.55	St. Mary's Road traffic light, continue south.
.70	4.25	STOP sign at Congress Ave., turn RIGHT (west).
.30	4.55	LEFT (south) on Cuesta Ave. Follow road to top of "A" Mountain. Rocks visible along road consist of Tertiary-Quaternary mud flows, basalts, and tuffs.
.95	5.50	One-way road.
.55	6.05	STOP 1, 15 minutes. Top of A-Mountain, name from the large "A" painted yearly by University of Arizona freshmen (see photos 1 and 2). View of Santa Cruz Valley, Tucson, and surrounding mountains. Follow road back down the mountain.
.45	6.50	Two-way road. The cuts in the hillsides are mostly older quarries when rock was mined for building purposes, dimension stone, and road ballast.
.90	7.40	Turn RIGHT (east) on Cedar St.
.25	7.65	STOP sign at S. Mission Road (Grande Ave.) turn RIGHT (south).
3.25	10.90	STOP sign at intersection with Ajo Road, continue south

1. **Looking south toward the irrigated lands of the Santa Cruz Valley. Sahuarita Butte, of Tertiary volcanic flows, in the background.**

2. **Tucson from top of "A" Mountain. Santa Catalina Mountains in background.**

3. **Rillito Creek in flood following 8-inch rainfall on Santa Cataline Mountains, March 1954. Note darker color and greater turbulence of water in main channel. "Standing waves" are present at far side of main channel, right center.**



1.0	11.90	Garden City subdivision at 3 o'clock. This is an area where the alluvial fill is underlain at shallow depths by volcanic rocks. One or two wells have encountered small water supplies along fault zones. Water supplies are plentiful in the Recent alluvium of the Santa Cruz River, at 9 o'clock.
1.3	13.20	Northern boundary of the San Xavier Reservation, mostly Papago Indians.
3.0	16.20	Turn LEFT (east) off Mission Road - Twin Buttes Road. The Papago houses are composed of combinations of adobe bricks and adobe plastered over ribs of sahuaro and ocotillo cacti.
.65	16.85	STOP 2, 10 minutes. San Savier Mission, the second oldest mission in Arizona. The present structure was built in 1783.
.05	16.90	Turn RIGHT (south) on gravel road.
.30	17.20	Turn LEFT (east) on gravel road. Note mesquite phreatophytes.
.30	17.50	Indian Service irrigation well. Characteristics of the well are as follows: Water level 36.25', discharge is 1,000 gallons per minute with a drawdown of 11', total depth, 265 feet. The specific capacity of this well is unique, as most wells in the area yield only about 10 gallons per minute per foot of drawdown.
.45	17.95	STOP 3, 15 minutes. Infiltration gallery of Midvale Farms in the Santa Cruz River. Buses stop and turn around on west side of channel. This is a constricted area where stream formerly was perennial. Note phreatophytes: cottonwoods, baccharis, and mesquite.
.75	18.70	Turn RIGHT (south).
.30	19.00	Turn LEFT (west) on Mission Road (paved).
.65	19.65	Turn LEFT (south) on Twin Buttes Road.
.55	20.20	Black Mountain at 2 o'clock. A mass of Tertiary-Quaternary basalt more than 1,000 feet high resulting from fissure eruptions of a vent 500 feet wide. Note Cholla ("jumping cactus") forest.
6.80	27.00	Low hill of Cambrian quartzite, reported to be a klippe. Sierreta Mountains at 1 o'clock. The mountains consist of a granite core with flanking sedimentary and volcanic rocks.

		The long slopes from the mountains have been cited in the literature as typical of alluvium-covered "pediment" slopes. Recent studies make such an interpretation questionable, especially on the north.
.85	27.85	STOP 4, 15 minutes. End of pavement. Discussion of desert flora and well-location program on the Papago Indian Reservation.
.60	28.45	Southern boundary of the San Xavier Reservation. The pre-Cambrian granite bedrock has average depths less than 200 feet; the water level in a test hole near the road is at a depth of 184 feet.
.70	29.15	Paleozoic sediments at 9 o'clock.
.50	29.65	Mineral Hill Mine (Tintic Standard Mining Co.) The company has a government contract to produce nearly 13,000,000 pounds of copper over a 3-year period. A new 400 ton/day concentrating mill is now being constructed. The copper deposits are of the contact metamorphic type and occur as replacements in limestone near a granite intrusive.
1.0	30.65	San Xavier Mine area (Eagle-Picher Mining and Smelting Corp.) The mine was closed down in mid-1952 because of the low lead and zinc prices. The ores belonged to the metasomatic lead-zinc-silver type. The principal deposits occur as replacements in Permian limestone within the San Xavier fault zone. In 1942 water stood above the 200-foot level and was pumped at the rate of 1,000,000 gallons per day. Between 1942 and 1952 the water level declined almost to the 900-foot level but has now risen to 632 feet. The water level is now rising a foot a week. The depth to water in adjacent Cretaceous beds to the southwest is only 60 feet.
.20	30.85	Pima Mine road at 9 o'clock. The mine, approximately 1½ miles east, represents an entirely new discovery for the area. The discovery was made by geophysical methods, which located mineralization in hard rocks concealed by a 200-foot cover of valley fill. Since May 1952, more than 26,000 tons of copper fluxing ore has been shipped to the ASARCO smelter in El Paso. The ore occurs as replacement deposits in Permian lime-

		stone. The mine pumps water at a rate of 350 gallons per minute from the limestone.
.10	30.95	First road cut on right after cattle guard, buses STOP, do not disembark. Note the intricate structure in the Permian strata. The rocks from here to Helmet Peak (10 o'clock) are mostly Cretaceous volcanics and sediments. These rocks represent the lowest part of the Cretaceous section in this area. On the east side of Helmet Peak the middle Cretaceous unit of red beds is present.
.85	31.80	STOP 5, 20 minutes. Walk 700 feet east along trail toward Helmet Peak, an anticlinal structure in Permian limestone, to see hardrock outcrop.
1.50	33.30	Cattle guard. Re-entering main part of Upper Santa Cruz basin. Twin Buttes at 12 o'clock. This is another mining area within the Sierreta mining district. This district is credited with a production prior to 1951 of approximately $26,000,000, from 41,193,000 pounds of copper, 50,950,000 pounds of lead, 77,647,000 pounds of zinc, $1,907,000 in silver, and $40,000 in gold. Empire Mountains at 11 o'clock and Santa Rita Mountains at 1 o'clock.
		Granite of Laramide age usually occurs at shallow depths throughout the area. Ground-water levels are erratic and range from 75 to over 300 feet. Some holes have been reported to be drilled to depths of over 400 feet without encountering water.
1.50	34.80	Turn LEFT (east) on Sahuarita Road. Twin Buttes at 11 o'clock are composed of Paleozoic limestone.
2.70	37.50	Paleozoic sediments, mostly limestone, at 9 o'clock. Some of these hardrock outliers are reported to be klippen.
2.80	40.30	Railroad crossing. Eagle-Picher-ore-processing plant at 9 o'clock. The concentrator has a daily capacity of 400 tons and, prior to 1952, handled the ore from San Xavier mine and other mines in the area. It is now shut down.
.70	41.00	SLOW for railroad crossing, bear LEFT (north).
.45	41.45	Turn RIGHT (east).
.20	41.65	Cross Santa Cruz River. The irrigated fields in this area are typical of those in the Upper Santa Cruz basin. Note use of liquid fertilizer near some ditches into the fields.

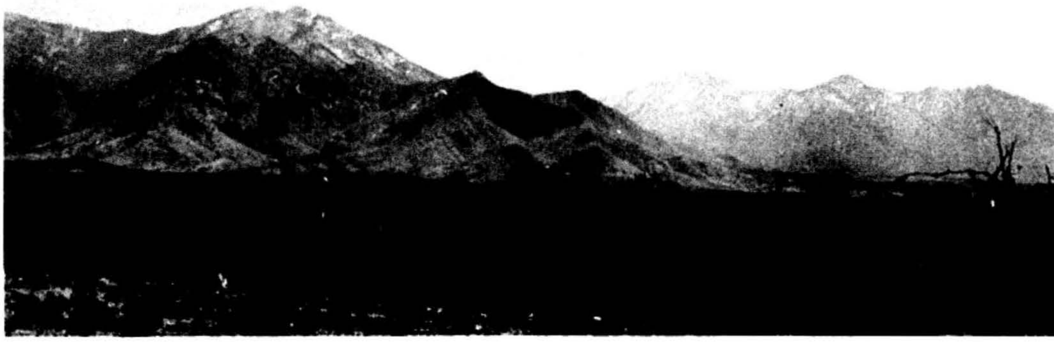
.20	41.85	STOP 6, 10 minutes. Typical irrigation well system of laterals, and system of fertilizing.
.40	42.25	Town of Sahuarita and cotton gin. STOP, then turn RIGHT (north) on U. S. Highway 89. In 1953 this mill gined about 7,600 bales of cotton, averaging 500 pounds per bale.
.05	42.30	SLOW for railroad crossing (siding, not main line).
.60	42.90	U. S. Geological Survey observation well, equipped with water-stage recorder, at 9 o'clock. STOP, but do not disembark. Since 1939 the depth to water has declined about 20 feet from 55.5 feet to 75.3 feet; 15 feet of the decline has occurred in the past 5 years. Deepened 60 feet with Survey funds in 1952.
.90	43.80	Newly cleared and leveled field at 3 o'clock far side of valley.
1.00	44.80	Santa Cruz River bridge.
5.80	50.60	Intersection with old road to town of Continental.
.30	50.90	STOP 7, 10 minutes. Buses pull off Highway to the left side (Continental Farms).
1.60	52.50	Road cuts in Recent valley fill. Note the size, assortment, poor bedding, and lack of continuity of the beds.
2.20	54.70	Canoa Ranch at 9 o'clock This is one of the original Spanish land grants known as the Baca Float. Such land grants were given, sight unseen, for favors rendered to the King of Spain.
3.10	57.80	Santa Rita Mountains at 9 o'clock (see photo 4). The altitude of the top peak, Mt. Wrightsin, is 9,432 feet. The mountains consist of a quartz monzonite core, capped by volcanic flows, and bordered with sediments that range from pre-Cambrian to Tertiary, with Cretaceous and Tertiary volcanics and a granite of Laramide age. The main structural features are associated with block - faulting and thrust faulting. The odd-shaped granite spire in the forerange is known as "Elephant's Ear." Occasional alluvial fans that have been incised since Pleistocene time are present locally along the mountain front.
2.50	60.30	STOP 8, LUNCH, 30 minutes. Buses pull off highway on left side. The Kinsley Ranch is headquarters for a wide range of activity including farming, ranching, well drilling,

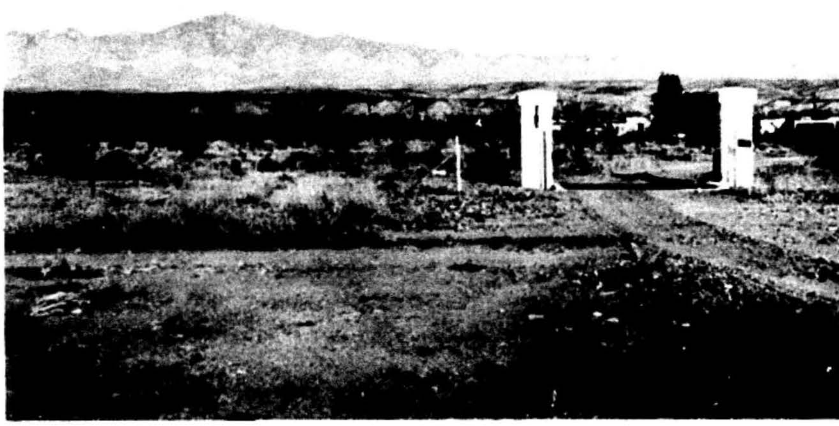
		and a rodeo. The artificial lakes provide water for irrigated fields below. Rest rooms and cold drinks available.
.15	60.45	Enter Santa Cruz County, leave Pima County.
1.30	61.75	Town of Amado. Note cotton gin. In 1953, about 5,200 bales of cotton were processed.
5.50	67.25	Terrace levels at 9, o'clock (see photo 5). There are at least three well-developed terraces cut into the valley fill. Most of the main valley in southeastern Arizona show the development of two or three terraces. These terrace levels are generally assigned a Pleistocene to post-Pleistocene age and are thought by some to be contemperaneous with Lake Bonneville levels.
1.40	68.65	Town of Tubac at 9 o'clock. Note dead and dying Cottonwood along the Santa Cruz River.
3.10	71.75	STOP 10, 45 minutes. Tumacacori Mission, U. S. National Monument. Conducted tour by guides of Park Service.
1.40	73.15	Continue south on U. S. Highway 89. Road cut with excellent section of Recent valley fill.
1.00	74.15	San Cayetano Mountains at 10 o'clock; a quartz monzonite stock with volcanic rocks on the east side.
3.40	77.55	Only one well-developed terrace remains, at 9 o'clock.
.20	77.75	Santa Cruz River enters the area from the southeast and is east of the small hills. Nogales Wash provides the major drainage from here to Nogales.
9.40	87.15	Tertiary tuffaceous rocks in low hills at 3 o'clock. Similar rocks occupy entire area around both Nogales, Ariz., and Nogales, Son.
3.30	90.45	City of Nogales, Arizona. Turn LEFT (east), SLOW for railroad crossing, STOP at street sign, then turn LEFT (northeast) on State Highway 82.
1.60	92.05	Fault in tuffaceous beds (see photo 6). The beds on east are younger and have been faulted down in relation to those on the west side. The fault continues for some distance, and can also be seen in the cut at 3 o'clock.
2.45	94.50	Thick horizon of "C" soil. Essentially weathering in situ.

4. West front of the Santa Rita Mountains. Imperfectly developed triangular facets occur at base of mountains on the left. An alluvial fan, on the right, has formed at the foot of Madera canyon.

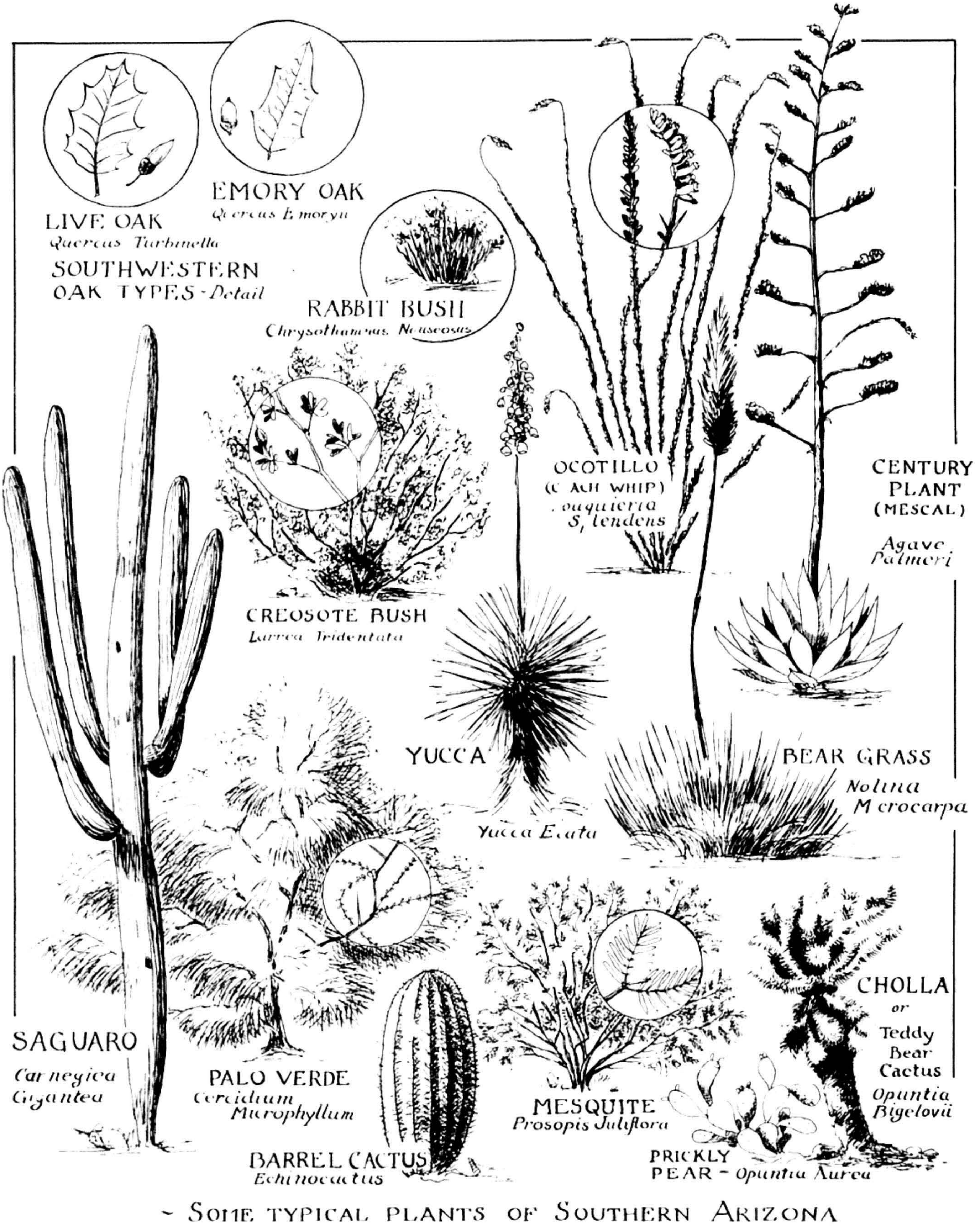
5. Southern part of the Santa Rita Mountains showing well-developed terrace levels in the valley of the Santa Cruz River, south of Tubac. Mile 67.25

6. Normal fault in tuffaceous rocks of Tertiary age, on the south side of Nogales-Patagonia highway. Mile 92.05.

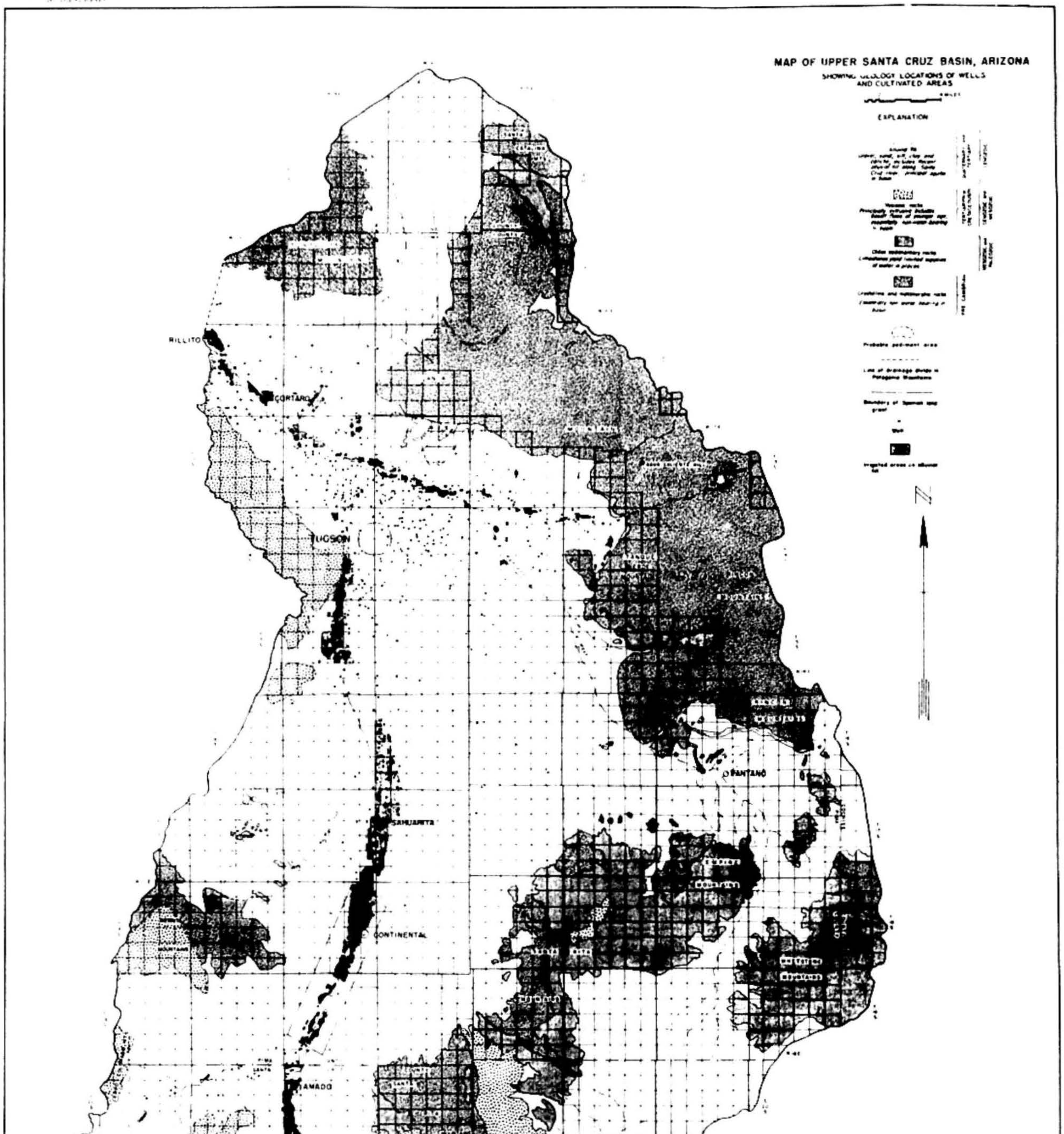




1.00	95.50	Santa Cruz River bridge. Pumping plant for City of Nogales, Ariz., at 3 o'clock.
6.85	102.35	Vegetation change with elevation. There are no cacti, instead there is a juniper - scrub-oak zone. Patagonia Mountains at 1 o'clock. The mountains are mostly composed of an intrusive quartz monzonite stock.
4.30	106.65	Red Mountain at 12 o'clock, consists of a thick series of andesite flows.
.00	106.65	Turn SHARP LEFT on dirt road.
.15	106.80	<u>STOP 12,</u> 30 minutes. Sonoita Creek, a permanent stream in the box canyon. Buses turn around.
.15	106.95	Turn RIGHT (east) on State Highway 82.
16.20	123.15	Turn RIGHT (west) across bridge. STOP, then turn LEFT (south) on U. S. Highway 89.
.65	123.80	Traffic light, continue south.
.40	124.20	International Boundary between United States and Mexico, Nogales, Ariz., and Nogales, Son.
		Disembark from buses.



– Some typical plants of Southern Arizona



MAP OF UPPER SANTA CRUZ BASIN, ARIZONA
SHOWING GEOLOGY LOCATIONS OF WELLS AND CULTIVATED AREAS
EXPLANATION
Probable pediment area
Line of drainage divide in Patagonia Mountains
Boundary of Spanish land grant
Well
RILLITO
CORTARO
TUCSON
PANTANO
SAHUARITA
CONTINENTAL
AMADO
TUBAC
PATAGONIA
CALABASAS
NOGALES