

ART. XIV.—*Origin of Rock Tanks and Charcos*; by KIRK
BRYAN.¹

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INTRODUCTION.

In arid regions small water supplies are very important. That a few gallons of water can be obtained at a certain place for a period as short as two or three days may make possible a journey which otherwise could not be undertaken. In the Papago Country, a great area in southwestern Arizona lying along the Mexican border between Nozales and Yuma, west of Santa Cruz River and south of Gila, such small water supplies are, in many localities, the only dependence of travelers. In a reconnaissance made in 1917 for the purpose of preparing a guide to desert watering places² considerable attention was given to rock tanks or "tinajas," and to charcos, or "mud holes." Both types of watering places are pools of water which remain in small depressions or basins after rains. The origin of these basins presents interesting problems in minor geology. The distribution, also, of both charcos and rock tanks is controlled by the physiography of the region. For these reasons it seems advisable to give an account of the origin of these watering places in advance of the publication of the final report.³

SUMMARY.

Rock tanks are located both in and away from stream channels. The latter variety are basins formed by the

¹ Published by permission of the Director of the U. S. Geological Survey.

² Bryan, Kirk: Guide to desert watering places in the Papago Country, Ariz., U. S. Geol. Survey, Water-Supply Paper 490-D, in preparation.

³ Bryan, Kirk: The Papago Country, Ariz., U. S. Geol. Survey Water Supply Paper in preparation.

irregular erosion of rocks, and are usually small. They are mere pockets in the rocks which hold water for a few hours or days after a rain. The rock tanks formed in stream channels are mostly plunge pools and potholes associated with falls. In the Papago Country they seldom exceed 10 feet in diameter and 5 feet deep. Sand tanks are similar basins which are filled with coarse sand by the tail end of floods. Water is held in the interstices of the sand. Since rock tanks are generally associated with falls, the distribution of these is of prime importance. In the Papago Country falls occur in streams mainly because of: (1) renewed uplift along faults parallel to the mountain ranges, but at right angles to most of the mountain canyons; (2) dissection of rock plains or pediments at the foot of mountains by headward cutting of small rock gorges. Falls produced by either cause, and therefore most rock tanks, occur at or near the borders of the mountains.

Charcos are depressions in adobe flats over which floods spread widely. The important charcos are formed by the swiftest thread of the current, which excavates a channel deeper in some places than in others. After floods, pools of water remain, the larger of which are from 15 to 30 feet across, and from 20 to more than 1,000 feet long. The largest adobe flats, and therefore most of the charcos, lie at the centers of the intermontane valleys.

ROCK TANKS.

Definition.

A rock tank is a cavity or depression in rock which is filled periodically with rain or flood water. The Mexicans commonly, and many Americans, use the Spanish word "tinaja," a bowl or jar, in speaking of rock tanks. These cavities may occur either: (1) away from stream channels, or (2) in stream channels.

Rock tanks away from stream channels.

In mountains or hills small rock pockets are found which are due to the unequal weathering of rock surfaces. They vary in size from a few inches across and a half-inch deep to pans which are from 5 to 20 feet across and 6 to 8 inches deep. Such pockets hold water for longer or shorter periods following a rain and are of little value as water supplies. Experienced hunters and

travelers, however, know well how to take advantage of these tanks for the few hours or days after a rain when they hold water.

Rock tanks in stream channels.

The most important rock tanks are irregularities in the rocky beds of streams which hold pools of water after floods. These irregularities are due to the eddies of the current which tend to erode the stream bed un-

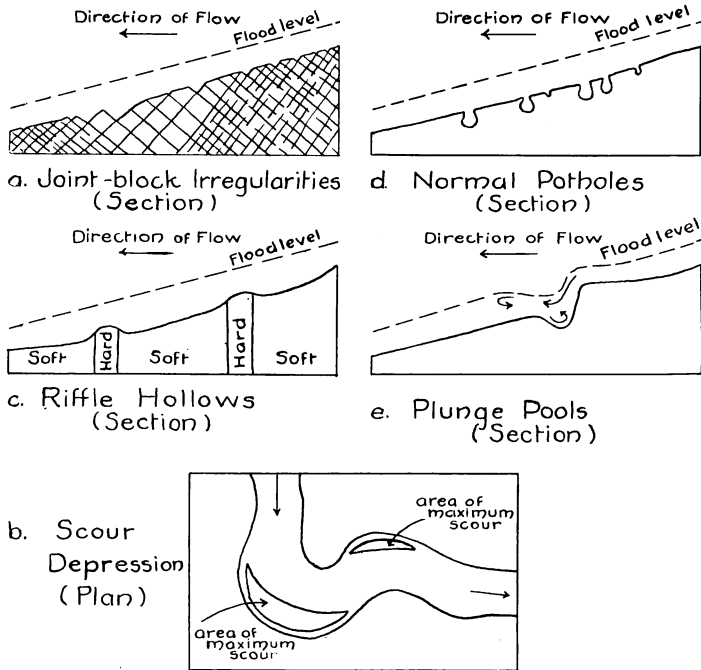


FIG. 1. Diagram showing five types of depressions in channels: a, joint-block irregularities; b, scour depressions; c, riffle hollows; d, normal potholes; e, plunge pools.

equally. The inequalities are probably no more common in ephemeral streams than in the permanent streams of humid countries. The beds of ephemeral streams are, however, exposed throughout their length during the greater part of the year, and undrained hollows or depressions are on this account easily found.

The common depressions are of five types: (1) joint-block irregularities; (2) scour depressions; (3) riffle hollows; (4) potholes; (5) plunge pools, fig. 1.

Most rocks are divided into blocks by sets of intersecting fractures or joints. The impact of the current and of sediment which it carries tends to break out blocks of rock in the stream channel. This process of plucking results in irregularities of the stream channel, as shown in fig. 1, a. When the joints are widely spaced the blocks are large, and the depressions are correspondingly large. Closely-spaced joints, however, produce a rough but comparatively even-floored channel. It is obvious that very wide spacing of joints will produce joint fragments too large to be easily removed and that there is for any stream an optimum spacing of the joints which will produce the maximum roughness of channel floor. In these rugosities water remains after a flood, but these pools are seldom of great importance as watering places. Commonly the process of joint-block plucking is combined with the processes detailed in the following paragraphs. A favorable spacing of joints is essential for the production of the larger rock tanks. The fractures must also be water-tight or nearly so in the bottom and downstream wall of the tank, else the water will drain rapidly. In some tanks it is evident that joints on the upper side of the cavity are open, and through them small amounts of water seep into the tank for short periods after floods.

Where the channel of a stream is curved the swiftest thread of the current is near the outside of the bend. The maximum erosive force of the current is exerted over a crescentic area in the bend, as is shown in fig. 1, b. These areas are likely to be scoured below the grade of the stream, producing the hollows here called scour depressions. In combination with joint-block plucking and the formation of potholes scour depressions are likely to form important tanks in hard rock. A scour depression in relatively soft hardpan appears to be the cause of one of the waterholes in the Vekol Valley, Maricopa County, fig. 2. This consists of a hollow at the point of an elbow in the sandy channel of the stream. A cavity in the underlying hardpan holds water after a flood. The pool of water is 6 feet by 4 feet, and 2 feet deep, located under the bank. Seepage from the sand of the stream channel and from the sandy clay of the banks maintains the water for a considerable time after adjacent charcos have dried up. The water does not last very long, for the level fell $1\frac{1}{2}$ feet between September 20 and September 22, 1917.

Riffle hollows occur when the bed of a stream is composed of alternate layers of hard and soft rock, as illustrated in figure 1, c. Erosion of the softer rock is carried below the grade established by the harder rocks which project in the stream bed and constitute obstacles to the stream flow. Such hollows are commonly from 3 to 12 inches deep, and vary in size according to the spacing of the harder portions of the rock in the stream bed. Riffle hollows make very shallow pools unless deepened by pothole action, or unless they grade into plunge pools.

A pothole is formed by the grinding or drilling of an original hollow in a stream bed by sand, pebbles, or boulders rotated by the current. The top of a pothole is nearly circular, and the diameter generally increases below, as shown in figure 1, c. The diameters of potholes

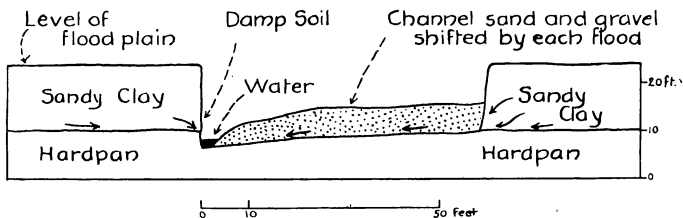


FIG. 2. Cross-section of the stream channel and waterhole in the Vekol Valley, Maricopa Co.

range from 3 inches to 10 feet or more, and the depths from 6 inches to 8 feet or more.⁴ Potholes develop in all streams actively eroding their channels in consolidated rock. They are, however, more likely to be found in gorges and below waterfalls. They are thus associated with and grade into plunge pools.

Plunge pools are formed by the impact of water and the sand and gravel which it carries, at the foot of waterfalls, fig. 1, d. A fall differs from the changes in grade of stream beds described in connection with riffle hollows in that it is usually sufficient to cause a flexure in the flood surface of the stream. Consequently, a very great velocity, accompanied by eddies and back currents, is present at the foot of the falls. The erosive effect at the foot of the falls increases with the discharge of the stream in flood, and the quantity and character of the

⁴Elston, E. D.: Potholes, their variety, origin and significance, *Sci. Monthly*, vol. 5, pp. 554-567, 1917, and vol. 6, pp. 37-51, 1918.

sediment carried. Streams of the size common in southwest Arizona are competent to erode pools about 10 to 20 feet in diameter and 3 to 10 feet deep. The shape of the pool depends on the character of the rock and the amount of modification due to joint-block plucking and pothole formation. Plunge pools are the largest type of channel irregularity, and consequently hold the largest pools of water. Most important rock tanks are of this class.

Physiographic relations of rock tanks.

From the foregoing discussion it is seen that the largest rock tanks are plunge pools at the foot of falls, and that even the other channel depressions are likely to be larger and more important in the parts of a stream near falls and rapids. The factors governing the occurrence of falls are thus of importance. Falls are found in southwest Arizona under at least three different circumstances: (1) where there are marked differences in the ability of adjacent parts of the rock to resist erosion; (2) where dissection of the mountain pediments on a new grade produces headwater falls; (3) where renewed uplift of fault-block mountains produces falls on a stream crossing the fault line.

Falls due to differing resistance of rocks to erosion.

Falls wholly due to an unusually resistant rock were found in only one locality in the Papago Country, and on a minor scale; but the locus of the falls due to other causes is often determined by a resistant bed, as in the case of the lower falls at Baker Tanks, southeast of Wellton, Yuma County. The variety of circumstances and the association of different types of tanks is well illustrated by this watering place. The tanks are in a streamway which leads in a northwesterly direction on the southwest flank of the Baker Peaks. Below the tanks the stream channel lies in a small canyon 150 feet wide, and about 25 to 30 feet deep. Above the tanks the channel is but 2 to 3 feet below the adjacent plains. Between these two parts of the stream is a stretch of falls and rapids about 1,000 feet long, which is shown in fig. 3. The rock in which these falls occurs is a coarse, arkosic conglomerate, which strikes N. 77° west, and dips 65° southwest. The bulk of the material is a granitic debris with pebbles one-eighth to one-half inch in

diameter. The rock is banded and cross-bedded, and contains many large boulders, singly or in groups and lenses. The boulders are from 3 inches to 3 feet in diameter, and are more or less rounded joint fragments of granite and gneiss. The bedding is massive, but there are numerous joints, some of which are slickensided.

Since deposition the conglomerate has been tilted and eroded so that its cut edges now form part of the pediment of the adjacent Baker Peaks. As in other parts of

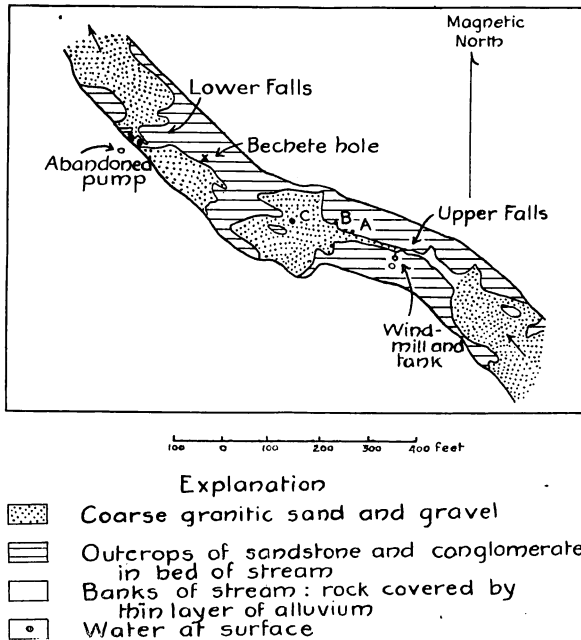


FIG. 3. Sketch map of Baker Tanks, Pina County.

southwestern Arizona, the pediment is dissected. Head-water cutting of a new canyon by the stream is the cause of the falls. As shown in fig. 3 there is a narrow gorge in the conglomerate beginning 150 feet southeast of the windmill. In this gorge are falls and rapids. From the windmill west for 150 feet is a narrow gorge from 10 to 20 feet wide with walls 10 feet high, the bed of which is a plunge pool. This is filled with coarse sand to a depth said to be more than 20 feet. The windmill pumps water from a pipe imbedded in the sand. At the lower end of

the little gorge at the points marked A and B are potholes about 3 feet in diameter developed along joint plains. Below the gorge is a flat about 500 feet long, which ends in a second fall. The flat has an irregular rock floor, the hollows in which are covered with sand. These hollows are due to irregular erosion. At the point marked C, there is a hollow somewhat deeper than the others, in which water may usually be found by digging away the sand.

The second or lower falls are about 6 feet high, and are caused by two beds of very coarse conglomerate which resist erosion somewhat better than the rest of the rock. The downstream bed of coarse conglomerate has been largely cut through; the upstream bed has been cut at only one point, near the abandoned pump. At

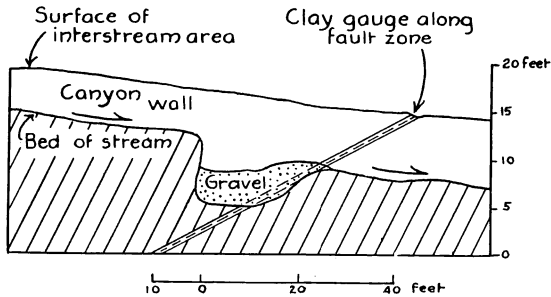


FIG. 4. Section along stream channel at Tabaseca Tank, Riverside County, Calif.

this place two very perfect potholes about 10 feet in diameter have been formed at one side of a narrow gully in the rock. Both of these hold about 4 feet of water, though the total depth of each is about 10 feet. Below the falls is a plunge pool covered with sand, in which water can be found by digging.

The influence of a notably soft rock in the production of falls is shown at Tabaseca Tank.⁵ This tank lies in an arroyo which drains the northern flank of the Chocolate Mountains in sec. 31, T. 7 S., R. 14 E., M. D. B. and M., Riverside County, California. The arroyo lies in a narrow gully about 10 feet below the level of the surrounding plain which is part of a slope cut on rock and

⁵ Brown, John S.: The Salton Sink Region, a geographic, geologic, and hydrologic reconnaissance, U. S. Geol. Survey Water-Supply Paper, in preparation.

extending along the front of the mountains. The plain is underlain by rhyolite which, in the vicinity of the tank, is broken along a fault plane that crosses the stream and dips upstream about 25 degrees (fig. 4). Shearing and decomposition by water percolating along the fault plane have changed the originally hard rhyolite to soft, claylike gouge about one foot thick. The gouge of the fault in its resistance to stream action is similar to any other soft rock layer. As the stream cuts down its bed the triangular block on the upstream side is constantly undermined by the ease with which the clay gouge is eroded. With the waterfall once initiated, the formation of a plunge pool is made easy by the presence of the soft layer, and the channel is excavated below grade. The pool is about 20 feet in diameter and filled with gravel

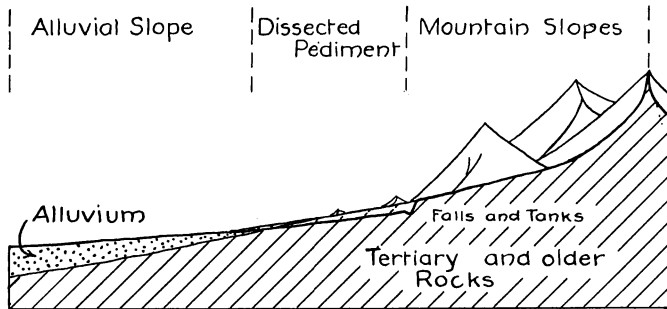


FIG. 5. Diagram showing the production of falls and tanks by erosion of mountain pediment on a new grade.

and boulders. Water is found in the gravel throughout the year unless campers have drawn too heavily on it.

Falls due to changes in stream grade.

Many of the mountains of southwest Arizona are surrounded by plains, sloping to the intermontane valleys. These plains or pediments⁶ are underlain by hard rocks similar to those of the mountains. The streams which once wandered more or less at will are in most of the pediments now entrenched in steep-walled gullies or little canyons which are deeper toward the mountains. The change in grade does not appear to be due to uplift

⁶Bryan, Kirk: Mountain pediments; a discussion of the erosion of desert ranges. Paper delivered Dec. 31, 1919, before the Geological Society of America, Boston, Mass., to be published under the title: *Geology and Physiography of the Papago Country, Ariz.*, by the U. S. Geol. Survey.

and seems to be due to a change in the supply of sediment and the volume of the streams. This change is perhaps climatic, and has certainly been general over large parts of southern Arizona and northern Mexico. The little canyons of the pediment increase in length by headward erosion. At the head of each little canyon is a falls or rapids which marks the separation between the old grade and the new. These relations are brought out in the diagram, fig. 5.

Since each stream which heads in the mountains suffers such a change in grade there are many falls. Though not every falls produces a plunge pool of sufficient size to make an effective watering place, the prevalence of falls due to the dissection of the mountain pediment is the principal reason for the large number of rock tanks in the desert region. The local conditions at each falls determine the size and effectiveness, as watering places, of the plunge pool and associated potholes. The variety of these circumstances can best be illustrated by an example.

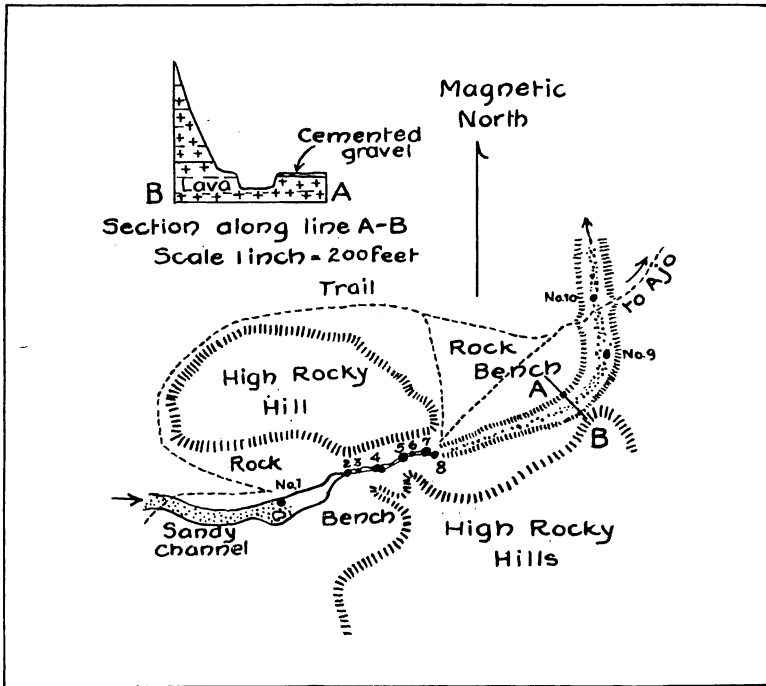
Black Tanks is a well-known watering place in the Crater Mountains, Pima County. The tanks consist of a series of plunge pools numbered from 1 to 8, in fig. 6, with two very temporary waterholes marked 9 and 10. The stream has a sandy bed about 2 feet below its flood plain in the open valley above and west of the tanks. Below the falls section with its 8 tanks, the stream flows in a steep-walled gully with banks from 10 to 20 feet high. The falls and rapids extend about 500 feet, with a total drop of about 50 feet between the upper and lower channels of the stream. Throughout this stretch the stream runs in a rocky gorge of variable width. The individual falls are determined by the resistance of the horizontal layers of lava which form the bedrock. The larger plunge pools are from 4 to 5 feet deep and 10 to 15 feet wide.

On either side of the channel is a rock bench which varies in width from 50 feet to several hundred feet. This bench slopes gently upward to the foot of the steep slopes of the hills, fig. 6, inset cross-section. On the north side of the stream below the tanks the bench is covered with from 2 to 3 feet of cemented gravel. The rock benches extend around the hills and are continuous with similar rock benches which connect with the mountain pediment. It is evident that Black Tanks are the head-

water falls of the new canyon working headward in an old valley with gentle slopes, which was formed at the same time as, and forms part of, the neighboring sloping plains or mountain pediment. Baker Tanks (p. 3) and many others belong to this type.

Falls due to renewed uplift.

Most of the mountains of southwest Arizona are narrow, uplifted strips of the earth's crust bounded by faults



SCALE OF MAP IS 1 INCH TO 622 FEET.

FIG. 6. Sketch map of Black Tanks.

on one or both sides. After uplift streams cut canyons and established smooth grades from the crest of the mountains to the adjacent valleys. In certain ranges renewed uplift took place on one side of the mountains only, probably along the same fault-plane on which the original uplift occurred. This uplift resulted in flattening the old stream grades in the higher part of the mountain and producing a cliff or fault scarp across the stream chan-

nels on that side of the range. Streams immediately began to cut headward through this fault scarp, and it has generally been removed. However, in certain ranges, the Estrellas and Tinajas Altas in particular, the new grade has not yet reached the crest of the range, and is separated from the old by falls, as illustrated in fig. 7.

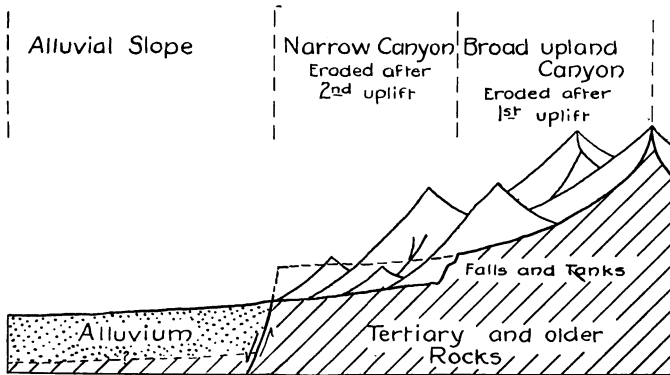


FIG. 7. Diagram showing production of falls and tanks by renewed uplift of eroded fault-block mountains.

The famous Tinajas Altas is the only watering place which can be definitely ascribed to this cause, but it is thought that a number of other tanks, including Tule Tank and Heart Tank, were probably formed in the same way.

Schrader has noted a number of rock tanks on the east flank of Estrella Mountains, Maricopa County, at the elevations of 2,000 to 3,000 feet.⁷ The Maricopa topographic sheet shows that in a number of these canyons the stream grades between the elevations of 1,500 feet and 3,000 feet are so steep as to be almost continuous falls. Above 3,000 feet the grade is flat and the canyon is wide with gentle slopes. There is thus good evidence that the Estrella Mountains have been rejuvenated by block faulting, and that the tanks are plunge pools and potholes associated with falls due to the dissection of the fault scarp.

⁷Schrader, Frank C.: Report on the Gila River Indian Reservation, Arizona, as to the mineral or non-mineral character of its lands, 1918. Unpublished manuscript in the files of the Land Classification Board, U. S. Geol. Survey.

The Tinajas Altas are situated in Yuma County on the east side of the Tinajas Altas Mountains, part of the Gila Range, 27 miles south of Wellton, and about 4 miles north of the International Boundary. This locality has been a camping place on the route from Sonora to the junction of Gila and Colorado rivers since prehistoric times. More than 300 persons are said to have died here of thirst and exhaustion during the gold rush beginning

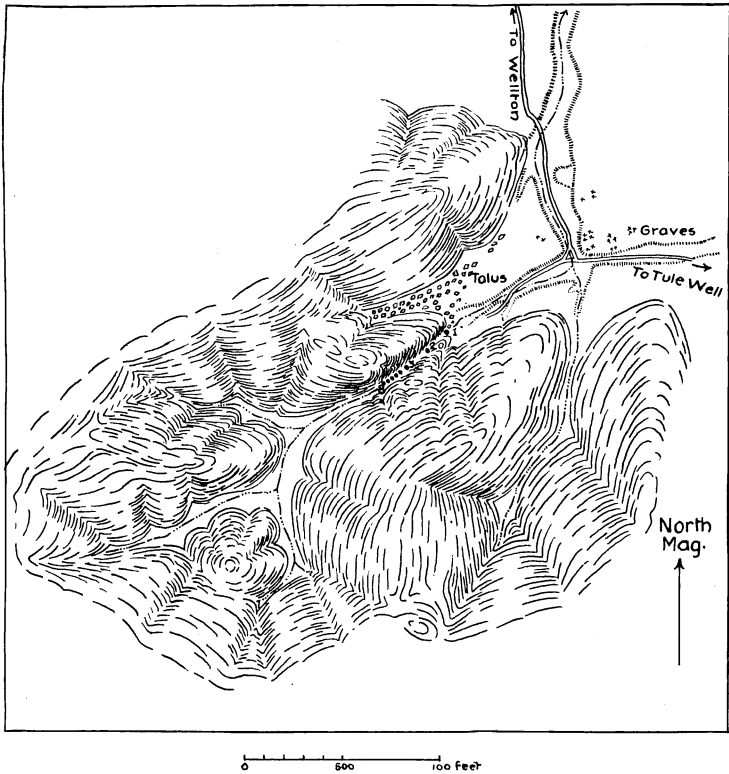


FIG. 8. Sketch map of Tinajas Altas from plane-table sheet by Kirk Bryan, and sketch by C. G. Puffer.

in 1848. About 60 graves were counted of which a few are located on the map, fig. 8. The Tinajas Altas consist of 8 tanks, distributed for 500 feet along a stream course so steep that it may be considered an almost continuous falls.

The map in figure 8 shows that the falls occur in an indentation of the mountain front, and that a consider-

able drainage area lies above the falls. This upland valley has relatively gentle slopes, and the grade of the stream through it is in marked contrast to the grade in the falls section, which is approximately 1 to 1.

The rock of this part of the mountains is a coarse, pegmatitic granite. Most of the surfaces are strained brown from the deposition of limonite, especially in the cove of Tinajas Altas. In such places there are many caves, reentrants, and pinnacles which add much to the picturesqueness of the mountain slopes.

The details of the falls, and the form and location of the plunge pools, are largely affected by the joints of the granite. The master joints strike N 2° E, and dip 65° NE, and divide the granite into great slabs, varying in thickness from 2 to 10 feet. A less perfect system has a strike N 80° E, and an almost vertical dip.

The profile shown in fig. 9 is made from the plane table location of the tanks, and an aneroid determination of the top of the falls by C. G. Puffer. It shows that in general the falls are parallel to the dip of the joints, and the plunge pools are located at places where the joints are closely spaced. In plan, also, the course of the stream is controlled by the joints, as shown in fig. 10. The steepest grades are parallel to the minor joint system, and the flattest grades to the master joint system. The plunge pools are located on the steps developed at the intersections of the joints.

The lower tank (No. 1 in fig. 8) fills with sand after a flood, and therefore the water lasts longer than in the others. The second tank is accessible by climbing along a cable fastened to the rock about 75 feet south of the channel. From the second tank the third is easily reached. The fourth and higher tanks are very inaccessible, and but little used except by mountain sheep. Animals, however, frequently meet disaster by falling into the water and drowning. Two dead sheep were seen in the upper tanks on October 22, 1917.

SAND TANKS.

Sand tanks are a variety of rock tanks formed in stream channels in the various ways previously outlined, and differing from other rock tanks only in being filled with sand. The tail end of the flood carries sufficient sand to fill the cavity, whereas with ordinary rock tanks the latter part of the flood is relatively clear. The sand thus deposited is saturated with water. The upper por-

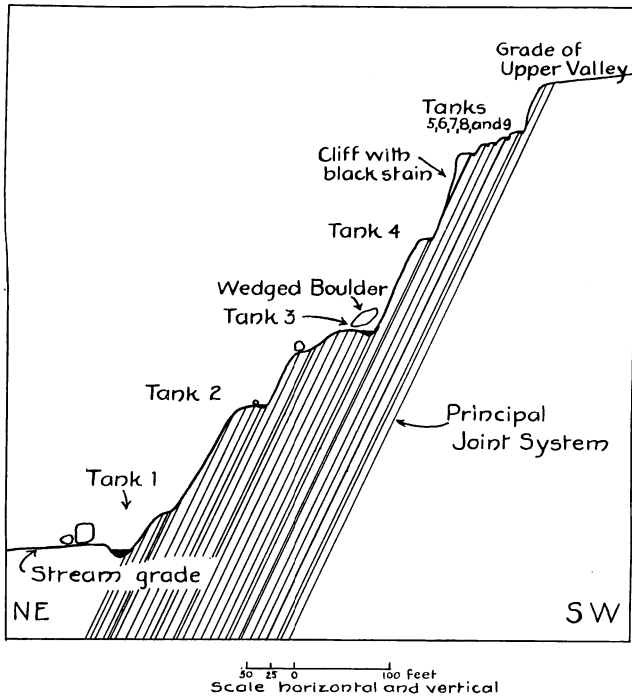


FIG. 9. Diagrammatic profile of falls of Tinajas Altas.

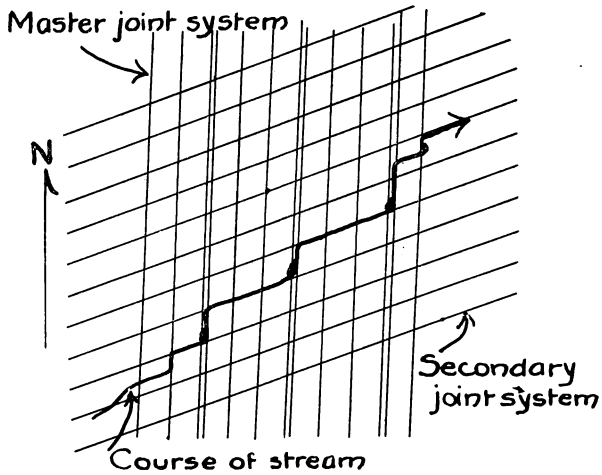


FIG. 10. Idealized diagram to show effect of joint system on course of stream and position of tanks at Tinajas Altas.

tion quickly dries, but because the pore spaces between grains are relatively large, and capillary action is unable to bring the water to the surface, further evaporation can not take place. Though for the same size of cavity the volume of water in sand tanks is less than a fourth that of rock tanks, the water commonly remains for a longer period after a flood than in rock tanks. The use of the water by animals is restricted because it is necessary for them to dig holes down to the water level and throw the sand out of the tank. Coyotes are able to do this with great ease, but horses, burros, and cattle have great difficulty in digging in the sand. Many rock tanks, on the other hand, are so accessible to wild animals and stock that within a few days after they are full all of the water has been used.

For instance, at Black Tanks, tanks 7 and 8 (fig. 6) are commonly filled with sand, and water is obtained by digging. The basins are relatively shallow, and though No. 8 is considered the best, in neither does water last all the year. Tank 4, however, is usually swept clean and makes a large pool. But as Nos. 1, 4, and 5 are accessible to stock the water is rapidly used up under ordinary circumstances. When, however, as sometimes happens, a flood leaves No. 4 tank full of sand, the water in the sand will last throughout the year. Nos. 2, 3, and 6 are too small to be of moment. Nos. 9 and 10 are very shallow. Thus, in dry seasons water is more likely to be found in the sand tanks Nos. 7 and 8 than in the clean rock tanks.

CHARCOS.

Charco is the name applied to natural water holes in adobe flats and washes in the Papago Country, but in other parts of the southwest, the same type of water hole is called a mudhole, or mud tank, or is not distinguished from other types of tanks and "tanques." Charco is a Spanish word signifying a pool of standing or stagnant water, and has the advantage of being a distinctive name. The word "tank" may then be reserved for natural reservoirs in rock.

Charcos are found as single pools or a series of pools along streams which deposit fine-grained material, usually sandy clay or adobe. They vary from shallow pans 18 inches wide by 6 feet long, to depressions 5 to 6 feet deep, 15 to 30 feet wide, and more than 1,000 feet long; see fig. 12.

The adobe flats in which charcos occur are the result of sedimentation from flood water streams which spread as a thin sheet of water over large tracts of country and deposit mud as sediment. This process produces smooth plains having a gentle slope in the direction of drainage, and generally unmarked by channels, or at most having very insignificant channels 2 to 5 feet wide and a few inches deep. However, in places where the current is exceptionally swift, part of the mud laid down by past floods is removed and a relatively large channel is formed. It is characteristic of these channels that they begin with a series of little cliffs, 6 inches to 18 inches high, which

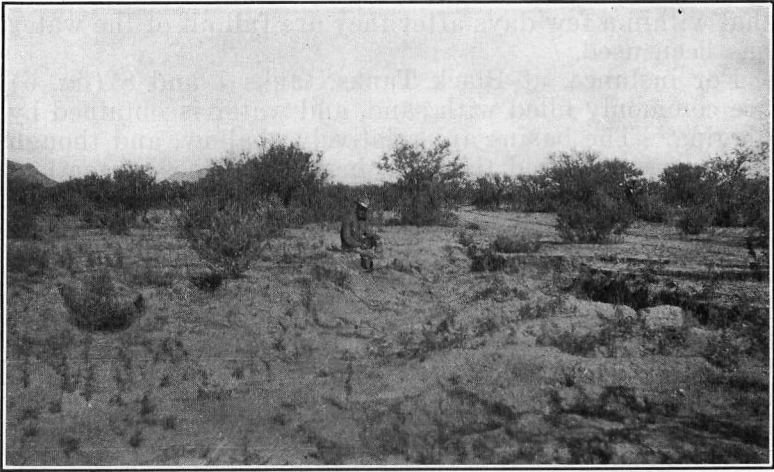


FIG. 11. Miniature canyons near head of a charco, La Guituni Valley, Pima Co., Arizona.

lead down to numerous small channels and rill marks which collect together into a single channel which pursues a somewhat sinuous course in the direction of the drainage, and finally ends more or less abruptly. In many instances the channel ends in a vertical wall 3 to 5 feet high. It is evident that concentration of the current of a flood normally spread in broad sheets over the flat, digs the original channel, and movement of water into this channel toward the end of the flood or during minor floods causes erosion of the fanlike set of miniature canyons at the upper end, fig. 11. The lower end of the channel is fixed at a place where the current again becomes less swift, due to the spreading of the flood to occupy a larger cross-section. The channels thus formed

are depressions below the general level of the adobe flats and in them water may remain after the passage of the flood, fig. 12. Whether water does so remain depends upon the porosity of the bottom of the channel. If erosion has carried the bottom of the channel below the adobe to some bed of sand or fine gravel, water will easily drain away underground. If, however, the channel is entirely in the usual fine-grained, claylike adobe, water will seep away more slowly. The principal losses will then be from evaporation or, dependent on circumstances, from use by stock and wild animals.

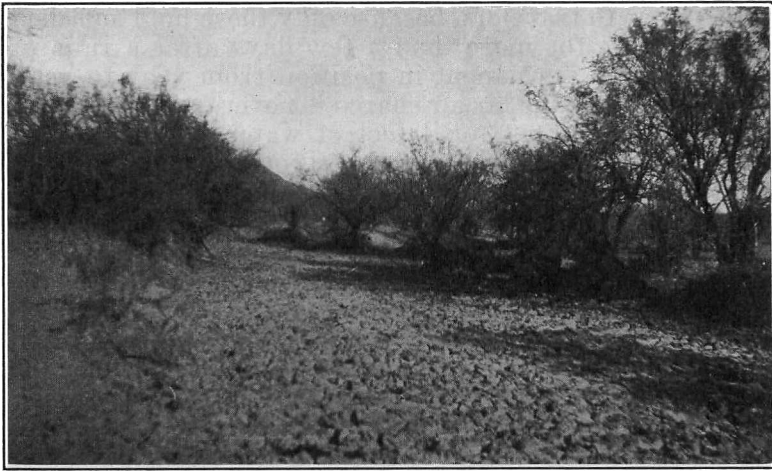


FIG. 12. Charco near Pozo Redondo, Pima Co., Arizona.

In this fashion the larger charcos are formed. The smaller ones, however, usually occur along some relatively small stream which spreads out over part of its course in a small, often grassy, flat. These flats are often only a few feet wide and a few yards long. Channel cutting of the kind previously described sometimes takes place in these flats, and many of the smaller charcos seem to be due to a breaking of the grass cover which allows erosion to take place over a very small area. Other holes seem to be due almost wholly to the activities of animals, both wild and domestic, which come to feed in the flat immediately after the rain. Very shallow pools of water attract them; they drink the muddy water, roll in the mud, and trample and compact the bottom. Thus a somewhat deeper hole is formed which, when the next

rain comes, will hold water for a longer time, and thereby undergo the same processes for a longer period. The maximum depth below the surface attained by this process seems to be about two feet.

In South Africa Passarge has found large basins which seem to be wholly due to the activities of animals. He has called the process zoögenous erosion. The animals involved are rhinoceri, elephants, buffalo, and wild hogs, whose size and weight being greater than that of Arizona animals, probably make possible the greater depth and size of the African basins.⁸

The larger charcos are, however, the only ones of great importance to travelers, because only these hold sufficient water to last for more than a few days after a rain, or are relatively permanent in position from year to year. Generally, even the larger charco is never quite full, holding not more than 3 or 4 feet of water. When one of these large charcos has once been formed it tends to be relatively long-lived, for the trampling of animals protects its bottom from seepage, in the same fashion that the bottom of reservoirs is puddled, and this trampling also increases the resistance to erosion of the bed of the charco. The trails which animals make in going to and from water are often from 3 inches to a foot deep, and tend to turn water toward the charco. In this connection note the trails between the bushes in fig. 12. However, a change in the main current of the flood waters may leave the charco on the edge of the floods, in which case it is very likely to become gradually filled up and obliterated. There are certain localities where a charco will be recurrent because floods are normally constricted in this part of their course. Such places are commonly along the foot of some isolated hill in an alluvial plain near the mainflood channel. A somewhat similar rocky projection of the wall of a valley will produce the same result. If for any reason the charco is temporarily filled up, a new one will form within a short distance.

Still other charcos are formed by the natural damming of the channel in an adobe flat. The mudhole near the Brush Corral in the Vekol Valley is due to the damming of the narrow channel of the main drain of the valley, at the lower end of a grassy flat by coarse gravel and sand brought in by a tributary stream. The lower end of this narrow channel remains full of muddy water after a flood and forms a charco.

⁸ Passarge, Siegfried: *Die Kalahari*, Berlin, 1904, p. 660.