

*Guidebook
to the
Geology of Central Arizona*



Donald M. Burt and Troy L. Péwé, Editors
Department of Geology, Arizona State University

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TERRACES OF THE LOWER SALT RIVER VALLEY IN RELATION TO THE LATE CENOZOIC HISTORY OF THE PHOENIX BASIN, ARIZONA

by
Troy L. Péwé

INTRODUCTION

The terraces of the lower Salt River Valley offer fine examples of physiographic features, along with pediments and caliche formation, that illustrate late Cenozoic events in the Phoenix Basin and adjoining mountains. The Phoenix Basin is a term loosely applied to a series of topographical and structural basins in southcentral Arizona extending from the Bradshaw-Mazatzal-Superstition Mountains area on the north and east to the general area of the Hassayampa River on the west and the Buckeye Hills and the Sierra Estrella Mountains on the west and southwest (fig. 1). The basin is interrupted by several small mountain masses such as the Phoenix, South, and White Tank Mountains and the entire complex is part of the Basin and Range Physiographic Province. The area is characterized by fault-block mountains with intervening basins filled with thousands of feet of unconsolidated sediments shed from the mountains.

All major rivers and most other streams entering the basin from the north and east are flanked by sets of paired river terraces, many of which are strath terraces. The terraces range from 10 to 300 feet above the river, and are floored with coarse, rounded river gravel. The writer has examined such terraces along the Agua Fria (Péwé, 1976), New River, Queen Creek, and Gila River near Florence and near Arlington.

He has studied with associates the terraces on the lower Salt and Verde Rivers (Péwé, 1966; 1970; 1971; 1975; Pope, 1974; Pope and Péwé, 1973; Kokalis, 1970, 1971), the adjacent mountains and alluvial fans draining into the Salt and Verde Rivers (Shank, 1973; Shank and Péwé, 1973; Péwé and Shank, 1973; Péwé, 1974; Christenson, Welsch and Péwé, 1975; Cordy, Holway and Péwé, 1977), and also some aspects of dust being deposited into the area and its possible relationship to caliche (Péwé, et al., 1976; Péwé, et al., in press).

RIVER TERRACES

Terraces which typify the important nonparallel sets and which are at right angles to the trend of the mountain range are those mapped eastward from Tempe to Stewart Mountain Dam along the Salt River (figs. 1, 2). Four paired terraces are present (fig. 3). Reconnaissance work indicates that these same terraces extend farther east to Roosevelt Lake. The lowest terrace, named the Lehi Terrace (Péwé, 1971), is only 5 feet above the present river level near Lehi and rises to about 20 feet above the river 15 miles upstream.

A higher terrace, the Blue Point Terrace, grades from 10 to 80 feet above the river between Tempe and Stewart Mountain Dam. It is a dissected strath terrace upstream from the mountain front and is covered with 10 to 20 feet of sand and gravel. The most prominent terrace is the Mesa Terrace (Péwé, 1971), an old, extensively dissected surface extending from Tempe, where it is 10 feet above the river, to near Stewart Mountain Dam where it is 220 feet above the river, and eastward to Roosevelt Dam where it is more than 300 feet above the river (fig. 4). Here it is believed to be truncated by a fault (Péwé, 1975).

The gravel of the Mesa Terrace is strongly indurated by caliche. Unlike the gravel of the younger Blue Point Terrace, which has cobbles slightly cemented, the older gravel is completely plugged by calcium carbonate and well developed laminar layers are formed.

The Sawik Terrace (Péwé, 1971) is the highest terrace, the most fragmentary, and lies 235 feet above the river at the mountain front. It decreases to an elevation of about 50 feet above the river in Scottsdale where it passes under the alluvial fan deposits shed from the Phoenix and McDowell Mountains. The gravel of the terrace is very strongly calichified. Both the Sawik and the Mesa Terraces have thick, well-calichified gravel layers near or at the surface.

The Verde River joins the Salt River near the west edge of the Mazatzal Mountains at the east side of the Phoenix Basin. The trend of the river is not at right angles to the trend of the mountains. Four paired, well-developed terraces are present on the lower Verde River (Pope, 1974; Pope and Péwé, 1973). Detailed work has been done on these terraces, and they are similar to the terraces on the Salt River and also converge downstream.

The Agua Fria River emanates from the north side of the basin near the Hieroglyphic Mountains, flows onto the sloping Phoenix Basin floor near Lake Pleasant Dam, and then trends southward to join the Gila River near the center of the basin (figs. 1, 2). The Agua Fria displays at least three paired terraces (Péwé, 1976) and, especially south from the Lake Pleasant Dam, they are fill terraces composed of coarse boulder gravel. At Lake Pleasant they are strath terraces. The gravels of the upper two terraces are completely plugged with caliche and laminar layers are present. The upper terrace at the dam site is approximately 130 feet above the river. The flights of terraces converge downstream (fig. 4). Although studied only in reconnaissance, it is evident from the amount of calichification, convergence of terraces in the downstream

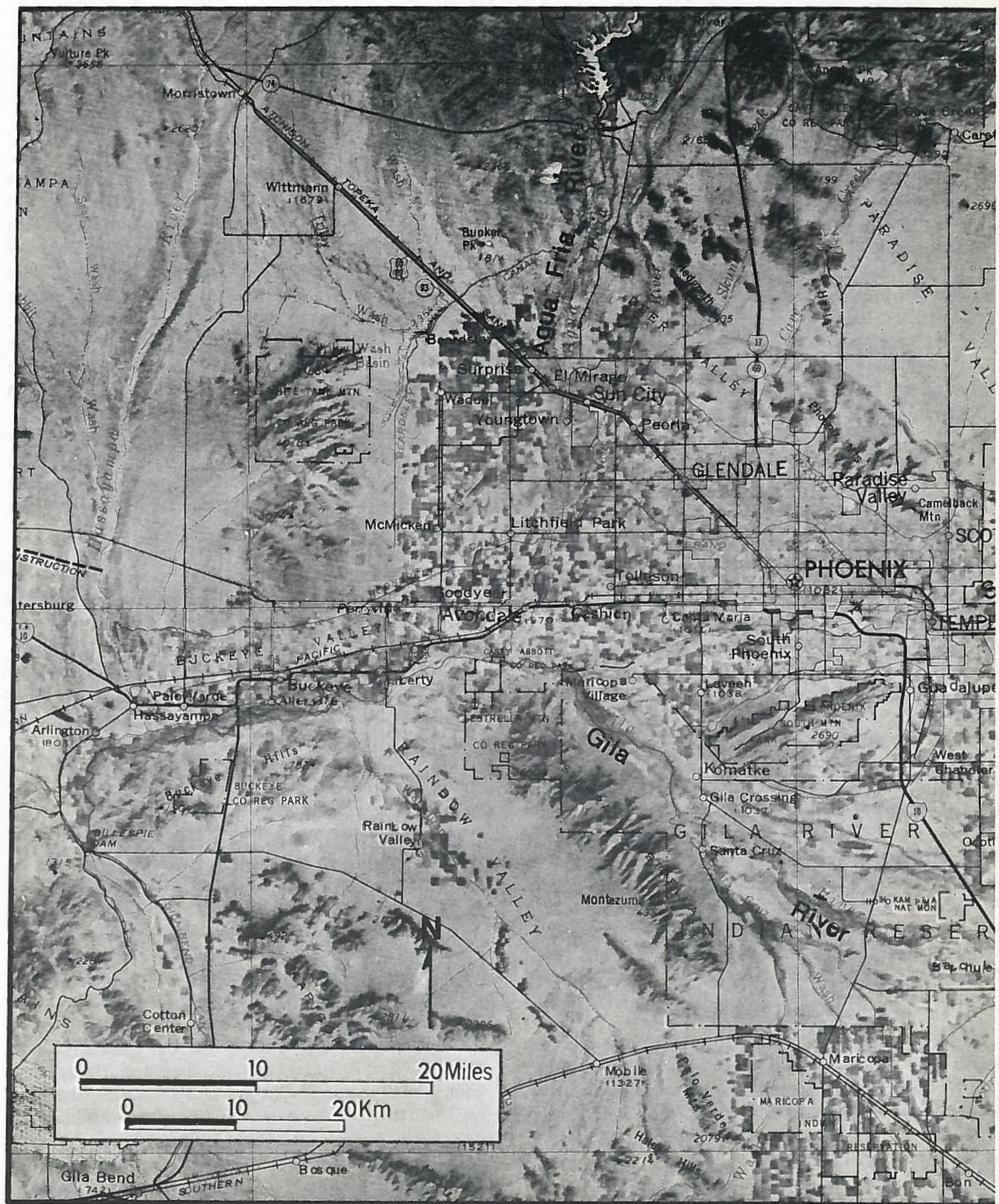


Figure 1. Index map of the Phoenix Basin, Arizona and adjoining areas. (Base from U. S. Geological Survey satellite image map, 1972-1973.)

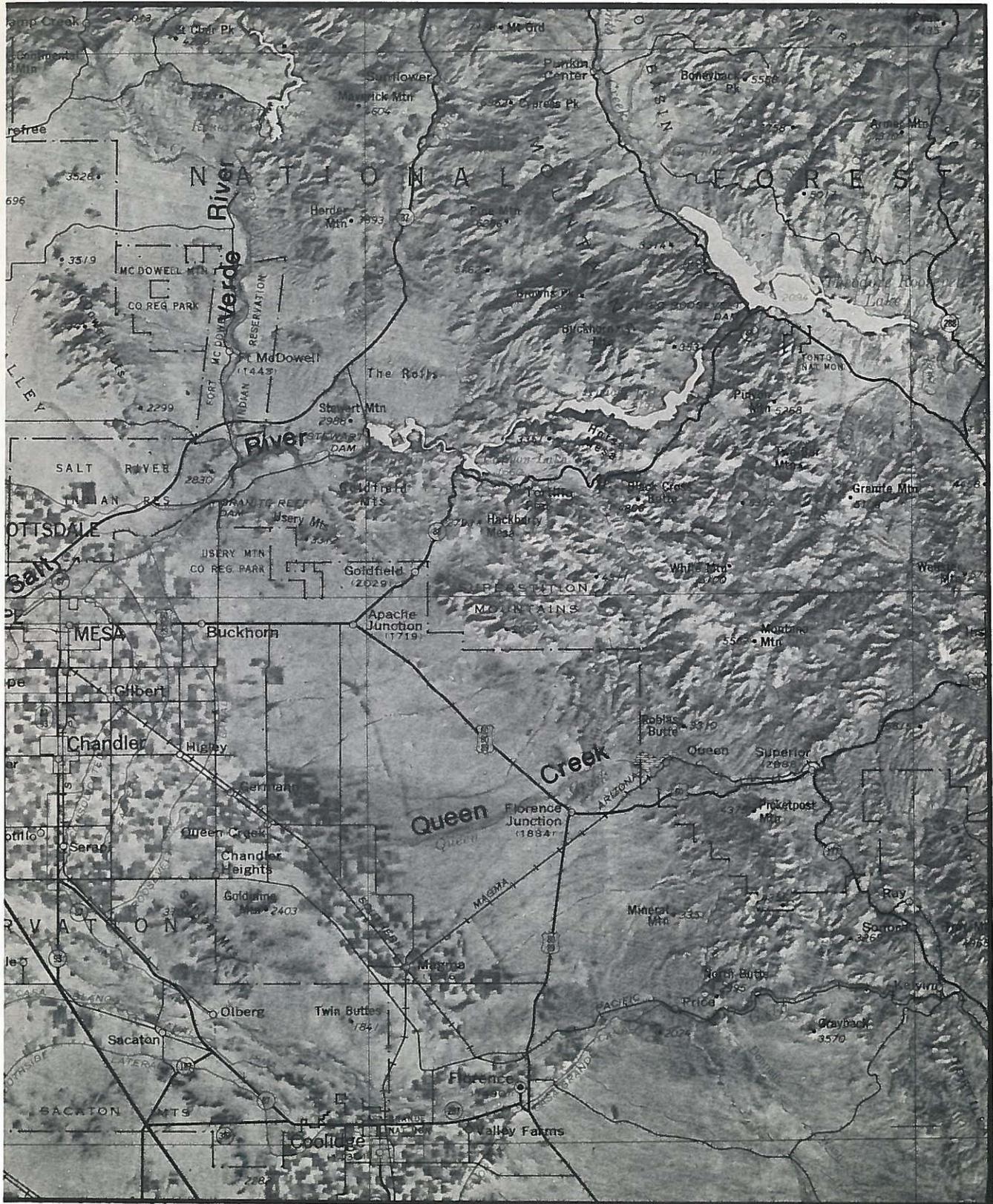




Figure 2. Physiographic diagram of the Phoenix Basin and adjoining areas diagrammatically showing sets of converging terraces along river valleys entering the basin. (Base through the courtesy of the Salt River Project, Tempe, Arizona.)



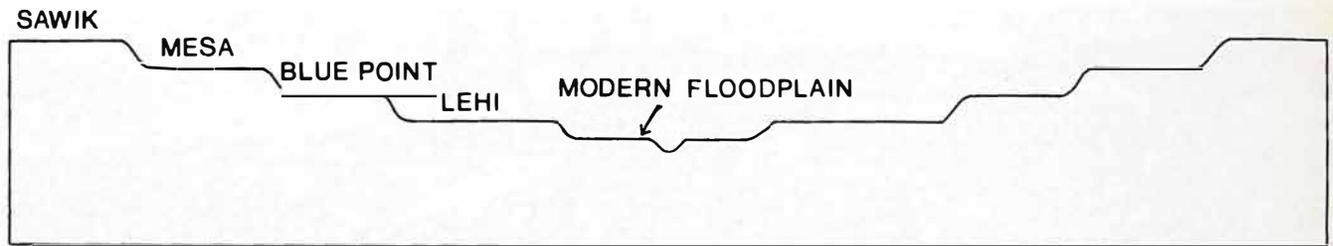


Figure 3. Diagrammatic transverse profile of paired terraces on the lower Salt River Valley.

direction, and size of the gravels that they are very similar to terraces on the lower Verde and lower Salt rivers (table 1). The boulder gravel and rock types from the northern mountains disappear into the center of the basin and only basin-fill silty sediments are exposed in the shallow banks of the river to the south.

Reconnaissance observations on the terraces on New River indicate that high-level strath terraces with gravel 5 to 10 feet thick occur near the village of New River and the terraces converge with the profile of the modern stream downstream. More work is needed to demonstrate existing multiple terraces in this area.

Table 1: Tentative correlation of terraces of streams entering the Phoenix Basin

Agua Fria River	New River	Verde River	Salt River	Queen Creek	Gila River
Pévé, 1973	This Paper	Pope and Pévé, 1973	Pévé 1971	This Paper	This Paper
Lake Pleasant	Present	"Lousley Hill" Deposit	Sawik	Radio Ridge	1
Landing Field		Mesa	Mesa	Bridge	2
McDowell					
Canal	?	Blue Point	Blue Point	Lehi	3

Prominent converging terraces are displayed on the sides of the Gila River Valley where the river emerges from the mountains into the Phoenix Basin near Florence (fig. 4; table 1). The reconnaissance information available indicates that these terraces converge with the profile of the modern stream to the east (figs. 1, 2; table 1).

About 5 miles northwest of Florence Junction (figs. 1, 2) in the southeastern part of the Phoenix Basin, Queen Creek flows westward from the Superstition Mountains onto the basin floor and disappears in the low land. The creek is flanked by at least two terrace levels that converge with the modern floodplain westward in the valley (figs. 1, 2; table 1). The gravel deposits are strongly indurated with caliche.

These rivers and creeks flow (or used to flow) through the Phoenix Basin but do not exhibit any terraces there

except low banks formed where the streams migrate laterally and cut into the alluvial fans composed of Valley Fill material. None of the rock types of the terrace gravels in the mountain edges occur along the Gila, the Salt, and the Agua Fria Rivers toward the west in the basin until in the vicinity of Arlington near the mouth of the Hassayampa River (figs. 1, 2). Here terraces 40 and 80 feet above the modern river are present (Lee and Bell, 1975). The rock types are very similar to those occurring on the Salt River terraces as studied upstream from Tempe and the terrace gravels are extremely well calichified. In the vicinity of Arlington and Gillespie Dam, the terraces are locally covered with basalt flows. From near the mouth of the Hassayampa River to a short distance west of Gila Bend, in the vicinity of Painted Rock Reservoir, the terraces appear parallel to the profile of the modern Gila River.

In the years 1902-1904 Willis T. Lee of the U.S. Geological Survey traveled to the then remote far western region of Phoenix, Arizona to investigate the underground streams and geology of lower Salt River Valley. He was preceded in 1896 by Arthur P. Davis, hydrographer of the U.S. Geological Survey, who studied the growing irrigation district near Phoenix and clearly described it in pioneer Water Supply Paper No. 2 of the U.S. Geological Survey.

Lee traveled the central part of the Phoenix Basin on foot, horse, and wagon as the first geologist to systematically collect geological and hydrological data on all the major wells and most minor wells drilled in the valley. He then studied the geomorphology and investigated the geology of the local bedrock hills and mountains. His classic report, published in 1905, remains the most thorough and accurate report on the subject to date. Later reports are replete with more detailed data on water quantity and quality but the outline presented by Lee is still workable.

From an examination of primitive well records of the time, Lee easily noted that bedrock in the valley was below sea level. Debris shed from the surrounding mountains accumulated in subsiding basins (1905, p. 115). Many "buttes" in the valley are knobs of bedrock projecting above a sea of alluvium. Faulting and block tilting were recognized as important in forming the basic structure of the region.

The coarse-rounded gravel of earlier river times expressed on the edges of the mountains as terrace deposits,

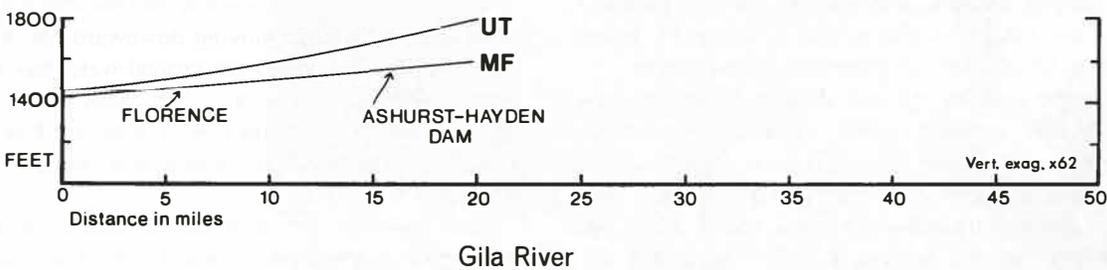
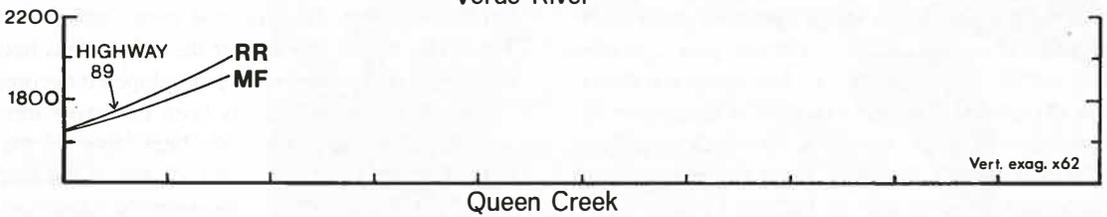
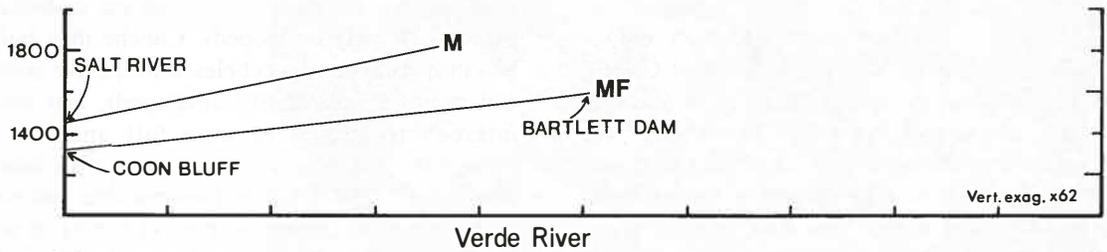
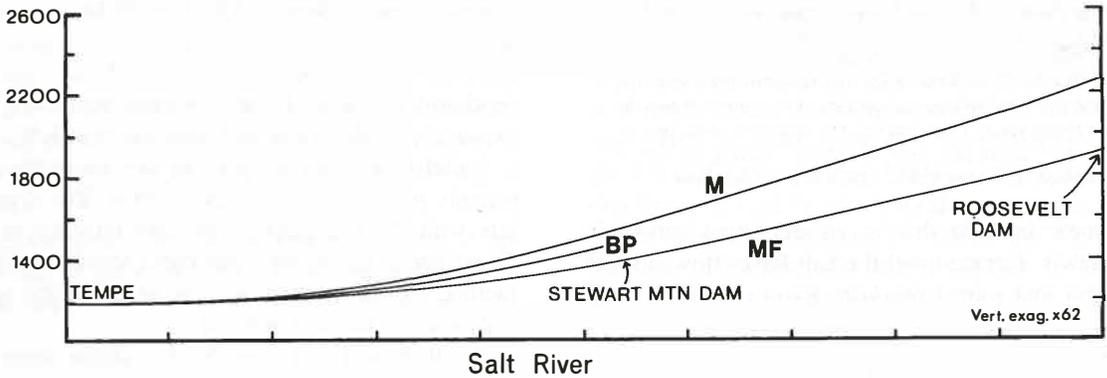
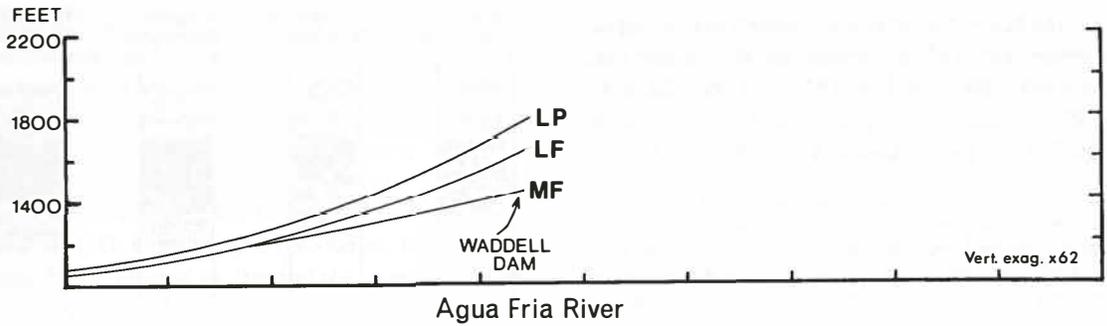


Figure 4. Converging longitudinal profiles of part of the floodplains and terraces of streams entering the Phoenix Basin from adjoining mountains on the north and east. MF—Modern Floodplain; LP—Lake Pleasant Terrace, LF—Landing Field Terrace; UT—Upper Terrace; M—Mesa Terrace; BP—Blue Point Terrace; RR—Radio Ridge Terrace.

disappear into the basin (fig. 4) and are to be found at depth. No clearer report has yet been written on the subject than those by Lee (1904; 1905, p. 125–135) who postulated the ancient Salt River location from gravels that exist to a depth of at least 620 feet (by 1905 records). Lee states,

“Since it is always the river that is making the deposits of gravel and boulders through which water passes readily, it naturally follows that the boulder beds mark the ancient courses of the river. It furthermore follows that the present course of the underflow is in general the course of the ancient river that deposited the gravels and boulders in which the underflow occurs. It remains, then, to determine the old courses as accurately as possible in order to place the pumping plants in the most advantageous localities. At first thought, this course should be in general down the valley, parallel to the river. But a little reflection indicates that this is not necessarily the case. As the floor of the valley was raised by the deposition of debris, the river shifted from side to side of the valley. When the level of the rising valley floor reached the saddle of some spur or divide, the river might pass over this divide, leaving its former course at one side. This is probably what Salt River has done . . .”

Drill records indicate that in ancient times (probably Mesa and Sawik Terrace time) the Salt River flowed south through Mesa and joined the Gila River south of South Mountain.

CALICHE

Stream terraces and alluvial fans on the edges of the Phoenix Basin expose sediments cemented by CaCO_3 —caliche. Caliche is a near-surface accumulation of CaCO_3 common to soils of low and middle latitudes in arid and semi-arid regions throughout the world. This “lime” accumulation transforms otherwise unconsolidated sand and gravel to “concrete,” much to the disgust of “users of the soil.” Although we have no record of the choice language used by ancient man as he hacked irrigation canals with crude implements from the caliche-cemented gravel of the Mesa Terrace, we do know that the first attempt to construct a canal in the Phoenix area by modern man in December of 1867 resulted in failure as red-headed K. W. (Jack) Swilling began construction on the north bank of the Salt River in the hard caliche-cemented colluvium of Papago Pediment opposite the present location of downtown Tempe (Peplow, 1970). He was forced to find a new location 2½ miles downstream at what is now 44th Street and Washington.

Caliche layers form as meteoric water percolates downward into the soil, carrying calcium carbonate in solution, and is stopped and/or drawn upward in its descent by capillary action. In situ evaporation of this water results in precipitation of the calcium carbonate in soil voids. Thus, the permeability of the soil or unconsolidated rock and the amount of rainfall influence the depth of descent of the percolating water, and the depth of caliche development. Climate is a critical factor in caliche development. Hot, dry climates where rainfall occurs in periodic thundershowers followed quickly by renewed sunlight and low humidity promoting evaporation are most favorable. The arid and

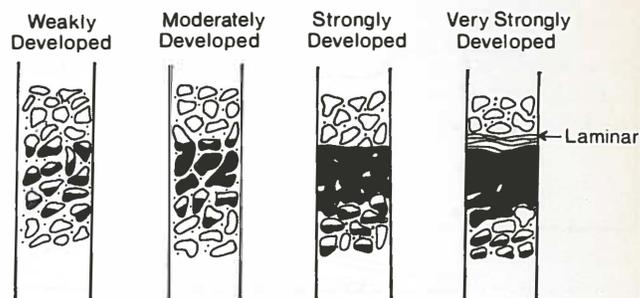


Figure 5. Development stages of caliche surrounding the pebbles and cobbles in gravelly sediment. (After Gile, 1975.)

semi-arid climates of the southwestern United States are extremely conducive to the formation of caliche.

Caliche deposits in general are sheet-like and form roughly parallel to the ground surface. The deposits undulate with the topography and vary laterally in thickness. These lateral variations in thickness are the result of various factors; including differences in permeability, topography, and nature of the host material.

As illustrated in Figure 5, the caliche layer exhibits a sequence of progressive development with time, beginning as a calcium carbonate coating on the undersides of rock particles (weakly developed). Caliche then builds up and fills in spaces between pebbles as the pebble coatings merge and coalesce (moderately developed), and eventually all interpebble spaces become full and the profile is “plugged,” forming a hard, concrete-like layer (strongly developed). This layer is impermeable and will become capped by pure, laminated layers of CaCO_3 as water can no longer percolate into the soil (very strongly developed). Thus, in general, the longer the caliche has been forming, the harder and more strongly developed it becomes.

The study of caliche has been extensive throughout the world and detailed work has been done in the southwest United States since the 1920s. Some of the leading papers on the subject are listed in the selected references.

While the general concept is that the CaCO_3 is precipitated from rain water moving downward, an older idea is that it was precipitated from ground water moving upward toward and near the surface. The earliest such suggestion for Arizona was by Blake (1901), although Lee (1905) felt that the deposition of caliche from downward-moving water was equally as valid.

The thickness and depth of the caliche profile is thus dependent on the depth of penetration of soil water. Other factors of soil formation include climate, vegetation, topography, age, and parent material. The occurrence of caliche in sediments of various compositions and textures indicates that it is not a primary depositional feature. Caliche deposits progress through a developmental sequence with time, as do soils.

The ultimate source of CaCO_3 in caliche in non-carbonate sediments has been a topic of great interest since these occurrences were first observed. In areas of carbonate bedrock or alluvial gravels derived from carbonate bedrock, no real problem is encountered in terms of source. Some of the concepts for noncarbonate rocks include chemical weathering of noncarbonate Ca-bearing parent material with additions of CO_3 from air and rain water, leaching of CaCO_3 from dust collected at the surface, and from the accumulation of Ca and CO_3 ions in water.

Over the last few years some observers have suggested an eolian source for the CaCO_3 . The writer strongly believes in such a source inasmuch as wind-blown dust is quite common and deposited in enormous amounts annually (P  w  , et al., 1976). Analyses of the dust in the Phoenix area based on 15 samples collected over an 18-month period give a percentage of CaCO_3 of from 1.2 to 3.8 (P  w  , et al., in press).

Although the details are not completely known, it appears that many of the grains and cobbles and perhaps even boulders in the calichified sand and gravel are in some

instances completely surrounded by CaCO_3 . They float in the matrix of calcite and are not in contact with one another. In most areas the simple fillings of the voids in the parent materials by CaCO_3 cannot account for the amount of CaCO_3 present. It is believed by many that there is as much as 25% expansion of the unconsolidated sediments with the crystallization of the CaCO_3 .

A great number of fractured pebbles and cobbles appear on the surface of the older two of the terraces in the Phoenix Basin and on very old alluvial fans (fig. 6). Cobbles on these terraces show postdepositional fracturing in which the CaCO_3 apparently invaded previously existing cracks and permeable zones in the cobbles forcing them apart below the surface. Frequently cobbles can be found in place with major cracks revealing as much as 2 inches of separation. This is more normally characteristic of the finer grained rock types. Young (1964) concludes that crystallization forces of CaCO_3 which result in a volume increase are responsible, and notes that the role of CaCO_3 in the disintegration of bedrock and surface deposits in semi-arid and arid lands may be underestimated.



Figure 6. Caliche-split boulder of quartzite on gravel surface of Sawik Terrace. Near Thomas and Higley Roads, Mesa, Arizona. (Photograph No. 4040 by Troy L. P  w  , September 17, 1977.)

ORIGIN OF THE TERRACES

Of utmost importance to an understanding of the late Cenozoic history of the Phoenix Basin is the origin of the sets of paired river terraces that converge downstream and border the basin on the north and east. The terraces represent periodic rejuvenation of the streams. The increase in the power of the streams and subsequent downcutting could be the result of climatic change (increased runoff) or tectonic disturbance of the mountains and the basins. The uplift of the mountains with concurrent depression of the basins increases the stream gradient. Although the climate must have changed slightly in this area during the Quaternary (the last 1.8 million years), such changes probably would have produced some terraces that would be parallel to the profile of the modern stream. However, the convergence of terraces downstream to the Phoenix Basin strongly suggests periodical regional uplift of the ranges over a long period of time.

Convergence of terraces downstream due to tectonic uplift is not unknown. This phenomenon is widespread and important in interpreting and dating tectonic movements. Convergence has been recorded along the Nanana River in the Alaska Range (Wahrhaftig, 1958), for example. Especially clear is the detailed study on the Rangatiki River in New Zealand by Milne (1973). He illustrates convergence of terraces due to uplift of the mountains where the river originates. Although preliminary studies strongly indicate that these terraces are tectonic in origin, climatic effects may also be involved. Another concept is that as the mountains are worn down the streams have less material to carry and so they begin to cut down more rapidly. This would result in the formation of one set of terraces but it is difficult to illustrate multiple paired terraces unless the system were "rejuvenated," probably by uplift. Until otherwise demonstrated, the convergence of terraces downstream to the Phoenix Basin seems to indicate periodic regional uplift of the ranges in relation to the Phoenix Basin over a long period of time.

AGE OF TERRACES

Of critical interest is the age of terraces and therefore the age and rate of supposed tectonic disturbance. No direct, absolute dating is currently available for the ages of terraces. Fragments of the Geronimo Head Tuff, with a minimum age of 16 million years (Stuckless and Sheridan, 1971), occurs in the Sawik and other terrace gravels on the Salt River; therefore, the terraces flowing through the volcanic area of the Goldfield and Superstition Mountains are less than 16 million years old. A study of the distribution of gravels from ancient drainages from the south that used to flow north to the Colorado Plateau, suggests (McKee and McKee, 1972) that the reversal of the drainage occurred no earlier than 10 million years ago and no later than 5 million

years ago. Therefore the terraces could be as old as 5 million years.

Several converging lines of qualitative evidence indicate a great antiquity for these land forms. It is apparent that the upper terraces are very old as indicated by the fragmentary nature of their preservation. For example, evidence of great age is indicated by small remnants of strath terraces on granite just south of the Salt River 1 to 4 miles east of Coon Bluff (Péwé, 1971). These remnants are graded to a pediment that formerly extended from the Userly Mountains and sloped northward to the Mesa Terrace level of the Salt River. Subsequently, the pediment area has regraded to the Blue Point and modern floodplain 220 feet below the Mesa Terrace pediment level. It is not known exactly how long it takes to regrade a granite pediment of about 30 square miles to a level 220 feet lower than in the past, but to remove that much bedrock surely took hundreds of thousands of years, if not more than a million years.

A method not yet pursued in depth but which indicates antiquity of the terraces is the development of taffoni in rocks below the level of the Mesa Terrace. Taffoni are hollows or niches a few inches to many yards long produced in bedrock by cavernous weathering in desert areas (Péwé, 1974, p. 46-48). To form below the level of the Mesa Terrace these hollows had to form after downcutting and destruction of the bedrock floodplain floor that existed in Mesa time. Since it is believed that taffoni form slowly we have another qualitative factor indicating that the upper terraces are quite old.

Some of the best evidence for a great age of the upper terraces is the extensive development of caliche. Caliche is an epigenetic accumulation of calcium carbonate derived from soil processes in unconsolidated sediments in climates where moisture is deficient during all seasons. Such deposits are common throughout the Phoenix Basin and the adjoining and intervening ranges. The degree of development of caliche is directly related to age if other determining factors such as topographic setting, rainfall, erosion processes, and composition and texture of parent material are essentially the same. The thickest deposit of caliche occurs in the upper terraces, and in the Salt River area more than 45 feet of heavily cemented gravel occurs in sediments of the Sawik Terrace. The Mesa Terrace is equally well cemented with the extensive development of plugged horizons many feet thick with excellent development of laminar layers. In these upper terraces surface cobbles exhibit caliche rinds up to 4 inches thick. On the younger terraces, such as the Blue Point, there is a less well developed caliche layer and the gravels are less firmly cemented. Cobbles with caliche rinds are present but these rinds may be very thin to no more than $\frac{1}{4}$ inch thick. Extensive caliche development similar to that found in the upper terraces in the Salt River is common in all of the upper terraces examined

Meandering lower Verde River downstream 1 km east from Bartlett Dam. High terrace gravel knob on right, middle ground. Low strath terrace gravels on left, middle ground. 35 km east of Arizona. (Photograph No. 3223 by Troy L. Péwé, December 22, 1971.)



in the Phoenix Basin, including extremely old alluvial fans on the flanks of the McDowell Mountains (Christenson, Welsch, and Péwé, 1975) and the Phoenix Mountains (Shank and Péwé, 1973).

Similar caliche deposits have been described in southern New Mexico (Gile, 1975) and in Saudi Arabia (Chapman, 1974) on surfaces with comparable thicknesses and degree of caliche development as in the Phoenix Basin in terms such as very old and up to a million years or more.

Along the Gila River near Arlington, Gillespie Dam, and Gila Bend the 40- and 80-foot terraces of river gravel with rock types similar to the Salt River Terraces are extensively calichified and are firmly cemented. Here the terraces are overlain by lava flows that have been dated at 2 to 3 million years (Lee and Bell, 1975).

TECTONIC SIGNIFICANCE OF TERRACES ALONG STREAMS ENTERING THE PHOENIX BASIN

It is apparent from the study of the converging terraces on the streams flowing out of the mountains and entering the Phoenix Basin from the north and east that the mountain ranges in that area are undergoing a slow regional uplift, apparently periodically. It also is apparent that the stream terraces converge on the edge of the basins and disappear

under the valley fill deposits. It would appear that there has been slow down-dropping and filling of the basins over the last 2 or 3 million years, perhaps longer, and the river gravels are present at some depth in the basin. The exact depth is not known, but in the city of Tempe, gravel of the Mesa Terrace is anywhere from 10 to more than 30 feet deep, becoming deeper toward the southern part of the city. South of Mesa the coarse river gravel is at least 600 feet below the surface. No outcrop of the mountain gravels is known along the streams in the basin until the drainage network encounters similar caliche-cemented Salt River-gravel type lithology near the vicinity of the mouth of the Hassayampa River. It is therefore thought that the down-faulting extends westward to the vicinity of the Hassayampa River. From here downriver to Gila Bend the terraces are parallel, based on present reconnaissance work, and are not part of this original down-dropping that occurred or is occurring in the basin.

It is tempting to speculate on the rate of uplift. Assuming that the converging terraces do indicate rising of the mountains; assuming further that the maximum uplift is about 400 feet near Roosevelt Dam; and assuming that a period of 2 million years was involved, one could suggest that the rate of uplift has been about 1 inch/400 years or .0025 inches/year (.0001 mm/yr).

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GEOLOGY FIELD TRIP LOG ALONG THE LOWER SALT RIVER, ARIZONA FROM TEMPE BUTTE, TEMPE TO SAGUARO LAKE AND RETURN

The numbered stop locations are on topographic maps (fig. 7); these maps should be consulted for a clearer understanding of the discussion.*

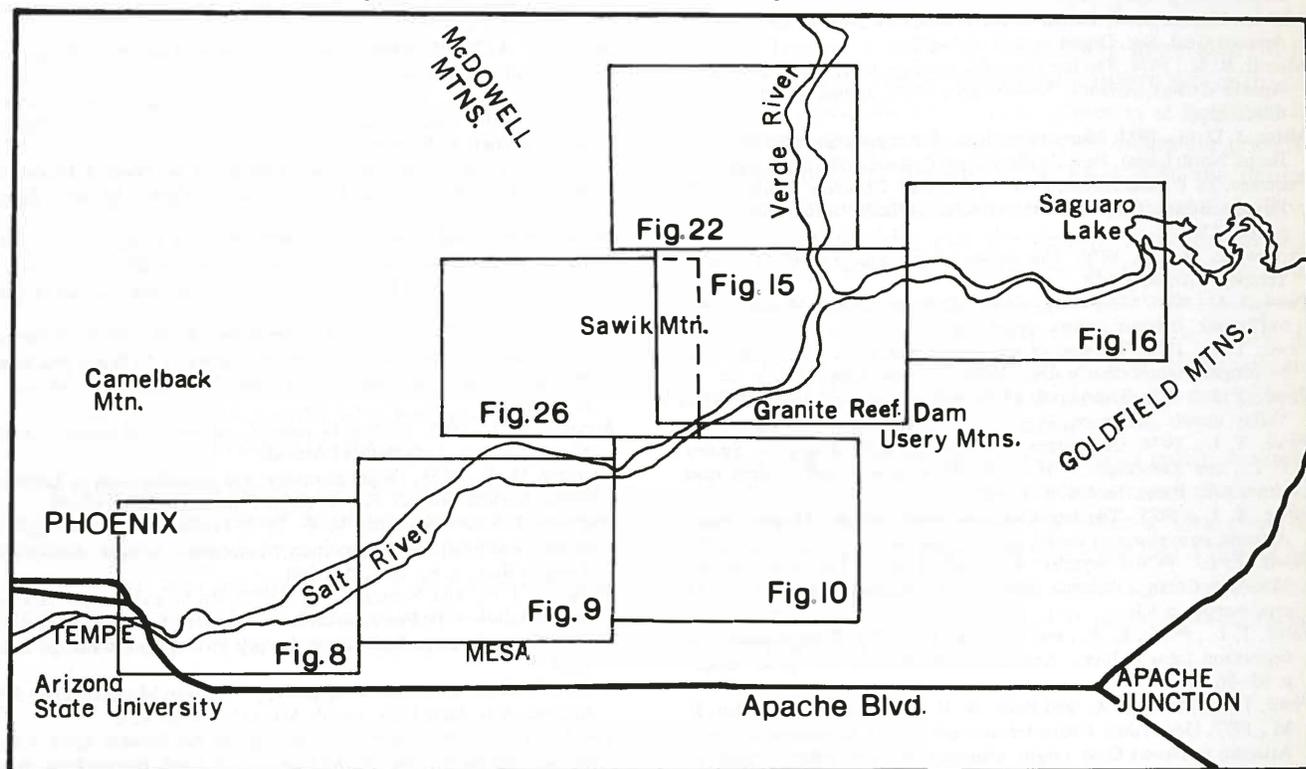


Figure 7. Index map showing location and number of topographic maps of field trip stops, lower Salt River Valley.

STOP 1. ARIZONA STATE UNIVERSITY (Tempe Quadrangle, 1952). On edge of river scarp near railroad track at Arizona State University overlooking fraternity houses (fig. 8). The fraternity houses to the east are on a low terrace of the Salt River which is really part of the floodplain. However they are not on the active part of the floodplain and were not flooded in the flood of December, 1965–January, 1966. The water reached an elevation of about 1,160 feet, about 3 or 4 feet below the level of the terrace and the fraternity houses. The scarp at **STOP 1** is about 10 feet above the active floodplain. The terrace upon which Arizona State University is built is part of the Mesa Terrace which is well displayed at **STOP 2** in Mesa, 3 miles to the east.

At this locality, the modern Salt River flows between Tempe Butte on the south and the Papago Pediment on the north (fig. 8). The bedrock is very shallow at this narrow constriction and actually crops out locally in the bottom of the floodplain. In the geologic past the Salt River flowed to the west

by going south of Tempe Butte and South Mountain (figs. 1, 2). At least four terraces are present on the map (fig. 8); they all have low scarps and appear to terminate in the vicinity of the western part of the map (Tempe Butte). No prominent terraces of the Salt River are exhibited downstream. On the ASU campus there is 3 to 6 feet of river silt overlying coarse, rounded river gravel of the Mesa Terrace. This gravel is exposed in the basements of most of the buildings constructed on the campus.

From **STOP 1** proceed east along University Avenue to **STOP 2**.

STOP 2. TERRACE SCARP. One of the best western exposures of the prominent Mesa Terrace that extends unbroken from here eastward 10 miles to the Usery Mountains (figs. 8, 9, 10). Gravel crops out and the terrace scarp here is 20 feet above the active floodplain.

As for all the major terraces, the overbank silt, or silt from the surrounding mountains which overlies the gravel, has been washed away at the terrace scarp, and it is here that the caliche-cemented gravel is well exposed.

*The topographic maps are part of various U.S. Geological Survey Quadrangles as stated in their title.

Proceed through Mesa to Country Club Avenue and then north on Country Club Avenue to terrace scarp at Mesa Country Club.

STOP 3. MESA TERRACE (Mesa Quadrangle, 1952; fig. 9). A road cut exposes the caliche-cemented gravel in the scarp of the Mesa Terrace. The Mesa Terrace was named (Péwé, 1971) from the City of Mesa, established by the Mormons in 1878 on a table land above the river. The Spanish name for table, mesa, was adopted as a name for the settlement. The Mesa Terrace is 40 feet above the modern floodplain at this locality. The scarp is well exhibited and a small colluvial apron extends from the scarp down onto the lower terrace.

The exposure is old and the caliche cementing the terrace gravel is beginning to be weathered. At the top of the scarp, holes dug for a sign that was never erected expose well-developed caliche. The caliche development is the complete plug stage and at places along the edge of the scarp laminar caliche is well formed.

From **STOP 3** proceed across the lower terrace north and east to the village of Lehi.

STOP 4. VILLAGE OF LEHI. This lower terrace is named the Lehi Terrace (Péwé, 1971) from the village of Lehi (fig. 9). The village was established in 1877 by the Mormons and was the first settlement in this immediate area. The term Lehi comes from the Biblical prophet of 600 B.C. who took his family into the wilderness to escape the destruction of Jerusalem. The name has great antiquity but the terrace is undoubtedly older. The terrace here is about 10 feet above the modern floodplain and was not flooded in the flood of December, 1965. However, the flood of 1965 did not reach its possible maximum because of storage provided by the six reservoirs on the Verde and Salt Rivers. Without the reservoirs the peak discharge at Granite Reef Dam would have been about 120,000 cfs (Aldridge, 1970, p. C-27). The largest known flood in the Salt River Basin occurred in February 1891 when a flow of 300,000 cubic feet per second (cfs) was recorded. Flood waters at that time invaded most of the downtown area of Phoenix and covered the Lehi Terrace.

From old records of the towns of Lehi and Mesa we learn that on February 19, 1891, the Salt River reached the highest point that could be remembered by the settlers and did considerable damage to their crops and buildings. However, 3 days later the river rose an additional 3 feet completely engulfing the bottomland. It is reported that five Indians were drowned, but all the white settlers escaped to the

mesa where they remained for 2 weeks. Most of the Indians and settlers lost nearly all their personal possessions in the flood and the canals were badly damaged. The water in Lehi was described as being waist deep, or belly deep to a pony.

The Lehi Terrace is a low terrace of the floodplain. Isolated remnants of the terrace are present upstream as far as Stewart Mountain Dam. However, with the establishment of the dams, the possibility of this terrace now being flooded is extremely rare. The top stratum silt is 1 to 10 feet thick and is underlain by sand and gravel.

Two hundred yards southeast from **STOP 4**, on Keal Road, Mr. Roger Sattler came across the remains of a fossil in an excavation for a septic tank. The writer investigated the site and recovered a fine carapace of a box turtle 14 by 10 inches which was at the top of the river gravel beneath 90 inches of top stratum silt. The fossil, which occurred in a silty clay which has tubules and small nodules of caliche, is probably late Quaternary in age; a study is underway.

STOP 5. SCARP OF LEHI TERRACE ABOVE MODERN SALT RIVER FLOODPLAIN. Beneath 3 or 4 feet of top stratum silt is a coarse, rounded river gravel with clasts about 4 inches in diameter. There is no cementation by caliche whatsoever but there is a very thin film of caliche completely surrounding the larger cobbles in the silty matrix. In the upper 2 feet of the section there are characteristic pot sherds of Hohokam culture, as well as lithic artifacts. The Indians probably used this flat area for agriculture 1,000 years ago and it was periodically inundated by the river until the building of the Theodore Roosevelt Dam. At this locality we are about 8 or 9 feet above the low part of the Salt River Channel. On top of the terrace scarp there can also be found a litter of pot sherds.

STOP 6. LOW TERRACE SCARP OF BLUE POINT TERRACE. The gravel terrace scarp, 3 to 6 feet above the Lehi Terrace, appears along the road to the south in this area. This is probably the most western exposure of the Blue Point Terrace. From this **STOP** one can see ½ mile to the south the prominent scarp of the Mesa Terrace, the top of which is here 60 feet above the modern floodplain. To the north one can see the counterpart of the 60-foot terrace across the Salt River Valley.

From here proceed to **STOP 7** just north of the Southern Canal about 1 mile east of **STOP 6**.

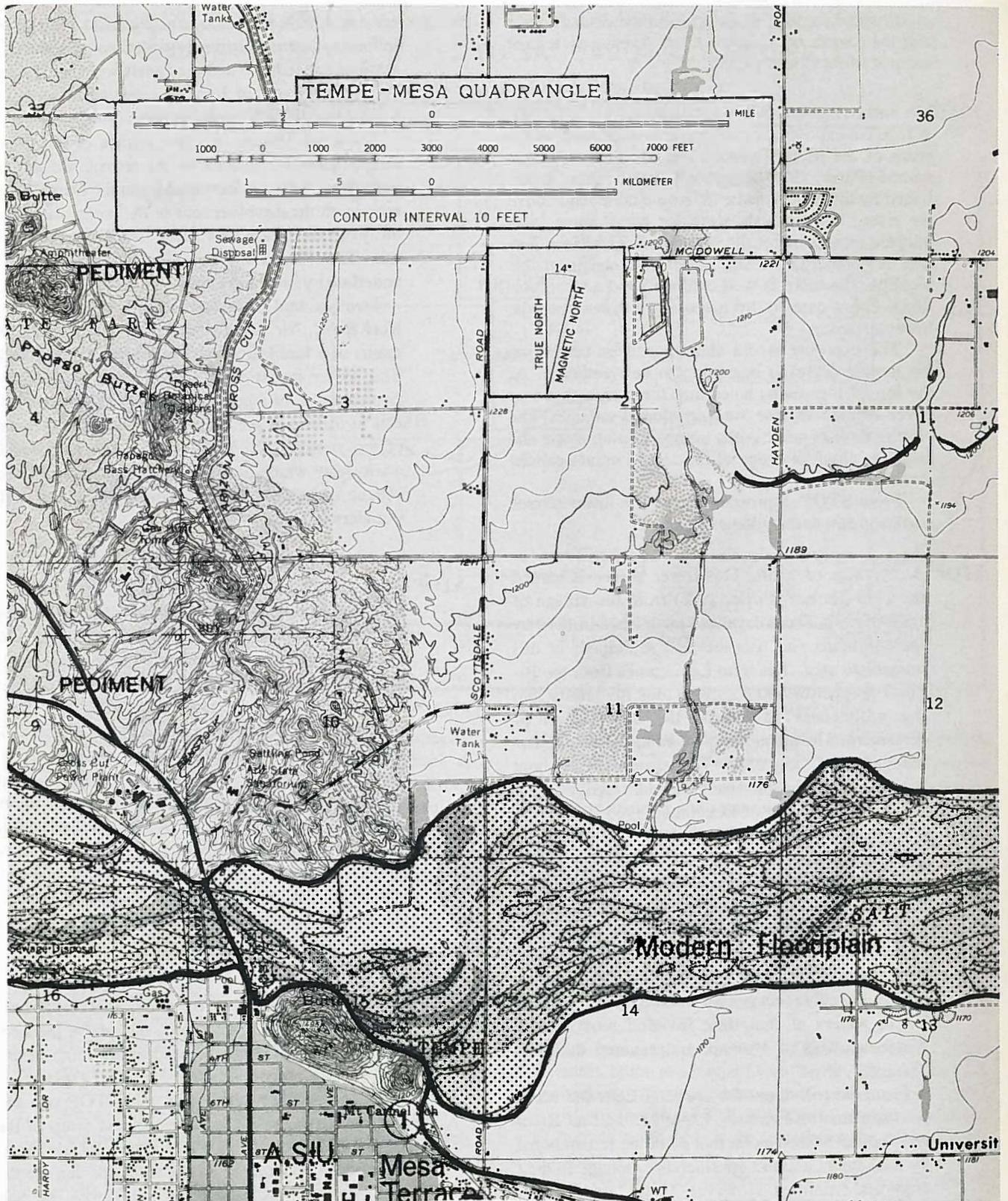
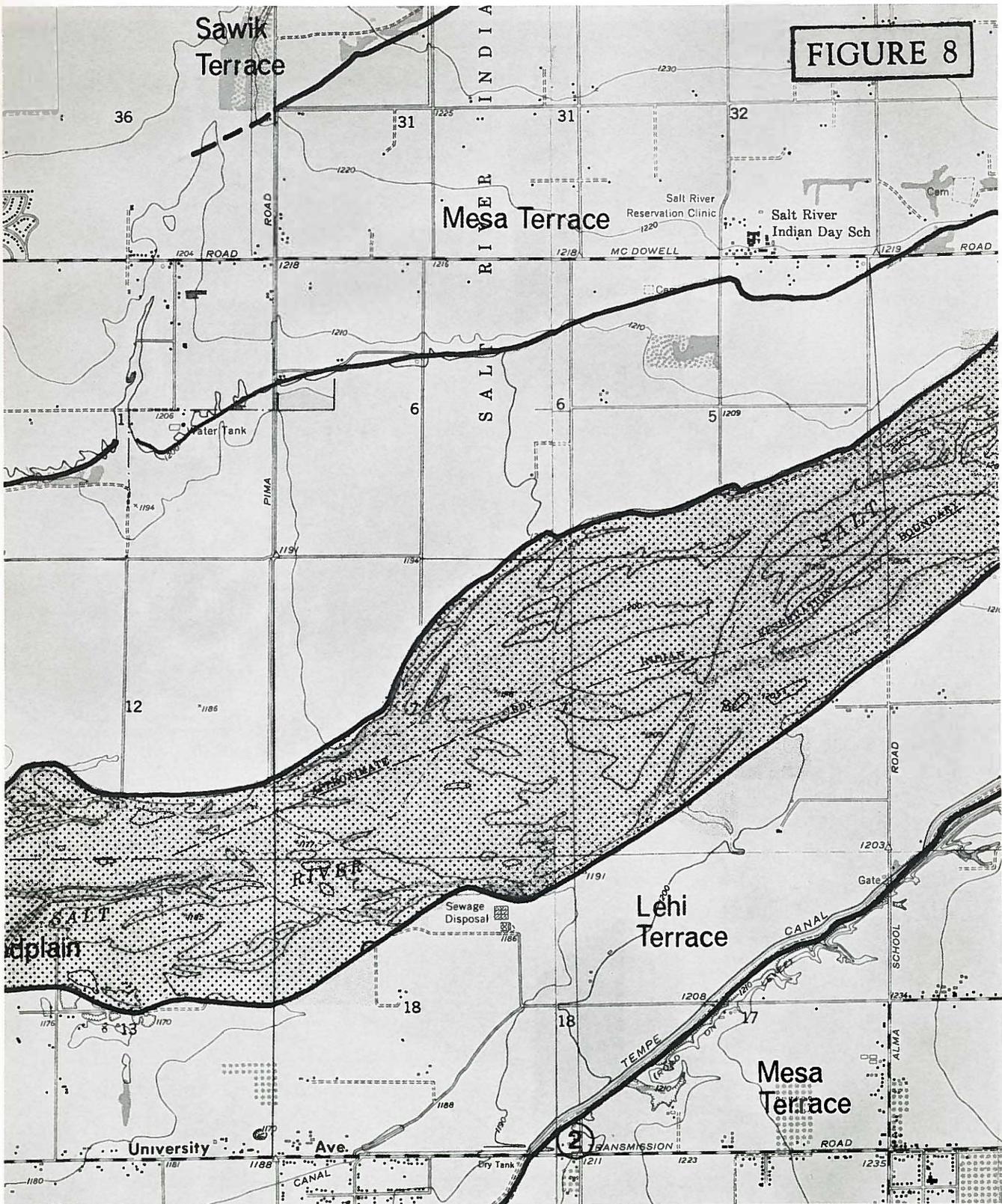


Figure 8. Field trip log map showing locations of STOPS 1-2.



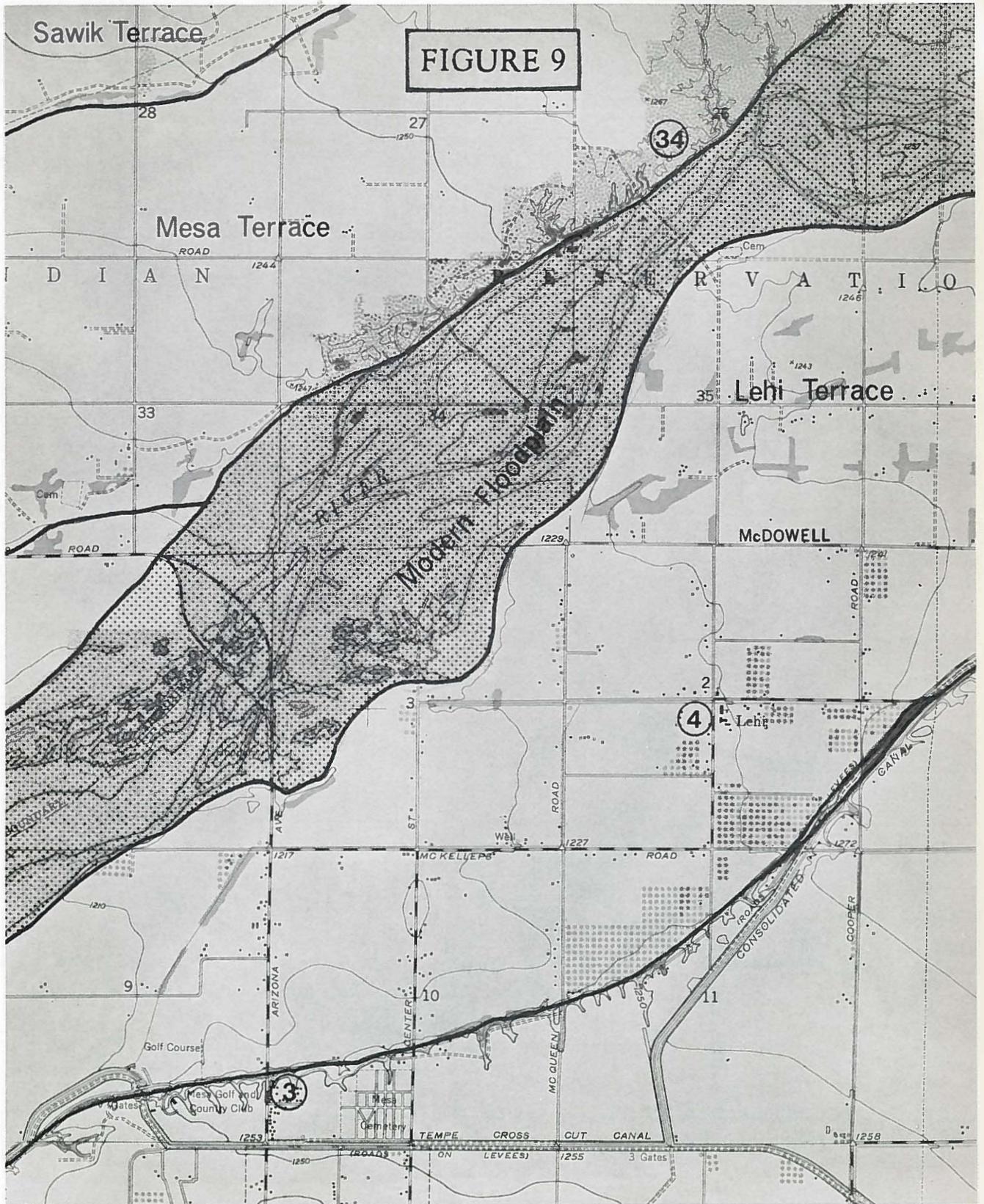
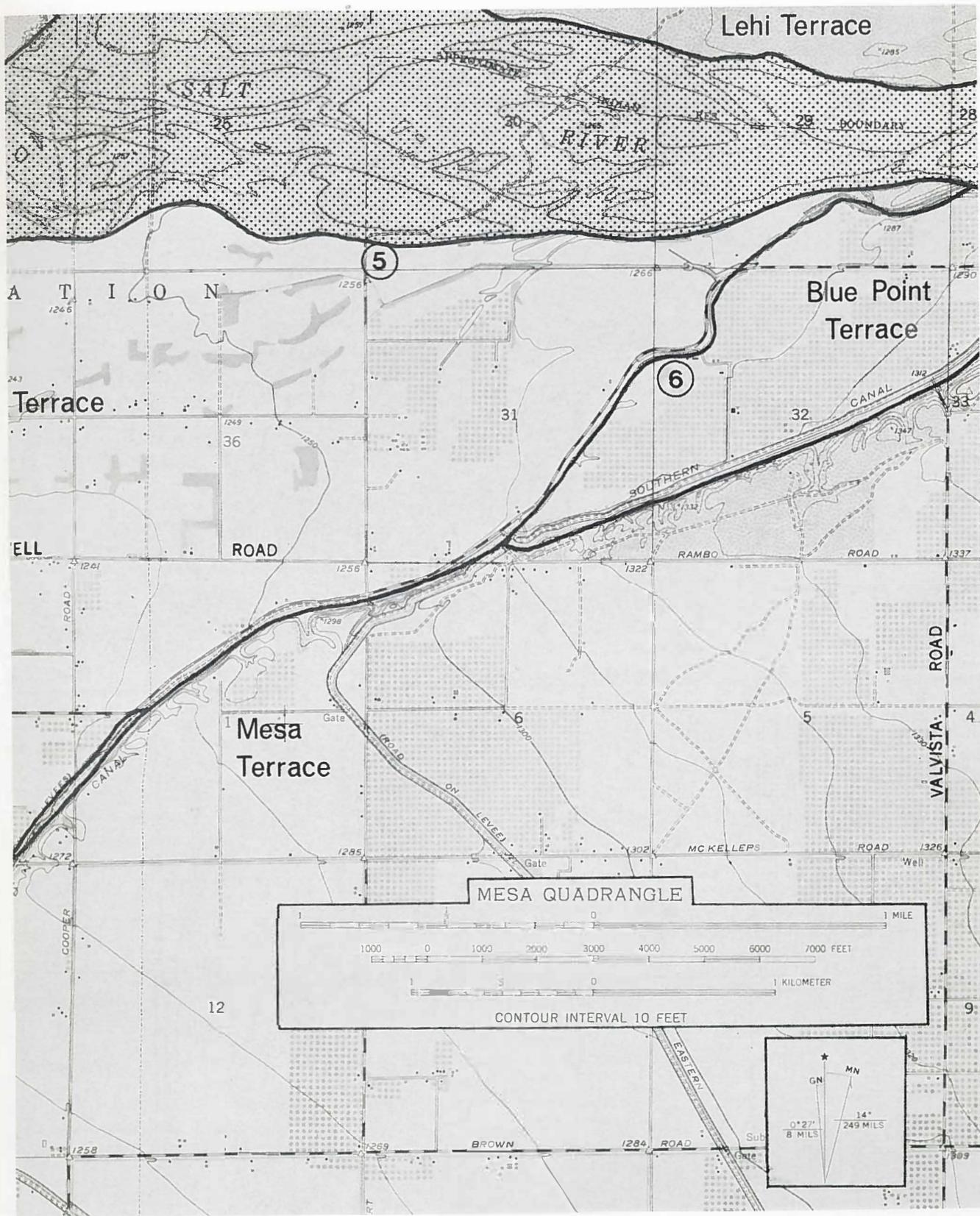


Figure 9. Field trip log map showing locations of STOPS 3-6 and 34.



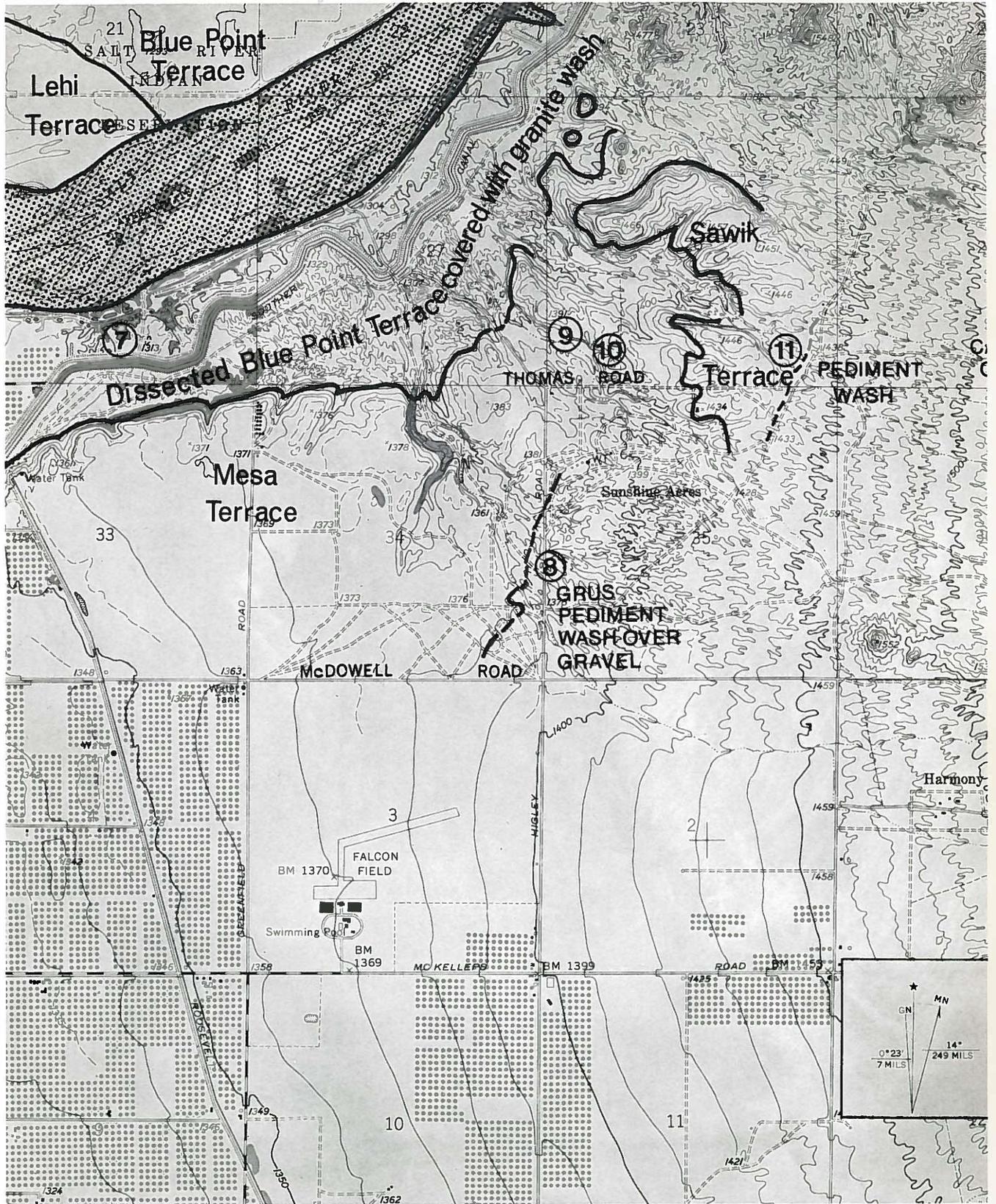


Figure 10. Field trip log map showing locations of STOPS 7-12.

T O N T O N A T I

FIGURE 10

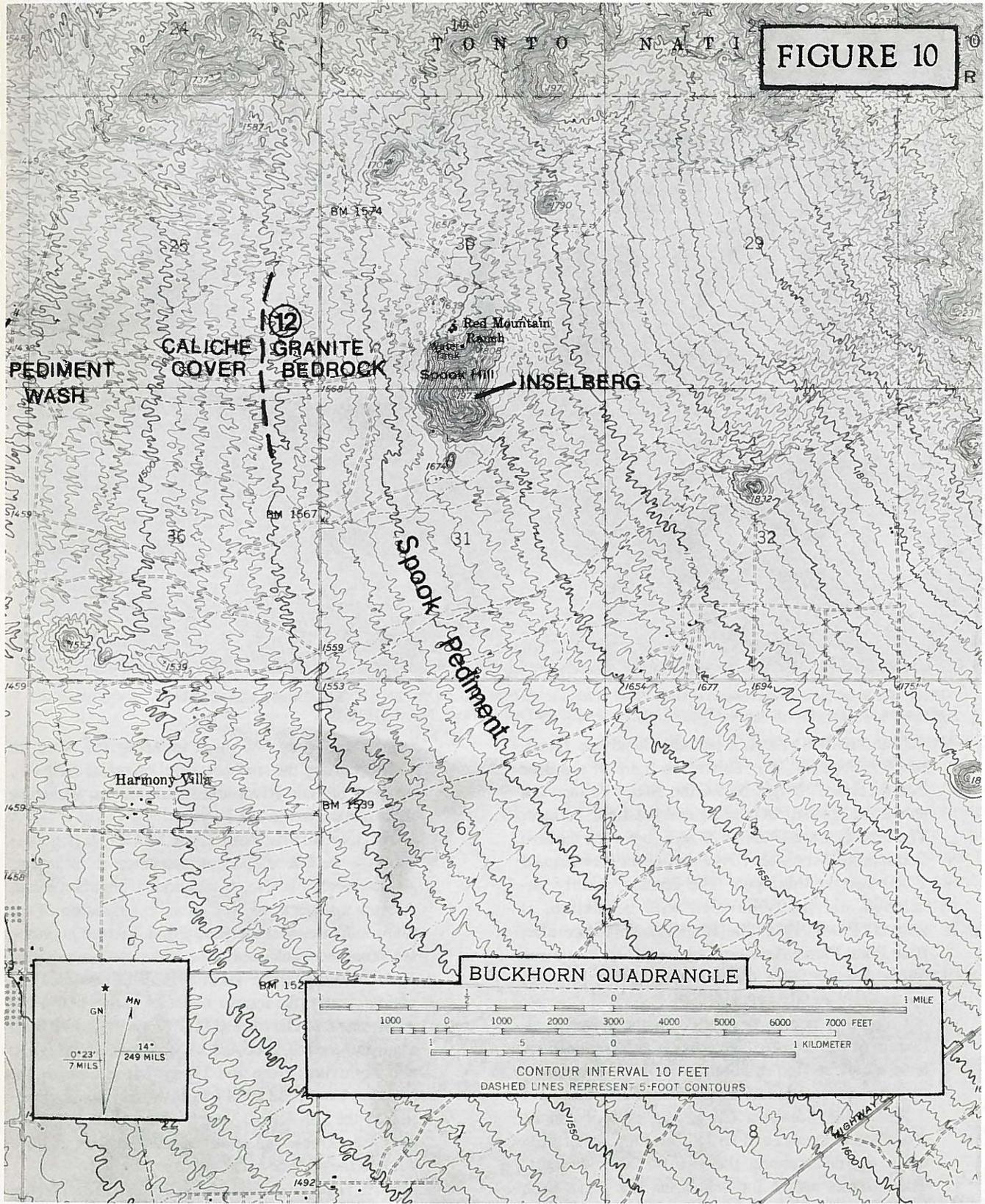




Figure 11. View downstream (west) of Blue Point Terrace scarp (SW Sec. 28, T. 2 N., R. 6 E.). Modern flood plain on right; Camelback Mountain on right in far distance. (Photograph No. 14,263 by Troy L. Péwé, March, 1970.)

STOP 7. BLUEPOINT TERRACE SCARP (Buckhorn Quadrangle, 1956; fig. 10). This is the scarp of the Blue Point Terrace. It lies below the Mesa Terrace but above the modern floodplain and the Lehi Terrace. The terrace scarp is about 20 feet above the modern floodplain of the Salt River and at an elevation of 1,300 feet at this spot. The terrace, poorly developed and partly covered with colluvium, is termed (Péwé, 1971) the Blue Point Terrace after Blue Point Picnic Area near where it is well exposed on the south side of the Salt River, 8 to 10 miles upstream from this spot.

Caliche is poorly developed in the gravelly alluvium of this terrace. The cobbles and pebbles may have a caliche rind of about $\frac{1}{8}$ inch but there is no massive cementation of the pebbles or cobbles.

Along the Southern Canal at this spot can be found many small snail shells, but they are of little value for determining the age of the sediments. These shells are in the sediments that have been dredged from the canal during periodic cleaning and dumped on the side. The snails were introduced

from the Orient by ships entering the Gulf of California and the snails evidently worked their way up the Colorado River and its tributaries, including these canals, in the last 30 years.

A view downstream from **STOP 7** (fig. 11) shows a well-developed terrace scarp in alluvium. At this locality is also an abandoned irrigation canal. A view upstream, as well as an examination of the map, indicates that the Blue Point Terrace is only a few hundred yards wide from here to Granite Reef Dam. From near the Granite Reef Diversion Dam and upstream, the terrace is cut on bedrock and is a strath terrace. Between **STOP 7** and Granite Reef Dam the terrace is covered with a granite alluvium and colluvium from the Utery Mountains to the east. As local base level was lowered (the downcutting of the Salt River), much of this colluvial cover over the terrace was removed and the streams have cut into the surface of the terrace.

Kokalis (1971) made detailed analyses of the size-grade distribution of the sediments of the terraces as well as the modern floodplain. The sediments can be classed as gravels

to sandy gravels. He concluded that the average medium diameter of the terrace sediment is -4.0Φ (fig. 12) and that of the modern floodplain sediments is -3.4Φ . He further states that the average of the most coarse 1 percentile illustrates this difference, as that of the terrace sediments is -7.4Φ while the average for the modern floodplain gravels is -7.0Φ . His analyses indicate that for all practical purposes the size distribution of the sediments on the terrace is the same as that of the floodplain. However, there is a slight difference, and the regimen of the Salt River in the past may have been slightly more rigorous during the time that the

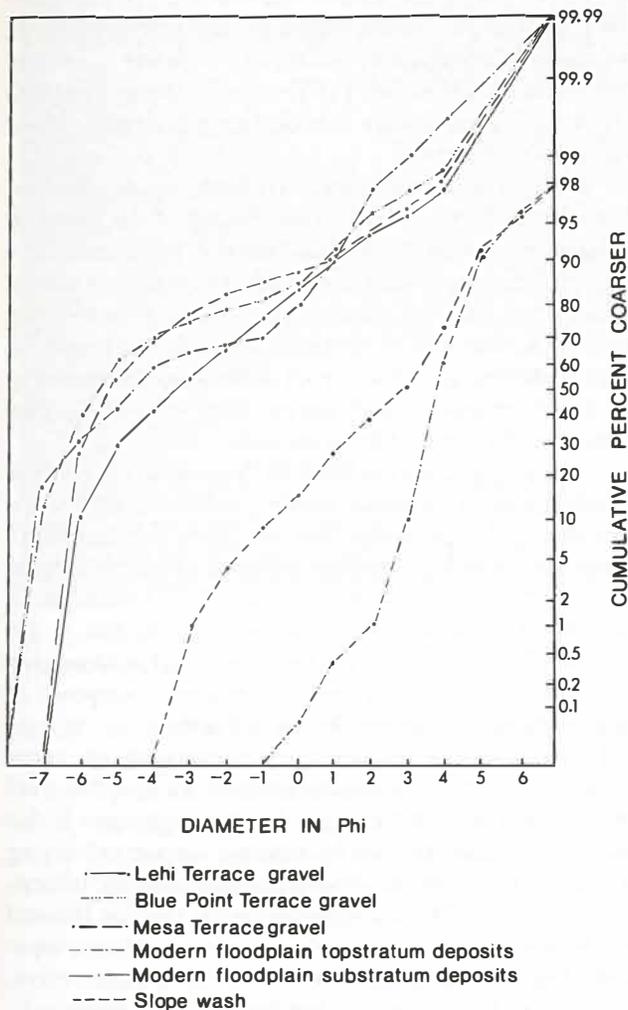


Figure 12. Cumulative-frequency distribution curves for analyses of sediments of modern flood plain and terraces of the lower Salt River Valley, Arizona. (After Kokolis, 1971.)

high terraces were produced than during the time of the modern floodplain.

Kokolis (1971) was able to demonstrate that in the reach of the Salt River from Stewart Mountain Dam to its mouth there was no change in size distribution of the sediments. Also, it was not possible to distinguish one terrace from another by size grade analyses alone.

Return to west along canal to Gilbert Road and south to McKellips Road. Proceed east on McKellips Road through the citrus groves.

At the Junction of Val Vista Road and McKellips Road examination of the soil in the citrus groves indicates that the coarse silt has many pea-sized gravel pieces of angular feldspar, quartz, and granite. This material is washed from Spook Pediment and forms a thin veneer over the underlying Mesa Terrace river gravel. The same type of soil is present in the vicinity of Falcon Field in Section 3 (fig. 10). Proceed north on Higley Road to **STOP 8** in the vicinity of Sunshine Acres.

STOP 8. SUNSHINE ACRES. Along Higley Road in the vicinity of Sunshine Acres one may notice that the grus pediment wash from Spook Pediment to the east thins and the caliche-cemented coarse gravel of the Mesa Terrace is exposed. In the sharp-walled gullies just west of Higley Road in Section 34 at an elevation of 1,361 feet is exposed highly indurated caliche-cemented gravel with no grus wash on the surface. The Mesa Terrace is here at an elevation of about 1,370 feet (fig. 10).

STOP 9. ROAD CUT IN MESA TERRACE ON HIGLEY ROAD. This is the surface of the Mesa Terrace at an elevation of 1,391 feet. The road cut has exposed highly calichified coarse gravel with lenses of silt and sand. The plug stage of the caliche growth is well exhibited on both sides of the road cut and especially on the small new cut on the south end of the east wall of the road. Many fractured cobbles and boulders can be seen with caliche-filled fractures. In many places on Mesa Terrace the fractured parts of the cobbles have been displaced as much as 2 inches. At this locality, laminar caliche is well developed. As much as 1 or 2 feet of laminar caliche can be seen, especially in finer material. The development of caliche indicates great antiquity of the terrace, and, as mentioned earlier, the surface of the Mesa Terrace is surely quite old; very early Pleistocene if not Pliocene.

Proceed south to Thomas Road and east on Thomas Road 100 yards to **STOP 10**.

STOP 10. DESERT PAVEMENT STUDY SITE. The study site is on gravel of the Mesa Terrace. To the north and east a higher level terrace can be seen. The level is well displayed and represents the highest of the series of terraces, the Sawik Terrace, 185 feet above the modern floodplain.

Excellent desert pavement has formed on the terrace gravel surface in many places. Desert pavement is a stone mosaic composed of pebbles which lie flat and adjacent to

each other embedded in a fine matrix, generally silt. If there is a binding agent present such as clay or salt, the material is usually indurated to form a thin, strong carapace. If there is no binding agent, the fine material is loose. The desert pavement is generally very old and the clasts are highly patinated by desert varnish.

In an attempt to learn more about the origin and rate of formation of desert pavement, the writer, assisted by students, established three test sites on alluvial fans near Quartzsite, Arizona in March, 1975, and has periodically studied the sites. Three areas 9 yards square were carefully cleared of stones to study the rate of rejuvenation of the desert pavement. The weight, number, and volume of surface clasts were carefully measured. Also measured were the size, weight, and number of clasts in the silt recovered from a measured pit dug nearby.

To continue studies closer to Arizona State University, Site No. 4 was established near the corner of Higley and Thomas Roads on the surface gravel of the Mesa Terrace (fig. 13). The area is not as ideal as that near Quartzsite, but it is closer to Tempe. Site 4 was initiated by Mr. James Bayles, June 1, 1977, in the same manner as the first three sites. The 9-yard-square area was carefully cleared of stones by hand picking with little disturbance as possible to the underlying material. No clasts were at the surface after the area was cleared. The first step was to clear a 1-yard-square area within the 9-yard-square area. The surface clasts in the one-yard-square area were analyzed for size distribution and weight (table 2).

Table 2. Particle size and weight distribution of material at ASU desert pavement Site 4.

>32mm	>16mm	>8mm	>4mm	<4mm	Total
882gm	7973gm	5078gm	231gm	113gm	14,277gm

To produce a desert pavement it is necessary to concentrate the particles on the surface either by 1) deflation by wind, 2) erosion by water, 3) upward migration of particles from the subsurface material or 4) any combination of these. Many of the sites are in such a position that erosion by water would be relatively minor, nevertheless, some of the material is removed this way. Deflation by wind is always present in desert areas, and surely some contribution of erosion is by this method. At Quartzsite, considerable stone cover has already been regenerated on the cleared surfaces. The different parts of the area have been recleared at different times, and at this writing there are three different degrees of surface desert pavement regeneration present at the sites.

In Israel, Sharon (1962) performed in-place experiments on hamadas, the middle east term for desert pavement. Two different types of hamadas were studied: one was flint, and the other was a limestone cover. Both were carefully cleared of rocks to prevent unnecessary disturbance of the soil; one area was 150 m² and the other was 120 m². After 5 years the

two plots were photographed and the amount of surface lowering was measured. Both hamadas were found to have regenerated nearly identical amounts of cover, estimated to be about 60–80%; and their surface lowering was measured and found to be an average of 15–20 mm. The area outside the plot was also measured for surface lowering and was about 10 mm.

At the time of the writing of this guidebook, Site 4 has just been cleaned (fig. 13) and no information is available regarding regeneration of the surface. However, by measuring the weight, number, and size of pebbles underlying the desert pavement to the depth of one foot it can be calculated that if all the fines were removed (by wind or water) clasts remaining as lag would be enough to completely regenerate (by weight alone) particles to produce an armor similar to that of the original surface if the surface were lowered about 3 inches.

On study sites near Quartzsite preliminary analysis of the data indicate that in 10 or 12 years enough of the fines will be removed to generate an armor similar to the original.

In an attempt to investigate further the origin and time of formation of desert pavement, observations were taken on the intaglio southeast of Chandler, Arizona. An intaglio is an animal or human figure carved in the desert by disturbing the desert pavement. Such figures have been drawn over many years by ancient man in the area.

The exact age is not available for the intaglio southeast of Chandler (the Pima Indian culture's witch Ha-ak Va-ak). However, the area scraped for the figure in the ancient desert pavement has now been replaced by a new armored surface. But the new surface is composed of smaller stones than the original and also the color is not as dark as the original. The short study we have conducted at Quartzsite also indicates that the regenerating surface is composed of smaller clasts than those of the original surface.

The methods by which the clasts reappear are under study. Two of the most obvious methods are by either wind or water deflation of the fines. Another suggestion is that the stones migrate upward by repeated wetting and drying of the silty clay. This has been demonstrated in the laboratory (Springer, 1958) and supported in the field by Howard and others (1977). This upward stone migration is especially true if the clay fraction has expanding lattice clays. X-ray diffraction analysis of the clays near Quartzsite indicate the presence of montmorillonite and a variety of mixed layer clays usually consisting of montmorillonite and illite in all samples. Preliminary x-ray diffraction analysis work has been unable to determine the clay mineralogy in the silty clays at the Mesa Terrace site.

From **STOP 10** proceed eastward along Thomas Road. Here you find probably the only place in the world where a Saguaro cactus is growing in the middle of the road and traffic is detoured to each side. From here the road ascends

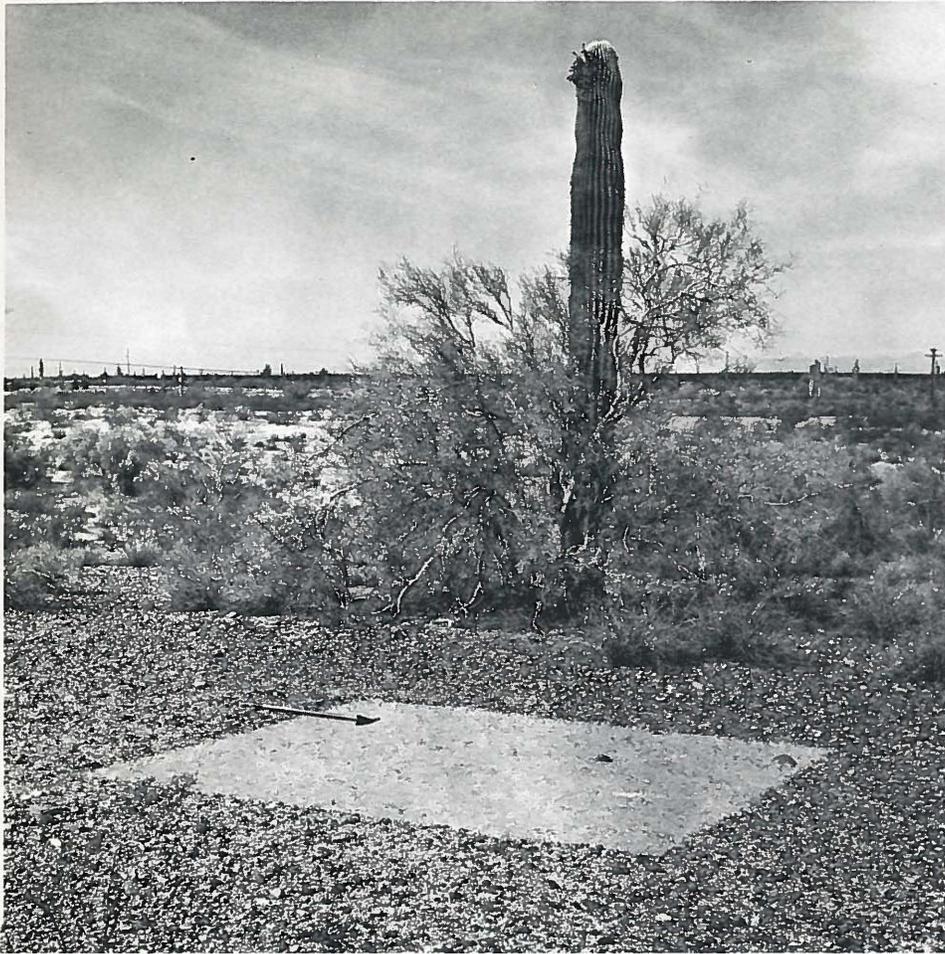


Figure 13. Desert pavement study site No. 4 near Thomas and Higley Roads. (Photograph No. 3946 by Troy L. Péwé, June 18, 1977.)

to the Sawik Terrace level (fig. 10) at an elevation of 1,400–1,450 feet.

STOP 11. PEDIMENT WASH (GRUS) OVERRIDING SAWIK TERRACE GRAVEL. At an elevation of about 1,433–1,438 feet in the southeastern one-quarter of Section 26 (fig. 10), the edge of the “pediment wash” sediments can be seen and the underlying rounded caliche-cemented gravels of the Sawik Terrace are exposed in shallow washes.

Proceed west over calichified pediment wash (grus) on desert trail until it intersects Bush Highway at **STOP 12.**

STOP 12. SPOOK PEDIMENT. The broad pediment cut on granite rocks is named the Spook Pediment (Péwé, 1971) from Spook Hill, a well developed inselberg projecting 300 feet above the gently sloping pediment surface in the northern part of the Buckhorn Quadrangle (fig. 10). Part of the pediment is graded to remnants of the Sawik Terrace, but most is graded to the Mesa Terrace in this area. Bedrock crops out along the Bush

Highway at this locality and stream cuts to the east and west. The typical gently sloping, smooth-looking pediment is gullied with shallow stream incisions 1 to 5 feet deep. The surface of the Spook Pediment in this area slopes about 100 feet per mile to the west and southwest.

STOP 13. GRANITE REEF DIVERSION DAM (Granite Reef Dam Quadrangle, 1964; fig. 14). A view of Salt River 2 miles downstream from the mouth of Verde River near Granite Reef Diversion Dam. From this locality the river and the low Granite Reef Dam can be seen (fig. 15).

Granite Reef Diversion Dam is one of the many facilities of the Salt River Project, an organization that brings power and irrigation water to the Salt River Valley. The Salt River project is the nation’s oldest and most successful multi-purpose reclamation development, providing a dependable supply of water and power for the greater Phoenix valley. The Project delivers water to 250,000 acres of land and electricity to approximately 240,000 customers (1976). The Salt River Project began

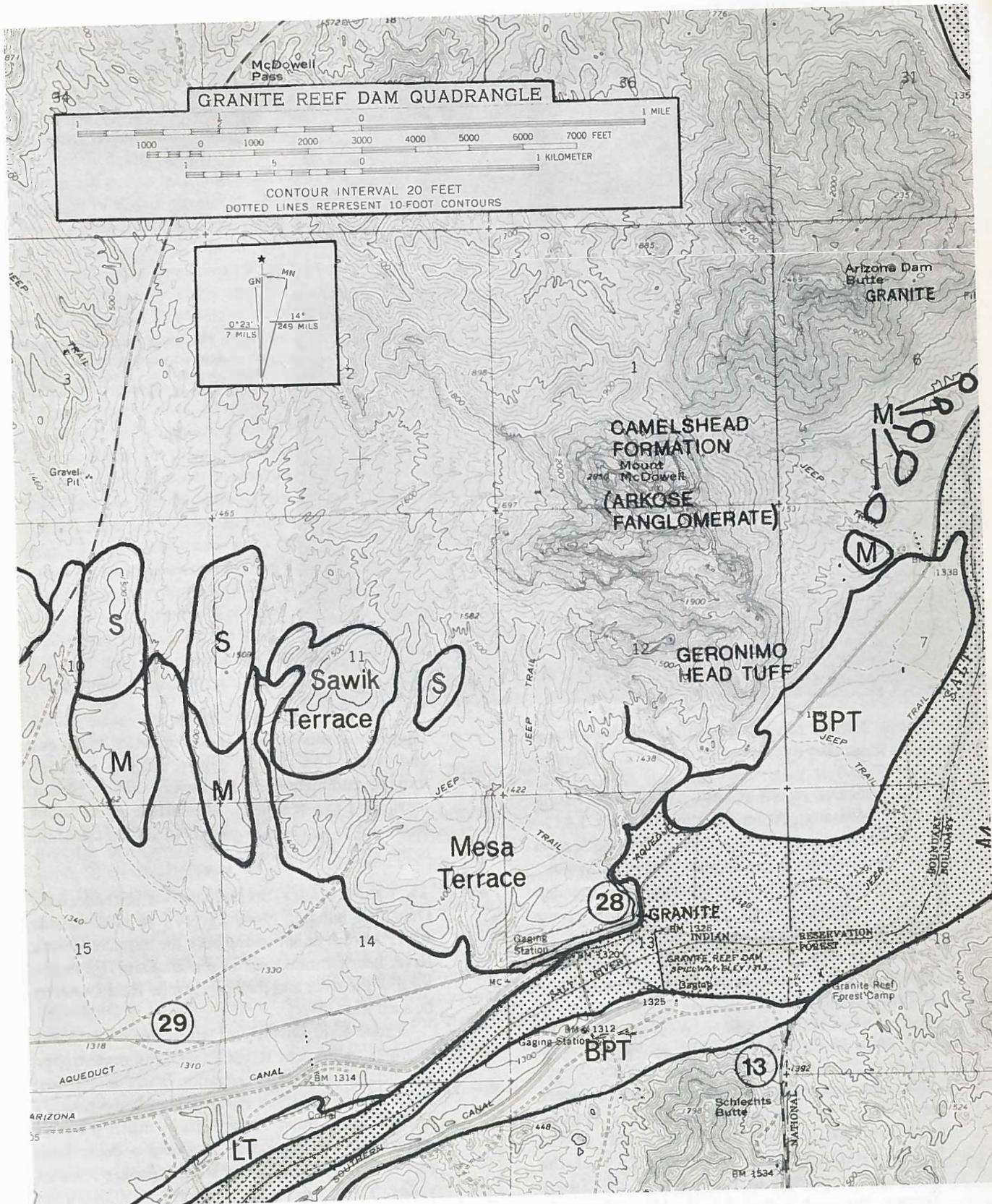
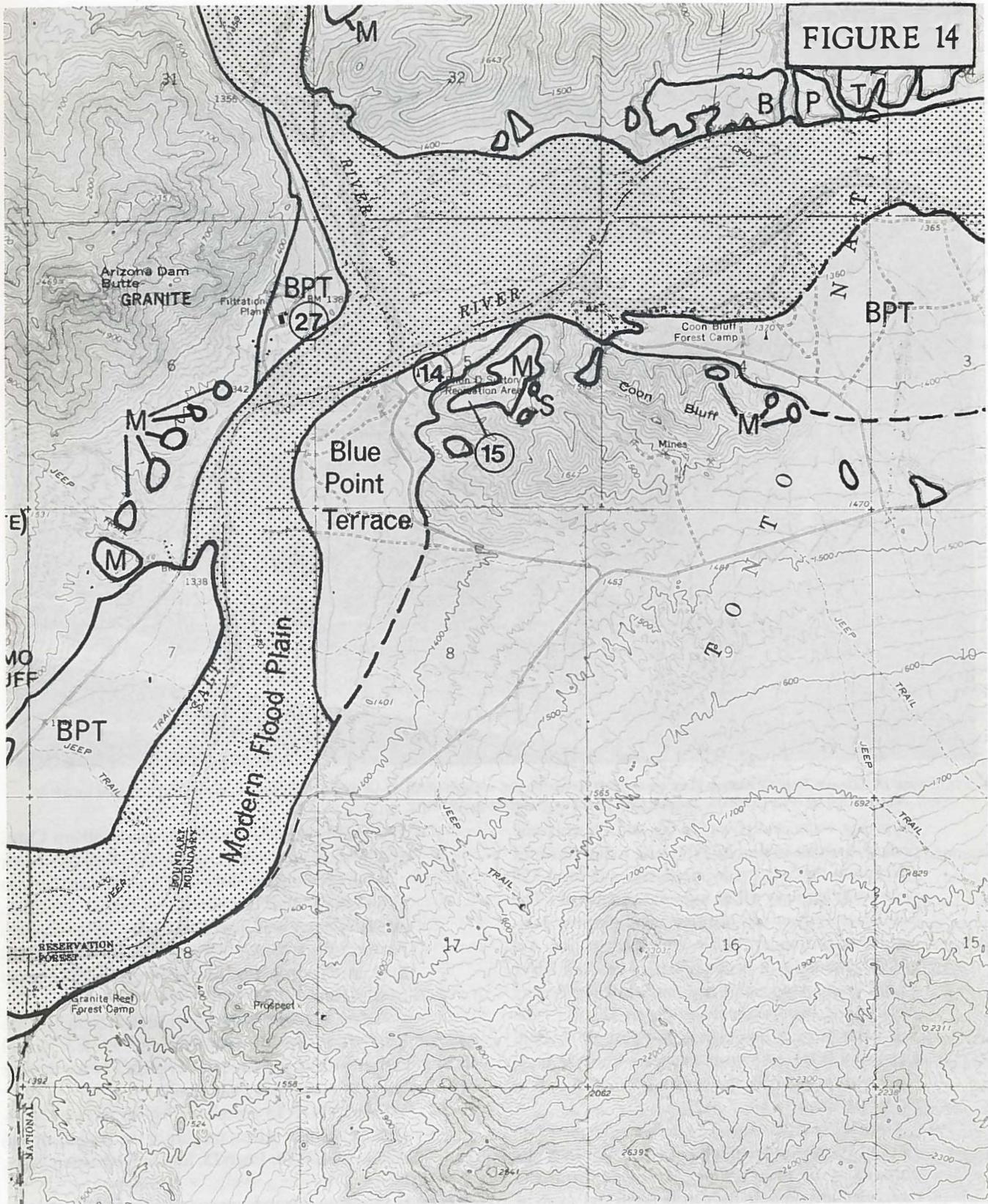


Figure 14. Field trip log map showing locations of STOPS 13-15 and 27-29.

FIGURE 14



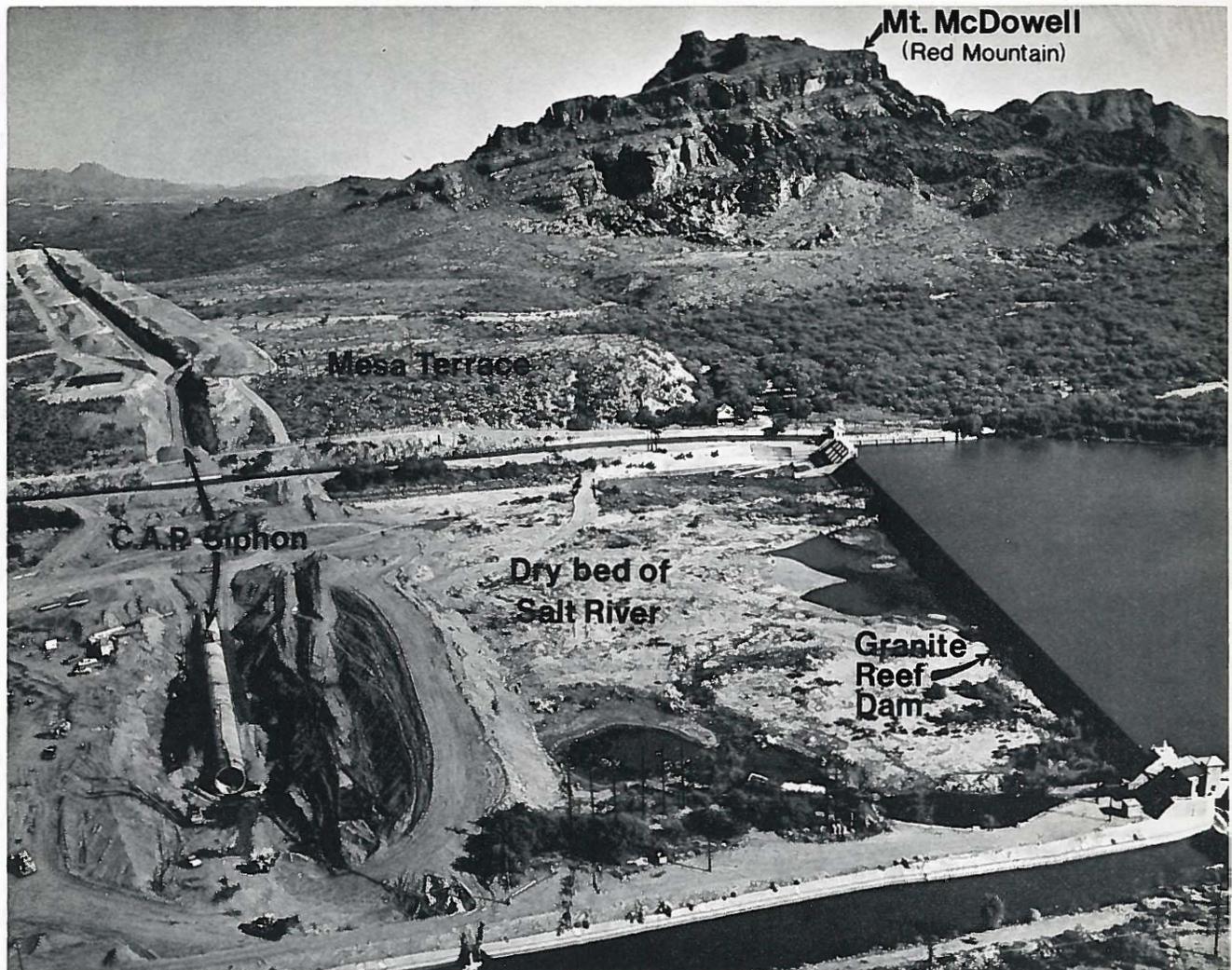


Figure 15. Granite Reef Diversion Dam on the Salt River. Aerial view to north. CAP siphon is being constructed in the open trench at left. (Photograph by Nyle Leatham, *The Arizona Republic*, September, 1977.)

supplying water and power to the arid Phoenix and central Arizona region in 1911, and today provides water from the Salt and Verde Rivers and from 255 deep wells through a 138-mile canal network. The Salt River Project was the first multi-purpose project authorized under the Federal Reclamation Act of 1902 and today it is comprised of the Salt River Valley Users Association and the Salt River Project Agricultural Improvement and Power District. The Salt River Project was organized February 9, 1903 by some 4,000 land owners to secure from the U.S. Government a loan for the construction of Theodore Roosevelt Dam.

Granite Reef Diversion Dam was completed in 1908. It is only 29 feet high but 1,000 feet long. Its purpose is to divert water, released from the reservoirs upstream, to the canals north and south of the river for delivery to water users in the Salt River Project. No power is generated at Granite Reef

Dam. The Arizona Canal and the Southern Canal are the most upstream canals on the lower Salt River and were built many years ago: the Arizona Canal in 1883–1884 and the Southern Canal in 1908. Actually, there was a small diversion dam called the Arizona Dam at this site many years ago. It was built in the early Eighties to divert water into the canals (Davis, 1897).

A few hundred yards downstream from Granite Reef Dam the Central Arizona Project Canal carrying Colorado River water passes under the Salt River by means of a giant siphon.

From **STOP 13** proceed along the modern floodplain of the Salt River; on part of the pediment; and then to **STOP 14**, Phon D. Sutton Recreation Area.

STOP 14. PHON D. SUTTON RECREATION AREA. This picnic area is on a low terrace of the Salt River about 40 feet above the river (fig. 14). It is part of the Blue

Point Terrace. Note that the Blue Point Terrace, as well as the Mesa and Sawik Terraces, are increasingly higher above the modern floodplain as one goes upstream.

STOP 15. COON BLUFF. A remnant of Mesa Terrace overlies bedrock at an elevation of 1,480–1,550 feet at this locality. The surface is 160–180 feet above the modern river. A great many of the large boulders have been fractured in place with displacement of 2 to 6 inches. Such fracturing appears to be present only of clasts on the Mesa and Sawik Terraces. The fracturing and displacement is by caliche formation while in the caliche level. Subsequent erosion and carbonate solution has exposed fractured boulders and cobbles.

It can be here noted that many of the boulders, especially the quartzite boulders, have well-developed impact scars or percussion marks, the results of large boulders saltating along the river bottom under high velocity flows of the stream. Such marks are well developed on the boulders of the Mesa and Sawik Terraces but poorly developed or absent on the lower terraces, although large boulders are present in all terraces. This may suggest a stronger stream regimen during the time of deposition of the upper terrace gravels.

The rock types represented by the cobbles and boulders of the Mesa Terrace are typical both of the deposits of the terraces and those of the active floodplain of the lower Salt River Valley. Kokalis (1971) examined 5,900 samples and determined that 15% of the clasts were from the Precambrian basement complex of igneous rocks; 36% were of the volcanic rocks of Tertiary age; and 48% were sedimentary rocks of Precambrian age. The rock composition of two typical Salt River gravel samples are illustrated in Table 2. The two most common rock types in the terrace deposits are orthoquartzite and rhyolite (metarhyolite). The larger the boulder the more likely it is to be one or another of these two types of rock.

As mentioned earlier, while it is not possible to distinguish the terrace sediments and the alluvium of the active floodplain of the Salt River on the basis of lithologic characteristics, Salt River deposits may be easily distinguished from other unconsolidated sediments in the valley.

Coon Bluff is in part made up of the Tertiary Camels Head Formation (arkose conglomerate). The cobbles weathering out of this conglomerate give rise to a lag gravel on top of Coon Bluff that could be mistaken for a terrace deposit. Examination of the rock types in this lag gravel quickly

shows that the percentage of sedimentary rocks of Precambrian age is very low and the percentage of granitic rocks very high; the rock types present a distribution of an over-all composition (Table 2) much different from the Salt River sediments (Kokalis, 1971).

The gravel of the Mesa Terrace on top of Coon Bluff is heavily cemented with caliche and the cobbles are entirely surrounded by calcium carbonate. Qualitatively, as mentioned earlier, it is evident that the gravel of the upper terrace, the Sawik Terrace, is most firmly cemented and has the thickest development of caliche. Thicknesses of 30 feet of caliche cap rock occur in the deposits of the Sawik Terrace and are almost that thick in deposits of the Mesa Terrace. Caliche development in Blue Point Terrace gravel is moderate to poor, relatively speaking, and is very weak to absent in gravel of the Lehi Terrace.

From this stop it is possible to look downstream at the north end of the Granite Reef Diversion Dam and see a continuation of the Mesa Terrace level.

At this stop gravels are lying 50 or 60 feet above the Mesa Terrace surface on areas of bedrock which are thought to be remnants of the higher Sawik Terrace (fig. 14).

Proceed from **STOP 15** to **STOP 16** on the Bush Highway across the lower edge of the pediment (fig. 14). The well-developed pediment extending north from the Utery Mountains to the Salt River in this area is termed the Bush Pediment (Péwé, 1971) from the new and old Bush Highways which traverse the pediment from north to south and east to west. The pediment today is, for the most part, graded to the Blue Point Terrace, although it is now being cut below this level in an attempt to be graded to the modern Salt River floodplain.

STOP 16. MESA TERRACE REMNANT (Stewart Mountain Quadrangle, 1964; fig. 16). A bedrock remnant about 200 feet above the Salt River is capped with weathered, caliche-cemented gravel which is part of the Mesa Terrace. Characteristics of the gravel here are similar to those described on Coon Bluff. A higher level gravel which is part of the Sawik Terrace lies 40 or 50 feet above this surface on bedrock. On the map (fig. 16) and the aerial photograph (fig. 17) it can be seen that there are several bedrock knobs extending 2 or 3 miles upstream, to the east, on the south side of the Salt River. The knobs bear remnants of the upper two terrace gravel deposits. This fact apparently was first pointed out by Tilford (1966, p. 19).

Looking south from this remnant up the Bush Pediment one can realize that at one time the Bush Pediment was graded to the Sawik Terrace level and

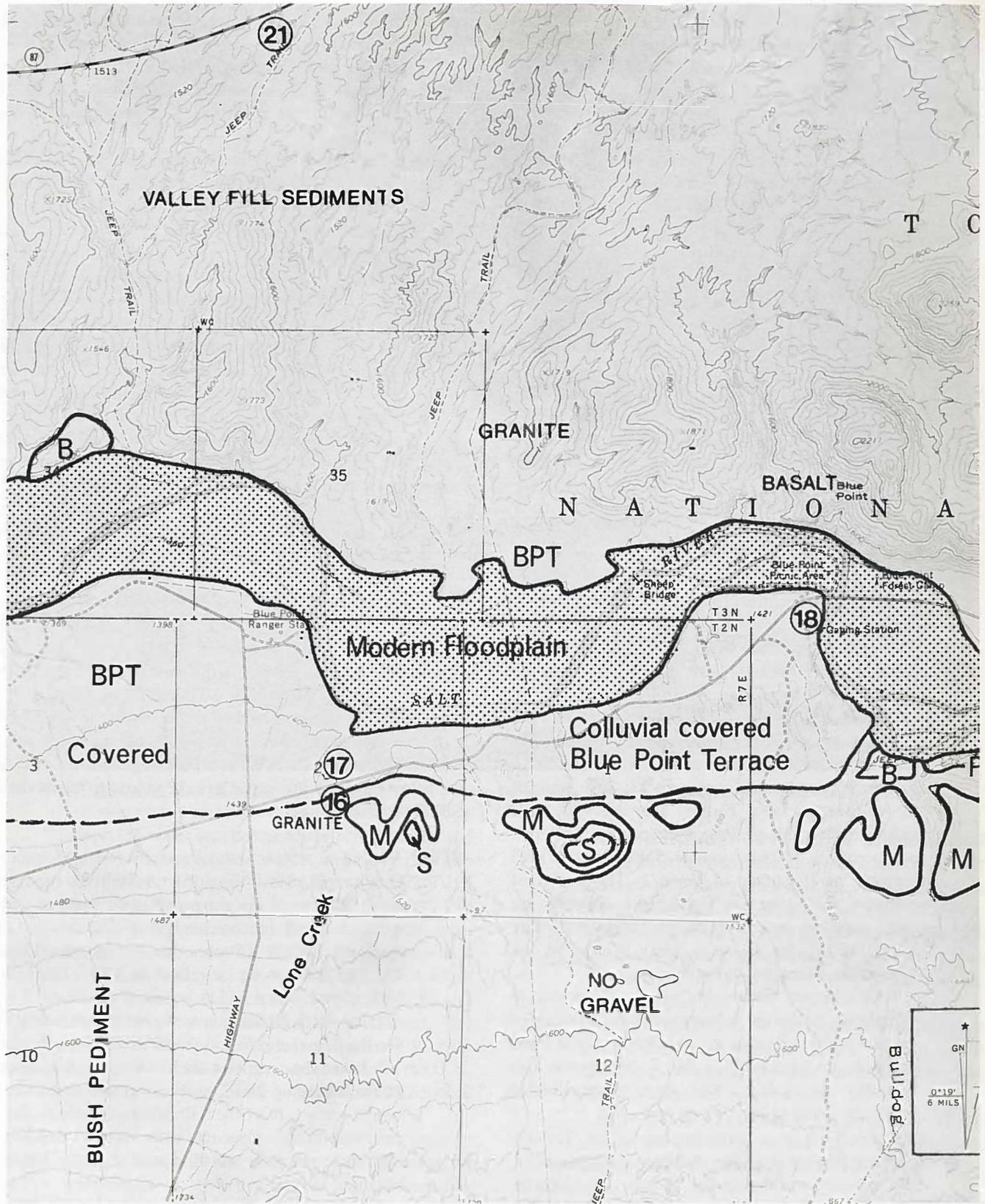


Figure 16. Field trip log map showing locations of STOPS 16-21.

FIGURE 16

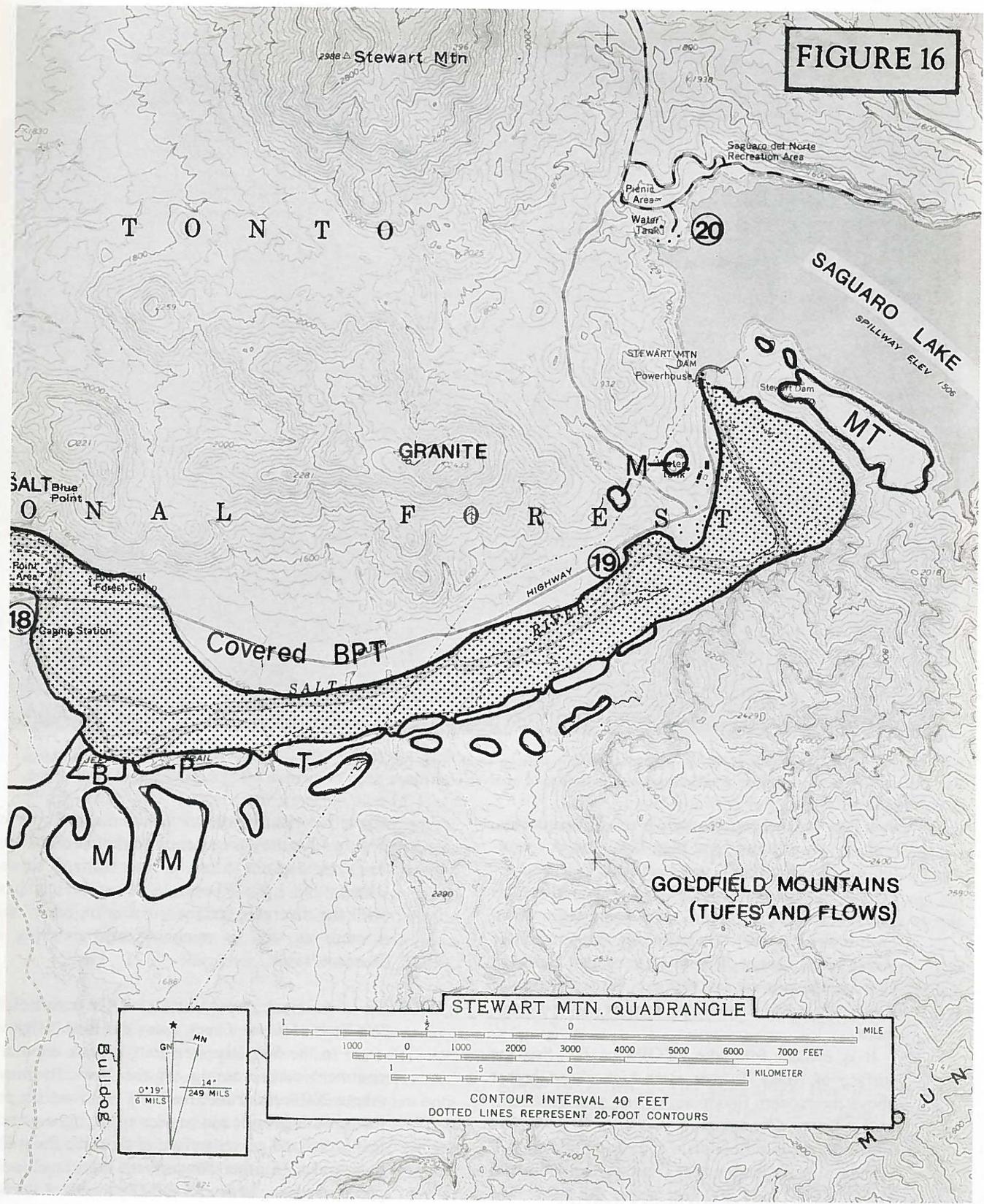




Figure 17. Aerial view of the lower Salt River Valley looking south from Lone Creek to Blue Point. Remnants of Sawik and Mesa Terraces on bedrock knobs in middle ground on southside of river (see figure 16). (Photograph No. PK 21,325 by Troy L. Péwé, June 11, 1977.)

then later to the Mesa Terrace level. Subsequently, with the lowering of local base level (the downcutting of the Salt River) the pediment has been regraded from the Mesa Terrace level to the Blue Point Terrace level, and is now being worn down even lower (fig. 17). Undoubtedly, the removal of such a large amount of granite has taken a considerable amount of time and supports the suggestion of considerable antiquity for the ages of the upper terraces.

It is evident from the STOPS so far, that the surface of Mesa Terrace rises higher and higher above the modern floodplain as one goes upstream. In the Tempe Quadrangle it was only 10 or 20 feet above the modern floodplain and cut on alluvium; it became a strath terrace near Granite Reef Dam and at this STOP it is 200 feet above the river. The surface continues to rise to about 220 feet above the river at Saguaro Lake and rises to more than 300 feet

above the river upstream toward Lake Roosevelt. Figure 4 illustrates a generalized profile of the modern river and the Mesa Terrace surface between Tempe and Lake Roosevelt. It can be compared with the diverging terrace surfaces on other major streams as well as minor streams entering the Phoenix Basin.

STOP 17. LONE CREEK CROSS SECTION. An exposure on the left limit of Lone Creek from the Bush Highway north to the Salt River exhibits a thick deposit of pediment wash coming off the Bush Pediment. About 200 feet north of the Bush Highway the pediment wash deposit can be seen overlying a more or less horizontal gravel surface of the Blue Point Terrace gravel. Further downstream the gravel is exposed overlying bedrock on the left limit of the Salt River at the junction of the stream and the river. A climb to the top of the terrace surface across the



Figure 18. View upstream (east) of lower Salt River, NE Sec. 2, T. 2 N., R. 7 E. Scarp of Blue Point Terrace on right in middle ground near river; remnants of Mesa Terrace on bedrock knob on far right. Goldfield Mountains in background. (Photograph No. PK 14,203 by Troy L. Péwé, March, 1970.)

exposed gravel indicates that there is very little caliche in the coarse gravel. A view upstream (fig. 18) from this vantage point (the junction of Lone Creek and the Salt River) shows the scarp of the Blue Point Terrace on the south side of Salt River; one-half mile southeast are bedrock knobs capped with gravel patches of Mesa and Sawik ages (fig. 16). Far to the southeast lies the front of the Goldfield Mountains of volcanic flows and ejecta (Fodor, 1969; Sheridan, Stuckless, and Fodor, 1970).

Between **STOPS 17** and **18** the terrace is covered with a colluvial apron of grus (granitic weathering debris) coming from the south (fig. 17), an apron which has been dissected by downcutting streams as local base level has been lowered since Blue Point Terrace time. These streams have not only cut through the grus cover, but through the gravel and into the underlying bedrock which is exposed on the terrace scarp and also in the small drainageways traversing the terrace between **STOPS 17** and **18**.

STOP 18. BLUE POINT GAGING STATION. At the bridge over the Salt River at this locality, gravel poorly

cemented by caliche overlies bedrock. The Blue Point Terrace is here about 40 feet above the Salt River. South from the bridge can be seen a cross section of the terrace showing the grus cover which thickens to the south toward the Usery Mountains. The Blue Point picnic area receives its name from Blue Point, a large mass of basalt cropping out prominently on the north side of the river at this locality (fig. 16).

From **STOP 18** cross to the north side of the river. The highway from here to **STOP 19** is on the Blue Point Terrace which is completely covered by a sloping colluvial blanket of grus.

STOP 19. BEDROCK CLIFF OVER RIVER. Here the grus cover is thin or absent, and gravels of the Blue Point Terrace crop out over bedrock cliffs 40 to 50 feet high above the river.

Upstream from **STOP 19** a large alluvial fan (fig. 16) from a small stream to the north deflects the Salt River to the south to cut into rocks of the Goldfield Mountains. A guest ranch which lies immediately



Figure 19. Aerial view of Saguaro Lake and Stewart Mountain Dam, looking south. Long finger of land extending toward dam is capped with gravel of the Mesa Terrace and is 220 feet above the river. Goldfield Mountains in middle ground behind lake. (Photograph No. PK 21,323 by Troy L. Pêwé, June 11, 1977.)

upstream from this fan in the right limit of the river is on a Blue Point Terrace surface.

STOP 20. SAGUARO LAKE RECREATION FACILITY. From the restaurant an excellent view can be obtained to the north, south, and east. To the north one can see a colorful volcanic tuff layer from the Superstition Mountain area overlying the granite. To the south is Stewart Mountain Dam holding in Saguaro Lake. A long finger of land (figs. 16, 19) stretching from the Goldfield Mountains to the dam has a relatively flat-topped area which is the surface of the Mesa Terrace at an elevation of 1,620 feet or about 220 feet above river level. When the lake is drained a well-developed surface of the Blue Point Terrace present under most of the lake adjacent to this facility is visible.

Stewart Mountain Dam is one of the six dams which regulates water flow for the Salt River Project. The first dam constructed by money lent by the Federal Government

(Salt River Valley Water Users' Assoc.) was the Theodore Roosevelt Dam (fig. 20). Construction of the dam began in 1905. The construction of the dam itself was a technique called cyclopien rubble. The faces of the dam were constructed from hand-hewn stones to give a finished appearance. In between the faces, the dam was filled with large boulders and mortar. Actual construction of the dam required cutting of about 350,000 cubic yards of stone from the side of the mountain.

Roosevelt Dam, the world's highest masonry dam, is 184 feet thick at the base, 16 feet wide at the crest and rises 280 feet. Its reservoir, Roosevelt Lake, has a capacity today of 1.28 million acre-feet. When filled, Roosevelt Lake has a shoreline of more than 88 miles. The dam also has a generating capacity of 36,000 kw.

To aid in water supply for irrigation as well as for power supply, additional dams were built on the lower Salt River. The first of these dams, Mormon Flat, was built between 1923 and 1925 and is located downstream from Roosevelt Dam. It has a water storage capacity of 50,852 acre-feet and

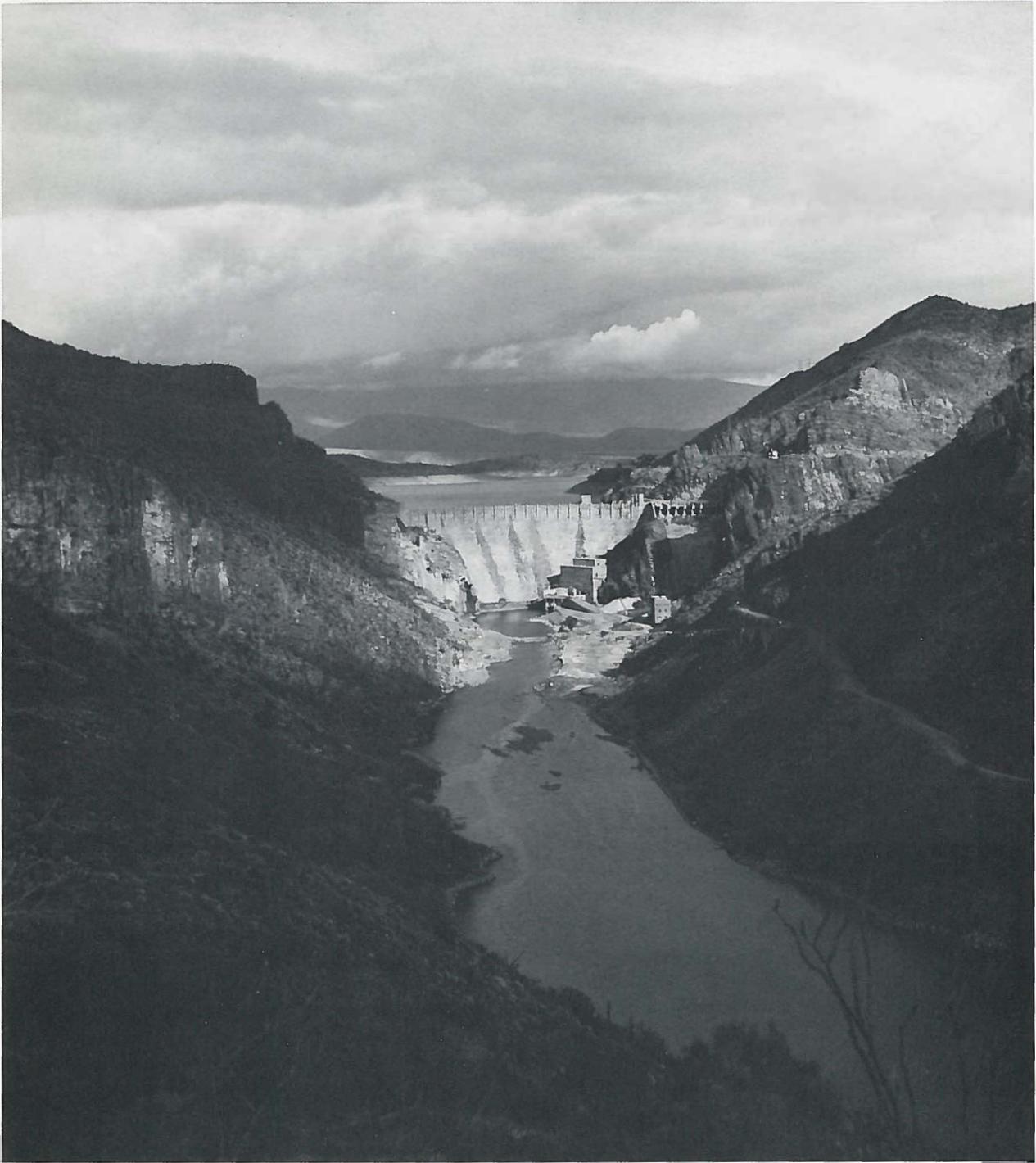


Figure 20. Theodore Roosevelt Dam and Roosevelt Lake on the lower Salt River, Arizona. Italian stone masons constructed the dam from local limestone. (Photograph through the courtesy of the Salt River Project.)

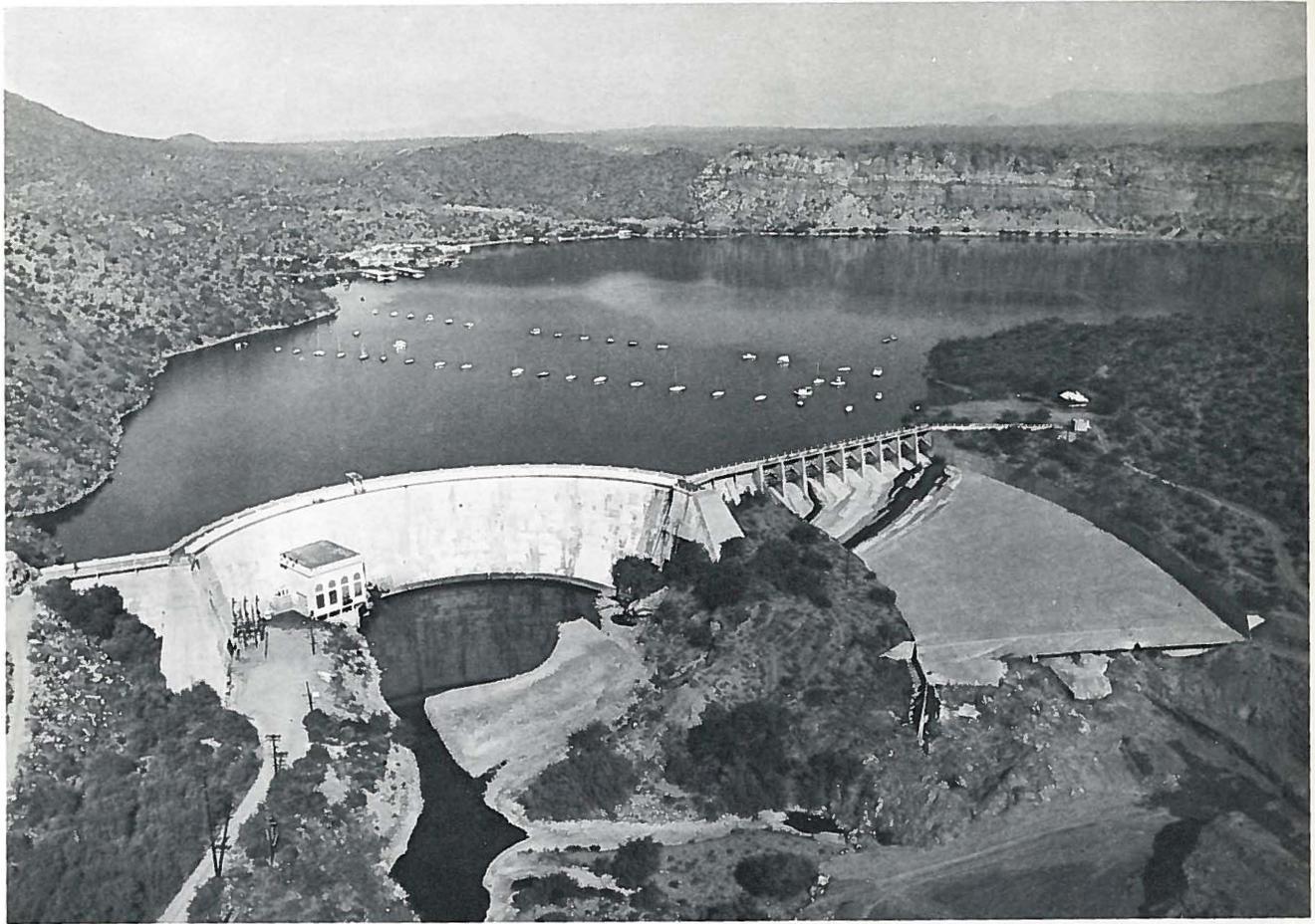


Figure 21. Stewart Mountain Dam and Saguaro Lake on the lower Salt River, Arizona. Volcanic tuff forms the light-colored cliff on the far side of the lake. Fault gouge zone extending under spillway apron is at far lower right. (Photograph through the courtesy of the Salt River Project.)

today has a generating capability of 60,000 kw.

In 1924, shortly after the Project began building Mormon Flat Dam, construction started on a third dam. This dam was named Horse Mesa Dam because it was built near a mesa allegedly used for hiding stolen horses. This dam is half way between Roosevelt and Mormon Flat Dams and forms Apache Lake with a storage capacity of 245,138 acre-feet. The generating capacity is 129,000 kw.

Stewart Mountain Dam was built during 1928–30 to provide more water storage facilities and more sophisticated regulation of water use in the generation of power in the three dams already constructed. The dam, which cost \$2.8 million, was named for its proximity to Stewart Mountain, landmark of the old Stewart Ranch. The reservoir created by this dam, Saguaro Lake, has a capacity of 69,765 acre-feet and the generating capacity is 10,500 kw.*

When Stewart Mountain Dam was constructed, investigations revealed that the depth to bedrock below present

*Nongeologic information on the dams and reservoirs has been provided by the Salt River Project.

stream-bed elevation at the site was 91 feet (Tilford, 1966, page 19). Stewart Mountain Dam has been an interesting structure for study by both engineers and geologists because as early as 1937 it was noted that separation of the arch section of the dam from the power house was taking place (fig. 21). The dam is sometimes referred to as "the walking dam." In 1939, survey measurements to detect the rate and direction of movement of the dam were initiated. General upstream deflection of the crest of the arch section of the dam was observed for some 10 years to occur at the rate of approximately $\frac{1}{2}$ inch per year. After 1950, the rate of upstream deflection declined to approximately $\frac{1}{8}$ of an inch per year and has remained relatively constant since (Tilford, 1966).

As a result of inspections of the structure in 1942 and 1943 by the Bureau of Reclamation, it was recognized that the structural deterioration of the concrete in the dam was due to expansion caused by an alkali-aggregate reaction. Many concrete study cores were taken from various parts of the dam and considerable concrete was added to parts of the

dam. It has been reported (Tilford, 1966) that the spillway was built in 1936 using the same aggregate but no concrete reaction has taken place. Also, no reaction occurred in the concrete in the Horse Mesa Dam upstream which was constructed using similar aggregate.

In 1965 Tilford began a geologic study of the dam site and he states (1966) that no geologic report on the foundation was completed before or after construction, or even during the period between 1937 and 1944 when the constructional deterioration of the concrete was studied. There was general acceptance of the hypothesis that the expansion by the alkali-aggregate reaction was sufficient and of suitable nature to have caused all observed net movement and cracking of the dam.

Tilford (1966) indicates two faults under the dam foundation. One fault containing soft gouge exists under the spillway and the present writer has observed this particular phenomenon. The material is so soft that in the flood of December 1965 water over the spillway undercut the spillway causing part of the apron to collapse (see fig. 21). It is along the same fault gouge zone near the spillway edge that a worker was killed while excavating the gouge for grout backfill in November, 1976. Tilford postulates a fault directly under the dam arch because the rocks on each side of the dam are different and the fault probably controls the location of the gorge. Such a fault has not been seen in the bedrock to the north or south of the dam.

Tilford (1966) suggests that the net movement could be due solely to the alkali-aggregate reaction or in part, perhaps, to some movement along the fault zones under the dam. Subsequent to 1966 more detailed geologic work was done by the U.S. Bureau of Reclamation and no detrimental geologic conditions were reported.

Proceed north to granitic terrain and then onto the poorly consolidated terrestrial detrital material called "Tertiary Valley Fill." Junction with Beeline Highway (Highway 87); proceed south to **STOP 21**.

STOP 21. TERTIARY VALLEY FILL. Exposed in road cuts along the highway is poorly consolidated, poorly rounded material of fairly local origin; however, when a weathered lag gravel appears on the interfluvies, it can be confused with terrace gravel of the Salt or Verde Rivers. Kokalis (1971), as well as Pope (1974), have demonstrated that there is a distinct difference in rock types between the Salt River gravel, Verde River gravel, and the Tertiary Valley Fill deposits (Table 2).

The Tertiary Valley Fill material is a term given to a widespread deposit of fine to coarse material shed from the fault block mountains and collected in the intervening basins. It includes a variety of fine to coarse-grained alluvial sediments with interbedded siltstones and sandstones. In this particular area, and

into the Verde River valley, the material consists of a variety of bedded rock types ranging from nearly pure orthoquartzites to subgraywackes. Various granitic rock types serve as the main detrital source followed by volcanic and metamorphic detritals (Table 2). The Valley Fill deposits are typical of the inter-basinal sediments in an arid to semi-arid region and are probably representative of late to middle Tertiary deposits. All terrace gravel of the Salt and Verde Rivers are younger than the Valley Fill deposits.

STOP 22. HIGH TERRACE REMNANT ALONG VERDE RIVER. Adjacent to the Beeline highway, both to the north and south on the east side of the Verde River, are well-preserved remnants of the high Mesa Terrace (fig. 22). The rounded river gravel of the Verde river overlies Tertiary Valley Fill deposits. The 20 or 30 feet of thickness of river gravel is exceedingly well cemented by caliche and forms a resistant caprock. The upper surface of the terrace has well developed laminar caliche several inches thick. The surface of the terrace lies approximately 150–160 feet above the Verde River and additional terrace remnants occur on the east side of the Verde river downstream to near the junction of the Salt River (fig. 22). In addition, remnants of the Mesa Terrace occur on both sides of the river to the north as far as Bartlett Dam. These terraces are the continuation of the Mesa Terrace surface of the Salt River.

SUMMARY OF GENERAL GEOLOGY OF LOWER VERDE VALLEY

A view upstream from **STOP 22** (fig. 23) illustrates the highlights of the late Cenozoic history of the lower Verde Valley. As part of an overall study of both age and origin of alluvial terraces, pediments, and a general understanding of erosional and depositional features, as well as Quaternary tectonic development in the Phoenix area (Péwé, 1966, 1970; Kokalis, 1970, 1971; Pope and Péwé, 1973; Pope, 1974; Shank, 1973; Shank and Péwé, 1973; Péwé and Shank, 1973; and Christenson, Welsch and Péwé, 1975), Pope and Péwé undertook a study of the general geology of the lower Verde Valley from Bartlett Dam to its confluence with Salt River with the main objective of studying the distribution, characteristics, and origin of the terrace remnants. As with the terrace study along the lower Salt River, many 200-pound samples were taken for detailed mechanical analyses and geologic studies.

Prior to the entrance of the Verde River into the present lower Verde Valley, the deposits were mostly local and from the adjacent metamorphic and volcanic mountains (Table 2). In addition to this coarse valley fill there are thick silt and clay deposits.

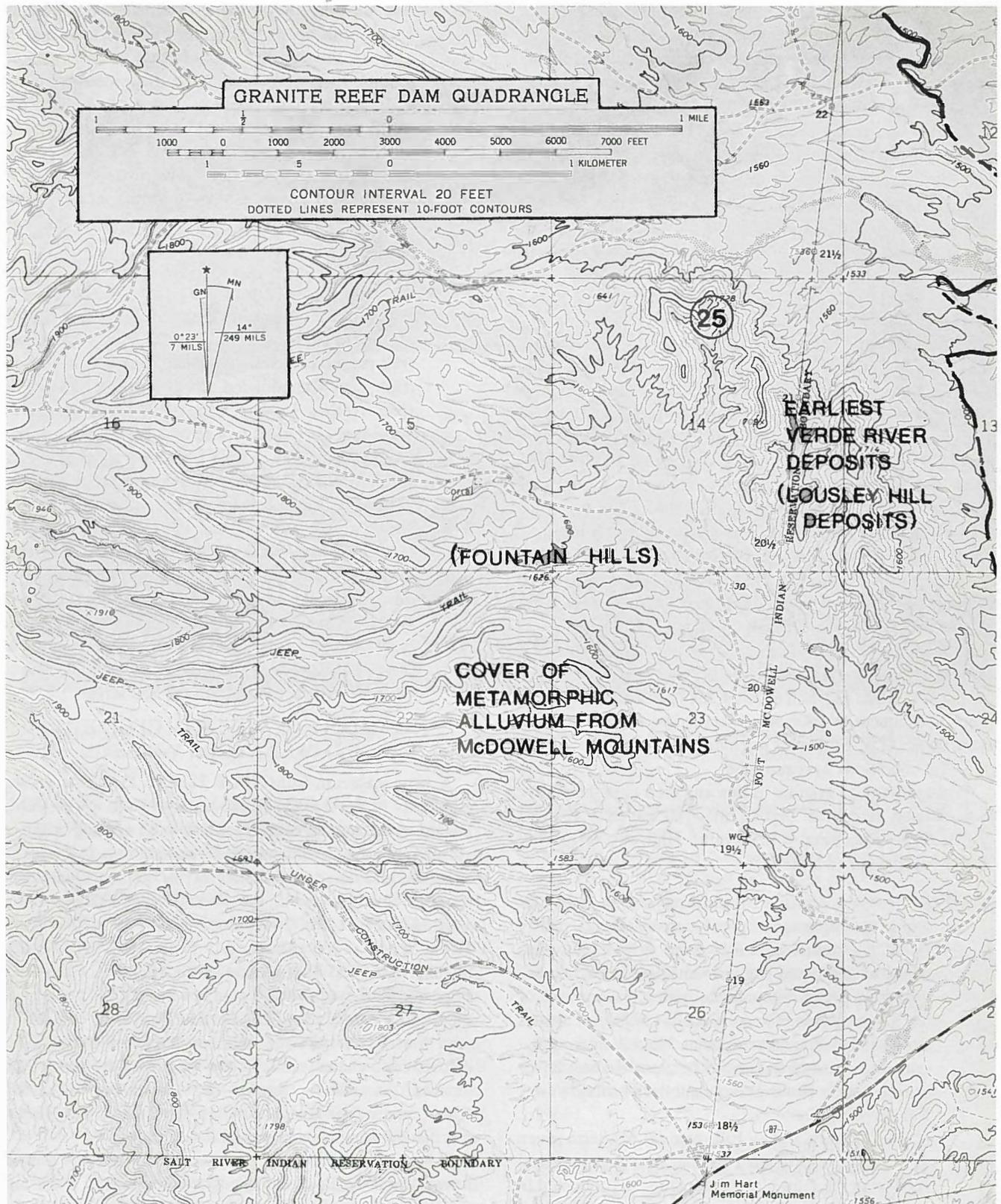


Figure 22. Field trip log map showing locations of STOPS 22-26.



Figure 23. Aerial view of lower Verde River Valley looking west-northwest. A—McDowell Mountains; B—“finger”-like projections of metamorphic colluvium; C—Lousley Hill deposits; D—McDowell Terraces; E—Blue Point Terrace; F—modern floodplain of Verde River; G—Mesa Terrace; and H—valley fill deposits. White cleared area is Fountain Hill Development (see fig. 22). (Photograph No. PK 15,836 by Troy L. Péwé, December 30, 1972.)

From earlier investigations in the surrounding regions, several observations can be made which are perhaps related to the geologic history of the lower Verde River Valley area. McKee and McKee (1972), Melton (1960) and Merrill (1974) suggest that central Arizona stood higher than the present Grand Canyon region and that the drainage was to the north until late Tertiary time. This highland provided gravels of the Precambrian, early Paleozoic, and middle Tertiary volcanic rocks to the northern region. More than 10 million years ago, either uplift began in the north or basin collapse began to the south, apparently causing drainage reversal to the south. This reversal was suggested to occur no later than 5 million years ago, subsequently forming the ancestral drainage of the Verde River (McKee and McKee, 1972). The earliest known sediments within the lower Verde Valley that might represent this initial reversal are the Lousley Hill Deposits. These deposits are of rounded river gravel containing rock types derived from outside of the basin, such as limestones and other rocks not present in the surrounding hills of the lower Verde Valley. Therefore, one can suggest that the drainage forming the Verde River was initiated no earlier than 10 million years ago and no later than 5 million years ago. Perhaps the river did not directly enter the present valley but may have

flowed into the Payson Basin (Pederson and Royse, 1970). Later diversion occurred causing the ancestral Verde River to flow into the present valley. The various gravels are highly calichified, greatly weathered and split by caliche formation, and occur above any of the lower terraces in the valley. Although no direct connection has been made, there is a possibility that these may represent gravel of Sawik age on the lower Salt River.

Following the formation of the Lousley Hill Deposits, the lower Verde River area was rejuvenated at least four separate times. The stages of rejuvenation are readily illustrated by three alluvial terraces and the modern Verde River floodplain (figs. 23, 24).

The Mesa Terrace remnants are well displayed and both the Lousley Hill Deposits and the Mesa Terrace gravels are well calichified. However, the gravels of all of the terraces and the Lousley Hill Deposits have similar rock types, and are distributed in the same size distribution. All are classed as a sandy gravel (fig. 25).

The two lower terraces, the McDowell and the Blue Point, have longitudinal profiles which are essentially parallel to the modern stream profile. However, the Mesa Terrace rises more than 93 m above the modern floodplain in

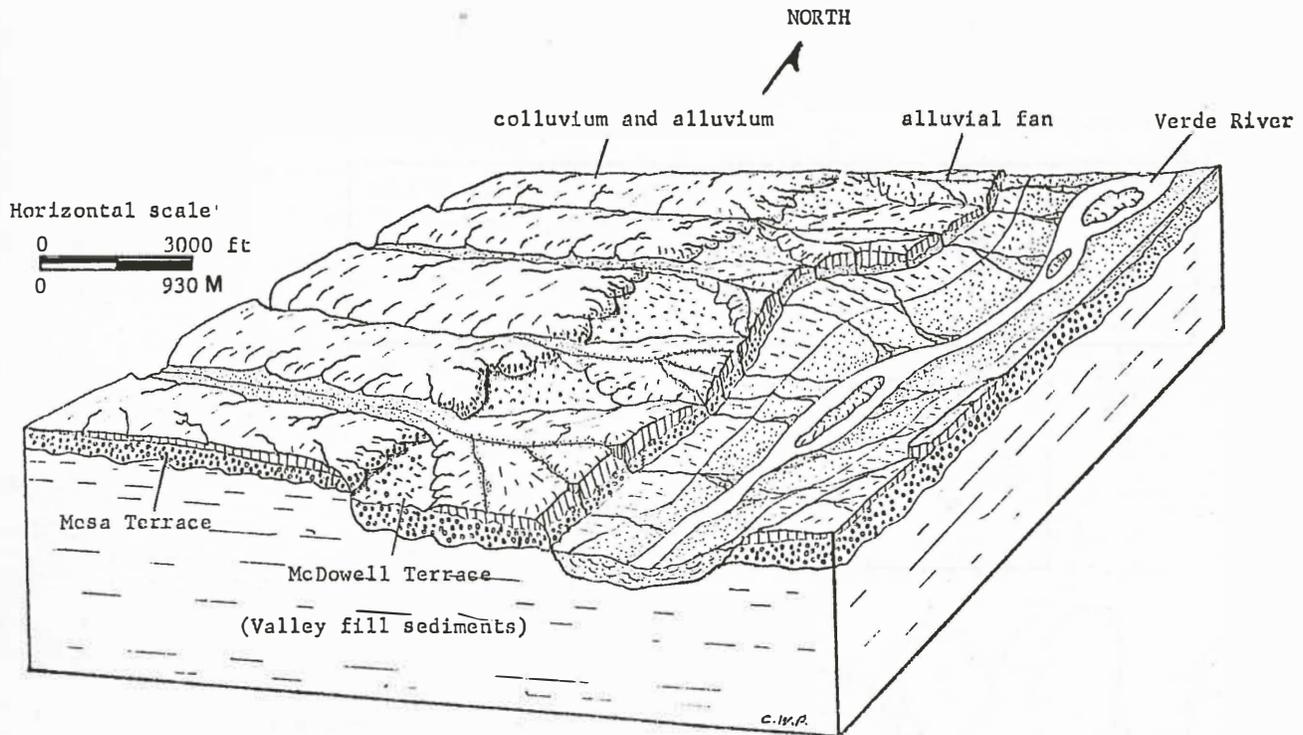


Figure 24. Block diagram showing alluvial and colluvial deposits shed from the McDowell Mountains overlying terrace deposits on the west side of the lower Verde River. Diagram portrays conditions during Blue Point time. (From Pope, 1974, fig. 17.)

the northern part of the study area from only 43 m above the modern floodplain in the south (fig. 4).

Work by Pope and Péwé illustrate that the ancient and modern Verde River alluvia are essentially the same. Throughout the development of the Verde River there has been no significant change in the rock types constituting the alluvium. Basaltic rocks remain the most dominant rock type (19–56 percent) followed by granitic rock types (10–26 percent), purple orthoquartzite (12 percent), metamorphic rocks (15 percent), volcanic rocks (18 percent), and minor amounts of a variety of other rock types.

The ancestral Verde River may have had a slightly higher regimen however, because the clasts are slightly larger (frequently 3 feet in diameter).

STOP 23. BLUE POINT TERRACE. The Blue Point Terrace is well preserved and extensively covered with as much as 30 feet of metamorphic colluvium and alluvium. This cover is spread over the terrace down to the modern stream channel. The upper surface is moderately dissected with an occasional vertically exposed section. Such sections can be seen about 1 mile north of **STOP 23** along the highway as well as in the southern part of Section 12 (fig. 22). The amount of decay and splitting of cobbles is negligible compared with that in the other terraces.

The Blue Point terrace is best preserved on the west side of the Verde River (fig. 23).

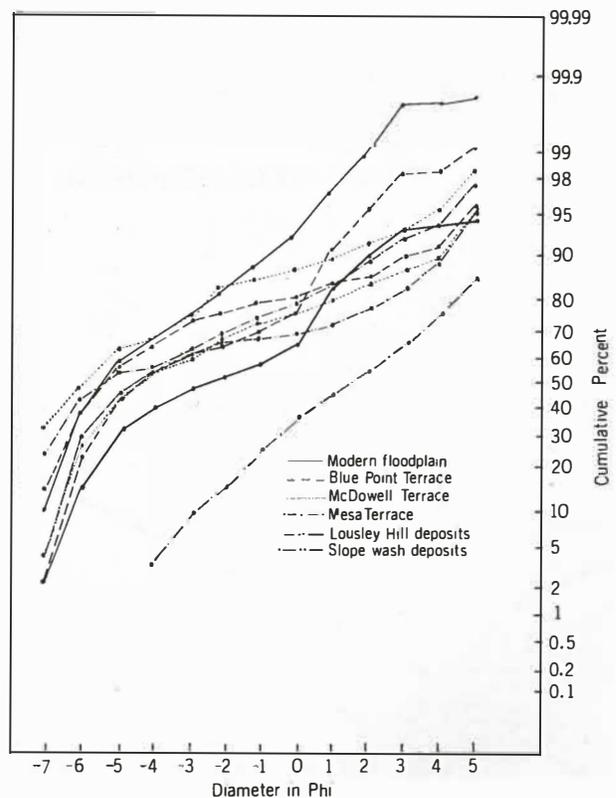


Figure 25. Cumulative-frequency distribution curves for analyses of sediments of modern floodplain and terraces of the lower Verde River Valley, Arizona. (After Pope, 1974.)

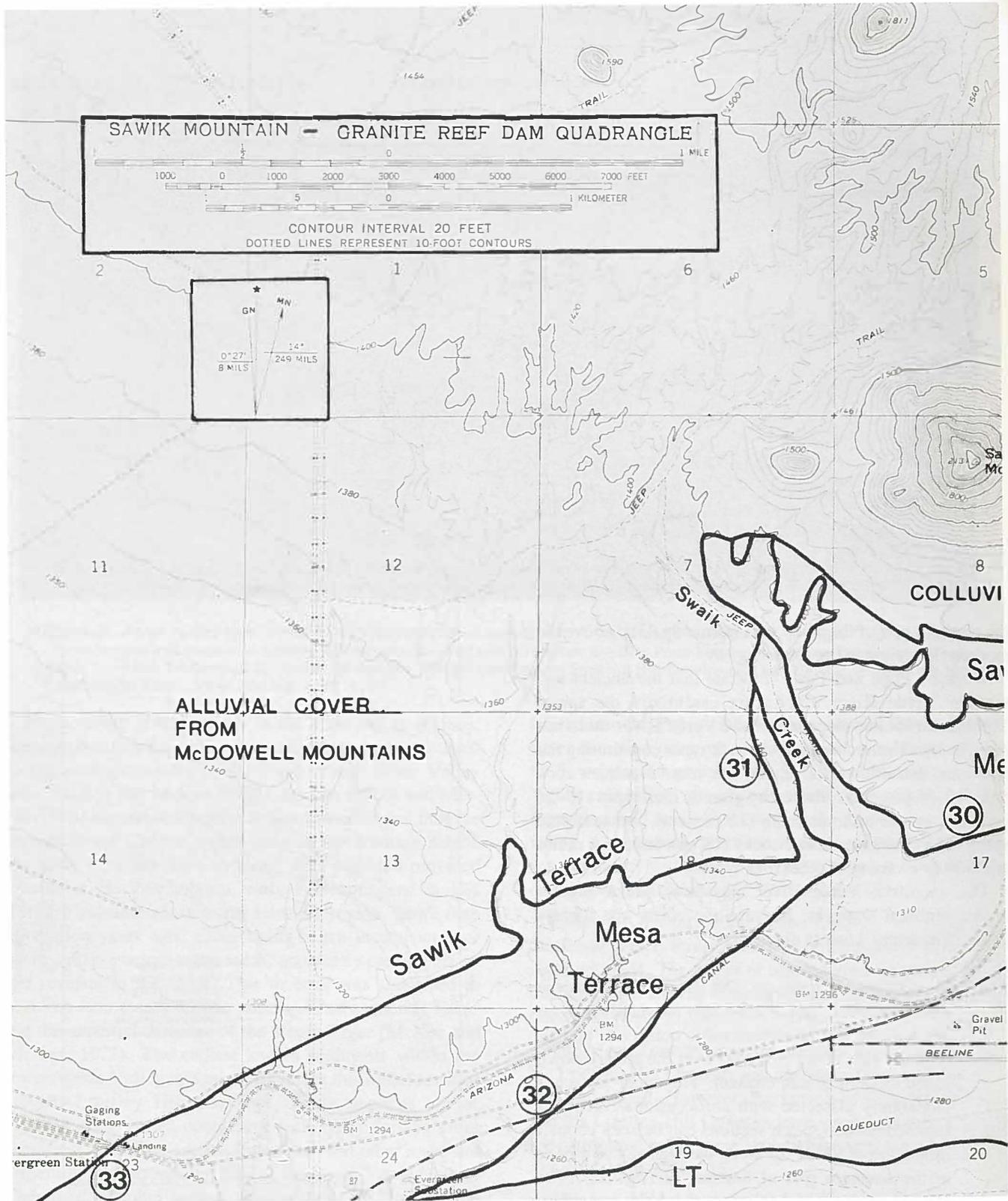
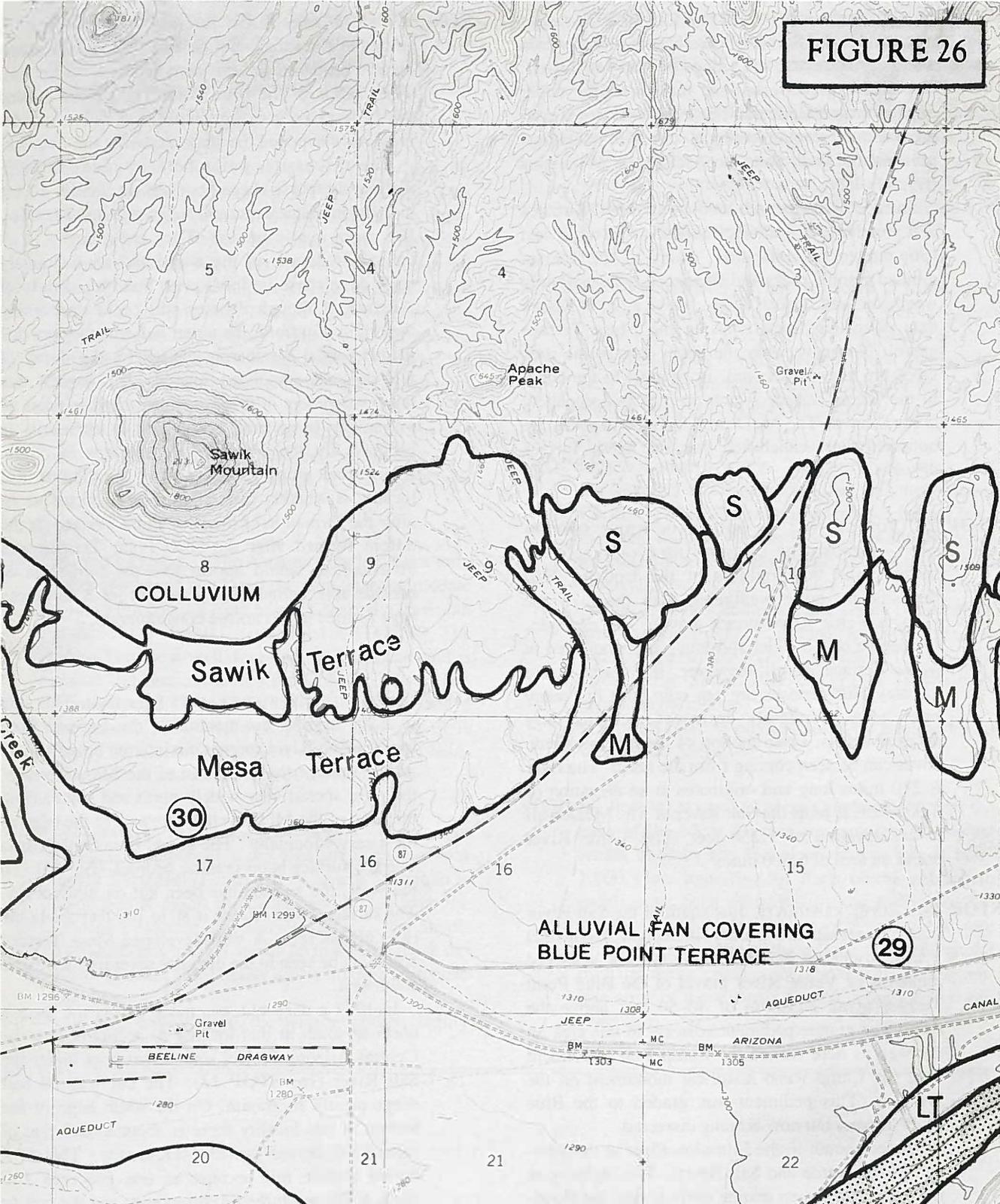


Figure 26. Field trip log map showing locations of STOPS 29—33.

FIGURE 26



STOP 24. MCDOWELL TERRACE. The McDowell Terrace is named after the Fort McDowell Indian Reservation and its predecessor, the village of Fort McDowell. The coarse gravel crops out mainly on the upper edge of the terrace scarp. The terrace surface is covered with a sloping colluvial cover of metamorphic debris shed from the McDowell Mountains (fig. 24).

Surface boulders and cobbles, mainly quartzites and rhyolites, are characteristically fractured and split due to calichification. Many of the coarse-grained granitic rocks and other rock types are badly weathered and broken down, but to a lesser degree than equivalent rock types in the Mesa Terrace gravel. Normally, only the upper part of the rock types are heavily decayed, in contrast to the clasts in the Mesa Terrace which are nearly completely broken down. The McDowell Terrace deposits are noticeably less calichified than the Mesa Terrace deposits.

STOP 25. TOP OF HILL IN FOUNTAIN HILLS SETTLEMENT—DEPOSIT OF LOUSLEY HILL GRAVEL. The cobbles and the boulders of the Lousley Hill deposits are more weathered than those of the younger Verde River terrace gravels. For example, the degree of "boulder splitting" is pronounced in Mesa Terrace gravel; however, the clasts in the Lousley Hill deposits are not only split but many have been completely destroyed, leaving only decayed debris. From the top of the hill the Verde River can be seen coming from the north. The river is 210 miles long and originates at an elevation of 6,000 feet. It joins the Salt River at Mt. McDowell at an elevation of 1,250 feet. The Verde River drains an area of 6,600 miles².

STOP 26. GRAVEL REMNANTS. Just south of the Salt River Indian Reservation boundary, in Section 30 (fig. 22) 1 mile south of Beeline Highway, are scattered remnants of Verde River gravel of the Blue Point Terrace at an elevation of 40–50 feet above the river. The granite pediment adjacent to this area on the west is here named the Camp Reno Pediment after the Camp Reno historical monument on the highway. This pediment was graded to the Blue Point Terrace but now is being dissected.

Proceed south to the Filtration Plant at the junction of the Verde and Salt Rivers. The highway at the base of the steep granite cliffs is near the floodplain level. The "granite" is really granodiorite and has been dated as $1,395 \pm 45$ million years (Stuckless and Naeser, 1972).

STOP 27. FILTRATION PLANT. Across the road (fig. 15) from the filtration plant, a small knob of Camels Head Formation (arkose conglomerate) crops out. The gravels of the Blue Point Terrace lap around this bedrock knob except on the river side where the river has steepened the slope exposing the bedrock.

The discussion point here involves taffoni. Taffoni are purse-shaped pockets or cavities 10 cm to 20 m in diameter weathered in granite or granite-like rocks in arid regions. They are common in all the major deserts of the world and are extremely well developed in the lower Sonoran desert of Arizona. Although debates still occur concerning the origin of taffoni, the writer believes they are due to differential weathering caused by the decay of feldspars and associated minerals. It is thought that the development of these erosional cavities takes an extremely long time and work is currently in progress by the writer and associates to obtain information along this line. The question at this locality is whether the taffoni developed before or after the formation of the Blue Point Terrace. If the taffoni formed after the Blue Point Terrace was dissected, it would appear that the terrace is of considerable antiquity because taffoni 3 m across have formed in this arkose conglomerate.

STOP 28. MESA TERRACE AT GRANITE REEF DAM. This stop is at the edge of the mountains; downstream from here the Salt River spreads out into the broad valley. At the time of the formation of the Mesa Terrace, the river spread very widely north and south, from the edge of the McDowell Mountains to the edge of the Utery Mountains. The gravel here on the Mesa Terrace surface is on granitic bedrock (fig. 15). To the west, the surface has been cut on alluvial fill. The surface of the terrace is 80 to 100 feet above the river at this spot. A well-developed Mesa Terrace scarp can be seen in the distance several miles to the southwest.

In 1977 a deep cut was made across the terrace north to south at this locality to accommodate the Central Arizona Project siphon that goes under the Salt River (see **STOP 13**). The cut was 50 feet deep, mostly in granite. On the south edge of the terrace at this locality there is about 8 or 9 feet of calichified terrace gravel over granite. This is a buried granite hill because as one proceeds 100 yards to the north the hill disappears and the cut, to depths of at least 40 feet, is entirely in Mesa Terrace gravel. The cut exposed about 3 or 4 feet of a reddish soil, 11 feet of highly calichified gravel, and

beneath was typical coarse Salt River gravel with crossbedded sands and gravel with clasts up to 2 feet in diameter.

From here proceed to the west over a large, gently sloping alluvial fan of silt.

STOP 29. ALLUVIAL FAN OVER BLUE POINT TERRACE (Sawik Mountain Quadrangle, 1964; fig. 26). This locality is in the center of a large alluvial fan about 10 miles square which emanates from a dissected pediment to the north and covers the widespread Blue Point Terrace here with silt and colluvium from 1 to 30 feet thick. Toward the distal end of the fan, remnants of the Blue Point gravel surface are exposed. The size of this fan indicates that a long period of time must have elapsed since the cutting of the Blue Point Terrace.

The Beeline Dragway (fig. 26) is built on this alluvial fan. To the north can be seen the scarps of the Sawik and Mesa Terraces. Proceed west on Beeline Highway.

STOP 30. MESA TERRACE. The Arizona Canal makes a very sharp southward bend near this stop to accommodate a small fan coming from Sawik Creek; the small fan is part of the overall fan described at **STOP 29**. The Mesa Terrace is well developed at this locale and is about 100 feet above the modern floodplain. The terrace is entirely cut in alluvium and stands above the alluvial fan described earlier. The gravel is highly calichified and a great number of split boulders are exposed on the edge of the terrace.

STOP 31. SAWIK TERRACE. The Sawik Terrace is excellently displayed in this area and is named from Sawik Mountain (Péwé, 1971). Sawik Mountain is composed of basalt and dacite, and rubble from the mountain overrides the terrace surface. The Sawik Terrace at this locality stands 20 to 40 feet above the Mesa Terrace, and extends westward into Scottsdale (fig. 26).

A fine exposure of the terrace gravel, highly

cemented by caliche, occurs in the middle reaches of Sawik Creek, a few hundred yards to one-half mile up from **STOP 31**. The cemented gravel forms vertical walls 20 to 40 feet high. To the north, colluvium from the McDowell Mountains have spread over the terrace. Where fine colluvium and alluvium have spread over the terrace immediately to the west, agriculture has been successful; but where the terrace gravel is at the surface, or close to the surface, the crops do not do well.

STOP 32. MESA TERRACE SCARP. Adjacent to the Beeline Highway (fig. 26) the scarp of the Mesa Terrace is dissected by transverse streams and caliche-cemented gravel is well exposed. Here also may be seen the river-truncated edge of the alluvial fan of silt that covers the Blue Point Terrace.

STOP 33. EVERGREEN STATION. The Evergreen station is at the junction of Camelback Road and the Arizona Canal (fig. 26). There is an overflow channel from the canal south to the Salt River. This channel gives an excellent cross section of the amount and type of colluvium overlying the Mesa Terrace. The colluvium is poorly cemented and about 10 feet thick near Evergreen Station; it thins rapidly to the south and is absent at the scarp of the Mesa Terrace. The underlying Mesa Terrace gravel is strongly cemented by caliche.

From **STOP 33** proceed south on Beeline Highway toward Mesa.

STOP 34. HOHOKAM CANAL (Mesa Quadrangle). Near the edge of the Mesa Terrace are remnants of ancient canals built by the Hohokam Indians about 800–1,000 years ago (fig. 9). Parts of the old Indian canals have been destroyed by the shifting of the Salt River in the last 1,000 years. The terraces were evidently hacked out of the caliche-cemented gravel by hand using crude stone implements. An extensive array of these canals existed in the valley many years ago.

Interleaf. Apache Lake and volcanic rocks of the Superstition volcanic field. High-level strath terrace gravels of the Salt River in foreground. 40 km east of Phoenix, Arizona. (Photograph No. 3018 by Troy L. Péwé, January 6, 1970.)

