QANATS, KAREZ, AND FOGGARAS*

GEORGE B. CRESSEY

FEW deserts are entirely without water; the problem is to make the water available at the proper time and place. Settlement and agriculture in dry lands usually depend on water supplied by diversion canals from exotic rivers, deep wells, springs, or near-surface ground water. In Southwest Asia and North Africa an important supply of water is obtained from underground infiltration tunnels, or "horizontal wells," variously known as "qanats," "karez," or "foggaras."

Qanats are found across the Arab world and beyond; in Iran they are present by the thousands. The essential idea is that of a gently sloping tunnel, often along the radius of an alluvial fan, which extends upslope until the water table is tapped and emerges at the downslope end to supply an oasis. To give access to the tunnel, vertical shafts are dug at closely spaced intervals. The length of a qanat ranges from a few hundred yards to tens of miles, and the upper end may be several hundred feet below the surface. The upper part of the tunnel, below the water table, serves as an infiltration gallery and may have several branches to increase the inflow. The lower, and longer, part is the conveyer channel. The section between two shafts is known as a *pushteh*. Seepage losses may be high, even as much as one-third, but in some cases the accumulated clay tends to waterproof the channel. The yield of water varies widely from qanat to qanat and from season to season, but it is usually several cubic feet a second.

By this means thousands of acres are irrigated and hundreds of villages receive their sole water supply. The idea is of Persian origin and dates back more than 2000 years; the palace city of Persepolis is thought to have been supplied by qanats about 500 B.C. Near the Mediterranean, qanats are erroneously attributed to the Romans. The term *karez* is Persian but is more used outside Iran than in the country, where preference goes to the Arabic word *qanat*, meaning a subterranean canal or conduit for water. In North Africa the usual term is *foggara*. There are some two dozen variants of the name or spelling: qanat, quanat, canant, connought, kanat, khanate, khad, kanayet, or ghannat; karez, kariz, kahriz, kahrez, karaz, or kakoriz (Southwest Asia); foggara, mayon, iffeli, ngoula, khettara, khottara, or rhettara (North Africa); falaj, aflaj, or felledj (Arabia).

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* An extensive bibliography on qanats, karez, and foggaras, compiled by the author, is on file in the offices of the *Geographical Review*. Copies are available upon request.—EDIT. NOTE.

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Qanats are limited to sloping lands, usually alluvial fans or gravel outwash at the foot of a mountain. In the area it is desired to irrigate, surface water is generally inadequate and local ground water too deep or too saline to be utilized profitably. By means of these nearly horizontal tunnels water is brought by gravity from a distant underground source.

The deserts of Southwest Asia and Northwest Africa consist of a succession of mountains and sedimentary basins, with great alluvial fans encircling

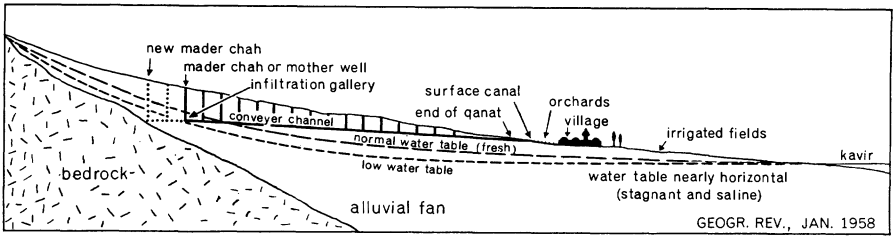


FIG. 1—Cross section of a typical qanat.

the depressions. Such rain as falls on the highlands runs quickly off the bedrock of the mountain face and seeps into the gravels and sands of the bordering fans. From the margins of the basins water moves underground toward the playa *(kavir)*. Nine-tenths of the runoff goes underground within a few miles. Although a cross section of the basin may show a gentle surface slope from the mountains across the fan to the playa, the profile of the water table is more nearly dish-shaped: it is flatter than the ground surface near the center, where the playa may mark the merging of the land surface with the water table, and rises only near the bedrock of the mountains (Fig. 1). Ground water near the center of the basin tends to be stagnant and highly mineralized, but near the peripheral sources of intake it is normally fresh. Where the source of the qanat is poorly located, the water may change from fresh to brackish as the water table fluctuates.

The yield of qanats varies widely, according to ground-water characteristics, the porosity of the soil, and the season. A qanat in porous gravels near Meshed, about a mile in length, which had a flow of 4200 gallons a minute in April, 1954, declined to 400 gallons on July 14 and was dry from August through the following March. Other qanats have a nearly constant flow throughout the year owing to the fact that they tap a stable groundwater source.

There are many variations in the qanat system. Where a single tunnel fails to yield an adequate supply, branch infiltration galleries may be added upslope. During dry periods, when the water table is depressed, the tunnels may be lengthened to reach more dependable supplies, or the uppermost well may be deepened and a pump installed. In a few places, notably east of Tehran, there is a succession of qanat systems down an alluvial slope, each drawing on the water of the others as it seeps into the ground from irrigated fields. Where the slope of the ground is sufficiently steep, the qanat canal may continue as an elevated aqueduct until it is some ten feet above the ground level when the water is dropped to operate a grain mill, half underground. The water may then continue, first in a qanat tunnel and again in an aqueduct, to operate a second mill. Sometimes there is a series of mills, all underground, where the qanat stream does not appear above the surface at all.

In many towns qanats terminate in the *suq* (the bazaar) or in a mosque or in the home of the owner. Where a qanat passes beneath a residential area, some houses have a summer living room alongside the flowing stream, several tens of feet underground. The water is usually cool throughout the year but may become polluted from use in similar rooms upstream.

Since qanats are the key to life in these arid regions, many laws have been developed to govern their construction and use. Some of these regulate the distance between new qanat tunnels and tunnels already in existence. Thus lines of qanat wells must be spaced at least 12 yards apart. Around each qanat entrance is a *hareem*, or reserved area. Other laws govern the distribution of the water or the responsibilities of the owner. Land near the mouth of the qanat is most favored, for it is most likely to receive water. The title to empty land may be awarded to whoever supplies it with water; and on rented land the owner of the water may be entitled to as much as 80 per cent of the crop. One book of qanat laws, the Kitab Qani, dates from the ninth century. Moslem law provides that drinking water shall always be free to all, but those who live upstream have the first right to use water for irrigation.

Methods of Construction

The construction of qanats is a specialized trade. The diggers, known in Iran as *moghanis* (in Afghanistan, *karezkan*), often conduct their business as a family occupation generation after generation. The life of the qanat digger is hazardous. Stones may fall down shafts, or the roof of the tunnel may collapse. The shafts have no ladders, and a rope is seldom used; instead the worker inches his way to the surface by bracing his back and toes against opposite walls. There is no proper circulation of air, so that asphyxiation is not uncommon. When a qanat caves in and dams the flow, it must be cleared out below the fall; this will release a sudden flow of water, which may drown the workers.

When a new qanat is to be dug, the *moghani* first locates a point on the surface below which it is hoped to find water. This is usually on the upper slope of an alluvial fan, perhaps near the mouth of a dry mountain valley; sometimes it is in an area marginal to a wadi, or dry stream bed. Experience is usually the guide. Here an initial shaft is dug. When the water table (*ab deh*) is reached and there seems to be an adequate supply of good water in porous gravels, a rough line of levels is run to see whether the water table is high enough above the desired outlet downslope for a gentle flow to reach the area to be irrigated. If not, other wells must be dug farther upslope. Leveling may be done by noting whether a drop of water on a wet string comes to rest at the middle. The most distant shaft upslope is known as the "mother well" (*madar chah*).

To dig the qanat, a line of shafts must first be sunk, spaced 30 to 100 yards apart. Often several men work together. One extends the tunnel, another puts some 60 pounds of earth into a small leather bag and drags it to the base of the shaft, still another operates a wooden windlass (*charkh*) on the surface. Where a shaft is deep, say 240 feet, two men operate the windlass, lifting a bag of dirt every six minutes. The diggers have small lamps that burn castor oil, and the quality of the air is judged by the flame; poor air is sometimes a factor in determining the spacing of the shafts. From each of the shafts the tunnel is extended in both directions. The qanat may start from the lower end as a shallow ditch (*haranj*), which is converted into a tunnel as the depth increases upslope. Or the diggers may start from the upstream end and work downhill from the mother well. However, if the flow of water is abundant, this is impossible because the tunnel becomes filled. In most qanats the water in the tunnel is six inches to a foot in depth and flows at the rate of a mile or two an hour. The slope must be gentle enough to prevent erosion.

Around each shaft a ring of earth accumulates, known as a *karvar*. Where the shafts are deep and widely spaced, and especially where the qanat tunnel is subject to caving in, these circular piles may be 6 feet high and 30 feet in diameter, but more commonly the dimensions are half these figures. From the air the ringlike mounds resemble small craters or huge doughnuts. One purpose of the circular piles is to keep out surface drainage that might flood the tunnel after a storm. This is especially serious where the line of shafts follows a wadi. To prevent blowing sand or flash floods from plugging the qanat, many shafts are covered with earth or a slab of stone.

Qanat tunnels are usually just large enough for the worker to crawl

FIG. 2—Excavation of a qanat shaft in Iran. The dirt is removed in leather bags. (Photograph courtesy of William E. Warne.)

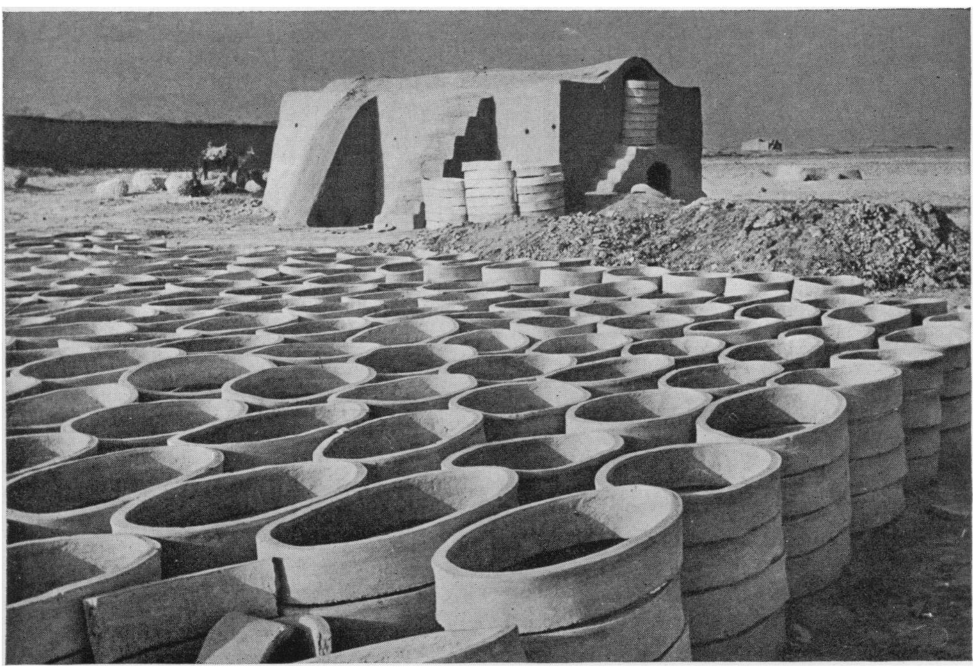


FIG. 3—Oval tiles, or *nars*, used to line the qanat tunnels. (Photograph courtesy of William E. Warne.)

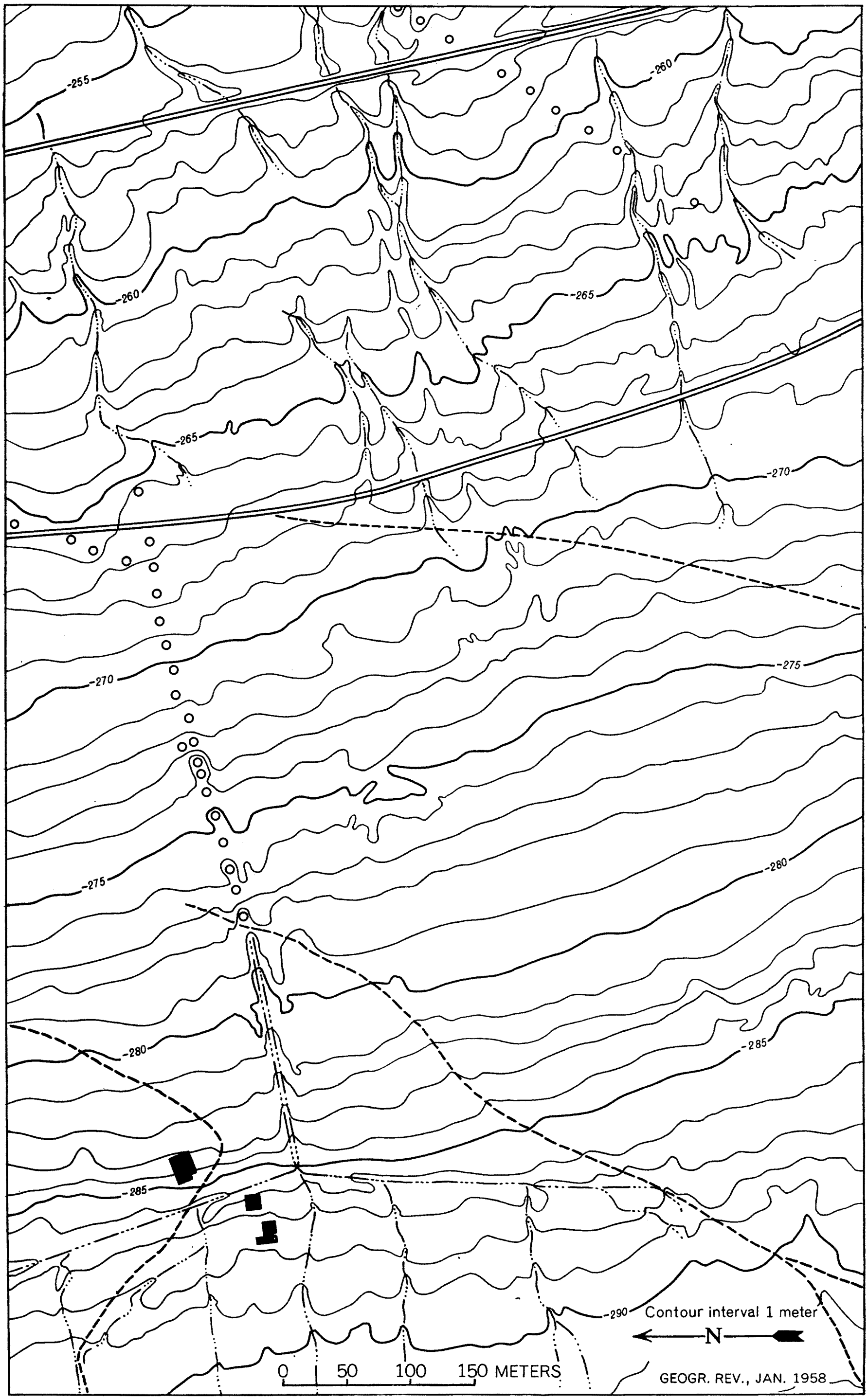


FIG. 4—Shunat Nimrun qanat No. 9, in Jordan. Source: Map of Yarmouk-Jordan Valley Project for the Hashemite Kingdom of Jordan, Point IV, Sheet 148.0/206.0.

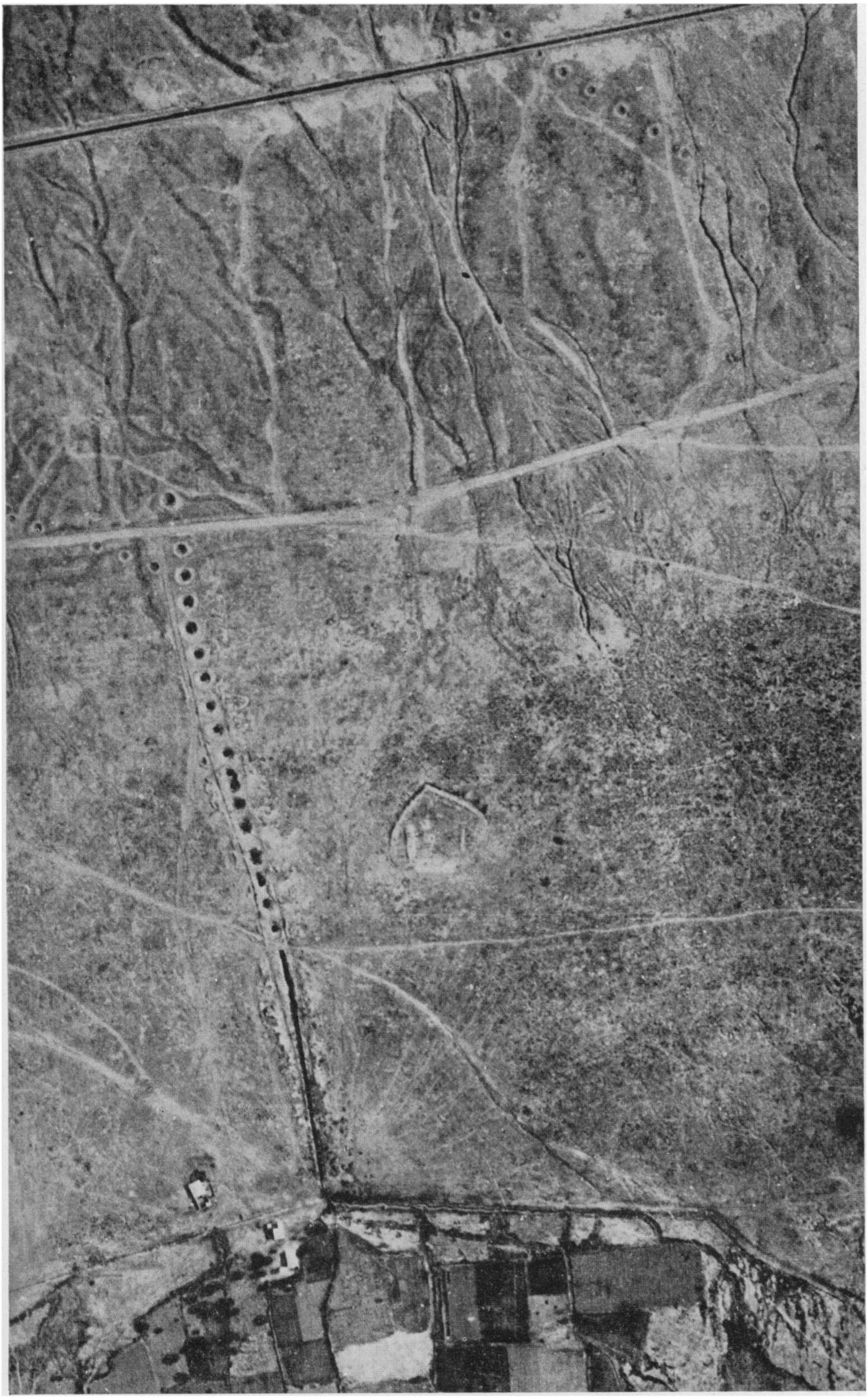
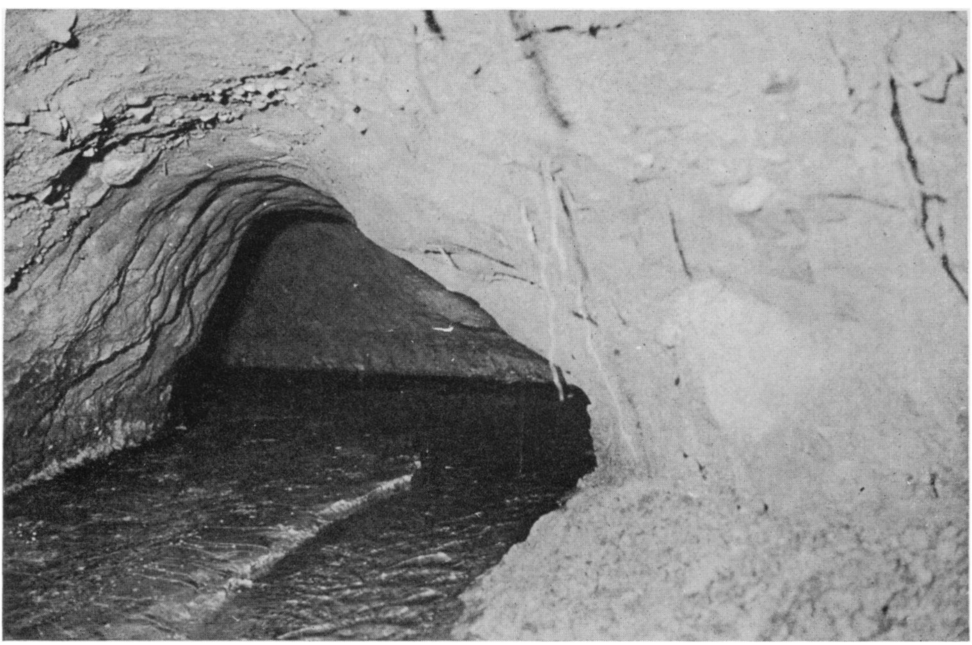


FIG. 5—Aerial photograph of the area shown in Figure 4. Note that the ring of excavated earth around each well shaft is plainly visible from the air.

FIG. 6 (left)—Caved-in shaft of the Shunat Nimrun qanat.

FIG. 7 (below)—Underground in the same qanat.



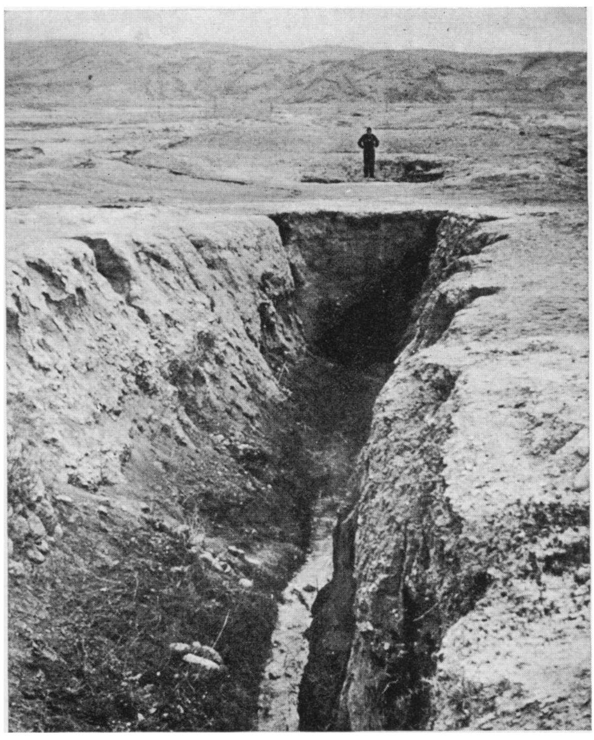


FIG. 8—End of open ditch at area irrigated by the same qanat.

FIG. 9—Open ditch viewed in other direction. Man stands at first shaft.

through, and boys are commonly used in the smaller qanats. Width ranges from two to three feet, height from three to four feet. Soft earth presents a problem, since it tends to cave in; under such circumstances the tunnel may be lined with oval tiles, *nars,* about a yard in their longer dimension and four to eight inches wide, so that thousands may be required. These tiles are often made on the spot in a kiln that uses local brush. Since fuel is scarce, the *nars* are poorly baked and do not stand much transportation. If an area caves in too badly, or if large boulders are encountered, a run-around may be necessary. Where the floor of the tunnel has been lowered by erosion, or where the roof has caved in, the ceiling may come to be 10 feet or more above the stream.

A long qanat system may have several hundred wells, and the total amount of earth excavated is considerable. If, for example, the cross sections of the tunnel and shafts average a square yard, the mother well has a depth of 50 yards, and the wells are spaced 100 yards apart, the total excavation of a 1-mile qanat will amount to some 6160 cubic yards. Qanats 5 and 10 miles long are common, and some tunnels are 20 miles and more. Long qanat systems thus call for the excavation of tens of thousands of cubic yards of earth, all of which must be lifted to the surface in small leather buckets. Such systems may require three years to construct, and the cost is large.

Economic Considerations

Since the development of drilled wells and diesel pumps, some qanat systems have proved to be uneconomic and have been allowed to fall into disrepair, but in other areas new qanats are being constructed. Many parts of Iran still depend exclusively on qanat water both for domestic supplies and for cultivation. In the Yezd area of central Iran in 1956, where many of the qanats are 15 to 30 miles long with mother wells 150 to 350 feet deep, a new qanat was being dug at an estimated cost of 10,000,000 rials (one rial was then about $0.135). Nearby was a new 8-inch drilled well, reaching 180 feet to water, equipped with diesel engines, and costing about 1,500,000 rials.

However, when once in operation the qanat flows night and day, and the only expense is for occasional cleaning, with labor at 20 rials a day. Pumped wells, on the other hand, require operators, fuel, and mechanical upkeep; thus the well mentioned above produces 750 gallons a minute at a fuel cost of 120 rials an hour. If operated 20 hours a day for 275 days a year (that is, throughout the growing season), such a well will supply 3 acre-feet of water for 253 acres of good crops at a fuel cost of 400,000 rials. Some qanats have a flow of 400 gallons a minute, but most are much smaller, about

30 gallons a minute. The flow is unregulated and usually varies somewhat with the season. One qanat is sometimes thought adequate for 200 acres, but an average flow of 30 gallons a minute yields annually only 1 acre-foot for 48 acres. Other qanats may irrigate 2 square miles, and their owners may well become wealthy.

Although qanats are wasteful of water, they have the great advantage of deriving their water high up on the alluvial fan where the supply is fresh and continuously replenished; in contrast, local well water is stagnant and inclined to be saline near the center of a basin and presumably will not stand continuous pumping. Iran has already had unfortunate experience in depleting ground water through overpumping.

The Overseas Consultants of New York give some pertinent generalizations in their engineering report on a proposed development plan for Iran.[1] The average qanat has a length of 4000 meters, of which 2000 meters requires lining; the mother well averages 30 meters in depth, and the flow at the mouth is 30 liters a second. Such a qanat costs 1,000,000 rials and requires maintenance averaging 26,000 rials a year. In comparison, a 6-inch-pump well would cost 500,000 rials but would require an annual operating expense of 82,000 rials. The qanat is thus usually cheaper in the long run, but since the water flows the year round and much of it is not needed during the winter, there is an annual waste of some 500,000 cubic meters.

Writing in 1935, Mrs. Merritt-Hawkes[2] gives the cost of a 21-mile qanat with a 90-foot mother well as 55,000 tomans (£6900). This system supplied the village of Ahmad-abad with its 7000 people. The value of the entire village with its houses, shops, mosque, and 80 carpet looms amounted to 25,000 tomans, or less than half the cost of the water supply. Figures for 1950 assembled by Beckett[3] place the cost of the qanat at Jupar at 52 to 66 tomans per yard of tunnel. Maintenance costs seem to average 0.5 per cent of the capital investment: the qanat, which would cost 500,000 tomans to replace, requires three men at a total cost of 2400 tomans for annual upkeep.

Most qanats are privately owned. Since land may be useless without water, ownership of water is the deciding factor in settlement. Some qanats are village property, or ownership may have been minutely subdivided by inheritance; those at Yezd, for example, have from 50 to 1000 owners.

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[1] Overseas Consultants, Inc.: Report on Seven Year Development Plan for the Plan Organization of the Imperial Government of Iran (5 vols., New York, 1949), Vol. 3, Agriculture, Water Resources . . ., p. 191.

[2] O. A. Merritt-Hawkes: Persia: Romance and Reality (London, 1935), pp. 161–168.

[3] Philip Beckett: Qanats around Kirman, *Journ. Royal Central Asian Soc.*, Vol. 40, 1953, pp. 47–58; reference on p. 55.

All qanats require maintenance. Where the tunnel passes through soft earth or is subject to caving in, it must be cleaned each year, and this may entail a large expense. During years of exceptionally heavy rain, the ground may become saturated down to the tunnel level, with resultant widespread collapse. Near Kerman a storm filled two of the shafts in a long qanat, and the system was ruined; this impoverished the owners, forced the abandonment of several villages, and resulted in the reversion of a considerable crop area to desert. Where owners are unable to keep a qanat in repair, the flow may decrease or cease entirely, so that the cropland and even the settlement must be abandoned. Many of the ruined villages and once-used fields frequently seen in desolate areas owe their abandonment to a failure to keep the qanat in repair; no climatic change need be assumed.

Most qanat tunnels continue downslope until the gravity flow reaches the surface in the *haranj*, the open canal. In a few, however, pumps have been installed in some of the shafts toward the end of the tunnel. These may be hand-, animal-, or motor-driven. Irrigation is thus made possible in areas otherwise without flowing water. Where water is in great demand and the source is so low in elevation that the tunnel cannot reach the surface, the qanat may terminate in an underground cistern (*birke* or *ambar*), from which water is lifted as needed.

Where a qanat supplies irrigation water to several canals, water is divided by a weir. Allocation to users is usually based on time rather than on volume: each part owner (or, more commonly, renter) is permitted to use the flow of the canal past his field for so many hours on certain days. In some areas there is an eight-day rotation.

Distribution of Qanats

IRAN

Iran, as we have noted, is the premier country for qanats. The traveler across the Persian plains, whether by air or on the ground, is seldom out of sight of qanat holes. The area around Yezd has some 400 qanats, most of them from 5 to 30 miles long. Both Yezd and Kerman are almost entirely dependent on qanat water; in Kerman it is said that one-seventh of the population are qanat diggers. Other areas of importance are around Tehran, Meshed, Isfahan, and Arak. The plain of Nishapur near Meshed is said to have "12,000 springs fed by 12,000 qanats." The city of Tehran is supplied by at least 36 qanats, which follow the alluvial slopes of the Elburz Mountains; one qanat ends in the British Embassy, another supplies a pool in the Gulistan Palace.

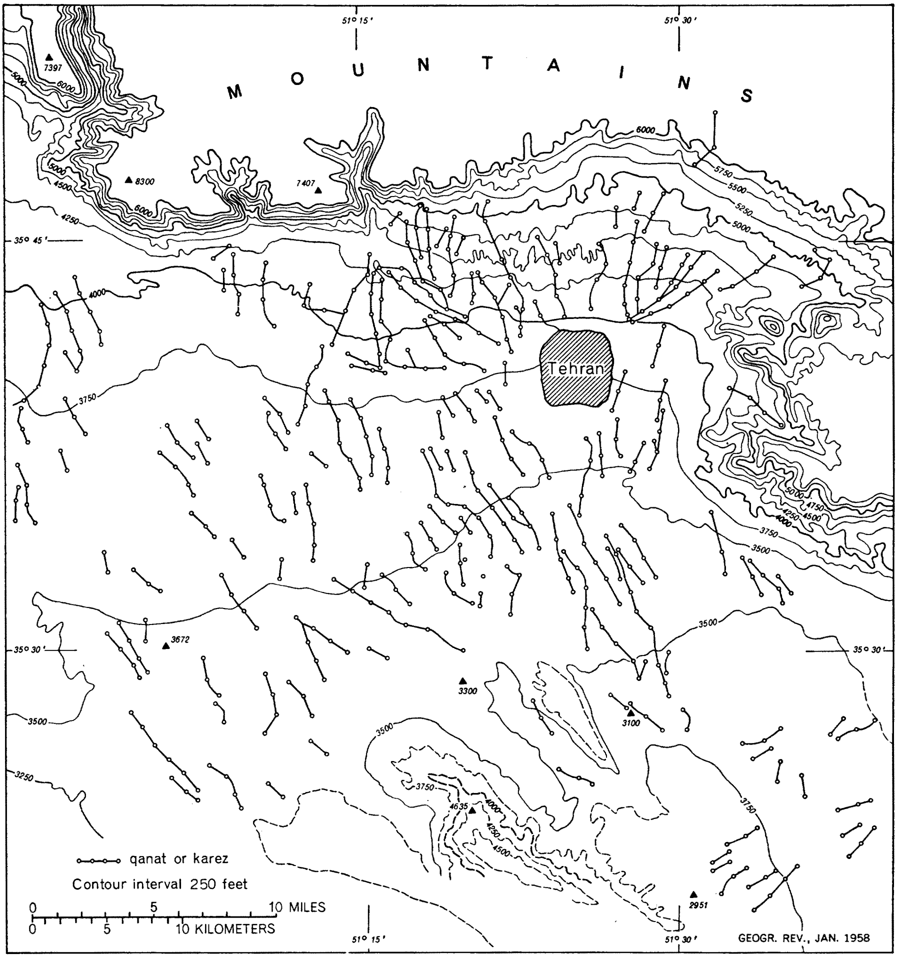

FIG. 10—Qanats in the Tehran area, Iran. Source: Army Map Service K501 (G.S.G.S. 3919), Sheet No. 9 M, Tehran.

The number of qanats in Iran, often estimated but not substantiated, is reported to reach 40,000, and it is said that they provide from one-third to three-quarters of all the irrigation water in the country. Their aggregate length has been placed at 100,000 miles, the total discharge at 20,000 cubic meters a second. Millions of man-days are expended annually on their construction and maintenance. The Irrigation Department of Iran sets the total at 20,000 and has approximate specifications and discharge measurements on 4073, scattered through the 10 provinces.[4]

The sheets of the United States Air Force Aeronautical Approach Charts for Iran, scale 1 : 250,000, based in part on air photographs, show 1766 qanats but omit them entirely in some areas where they are known to be abundant; elsewhere a field check finds that fewer than half of the qanats are mapped. Qanats are also shown on many of the quarter-inch maps prepared by the Geographical Section of the British General Staff. In numerous cases it is obvious that the surveyors did not understand what they were plotting and thus recorded the qanats erroneously. If these two series of maps are combined where only one or the other carries qanat indications, the total number of mapped qanats exceeds 2000.

The deepest qanat in Iran is thought to be at Gonabad, near the Afghan border, constructed some 500 years ago. It is 17 miles long and is said to be large enough in places that a horse could be ridden through it. The mother well is reported to be 1000 feet deep. Since it would be difficult at times of cleaning to raise the earth this distance in one lift, there are several offset shafts with openings at different levels where the buckets of dirt are transferred from one rope to another. Many long qanats lead into Kerman, some of them 20 miles in length. The longest qanat shown on the United States Air Force charts measures 17.4 miles, near Zarand, northwest of Kerman. Unverified reports credit Meshed with two 40-mile qanats, and a qanat near Isfahan is reputed to be 56 miles in length.

CHINA

Ancient China undoubtedly had some contact with Persia, though we have no specific record concerning the introduction of karez. In fact, only in the far western desert provinces would they be applicable. There is an account[5] of an elaborate engineering work known as the Dragon-Head Canal, constructed by Chuang Hsiung-phi in 120 B.C., "which involved tunnels and well-shafts at regular intervals."

Sinkiang, the northwesternmost province of China, has a few karez today in the Turfan Depression that bring water from the Fire Mountains. Cable and French[6] report as many as 200 shafts in a row, with a maximum depth of 50 feet. The heavy expense of construction is justified by the fact that they irrigate cotton, which is a cash crop for export. Some 40 per cent of the population in this district are said to be dependent on karez water. Karez are uncommon elsewhere in the province, though one is reported near Kuchengtze (Kitai). These karez are dug by Turki, never by Chinese, and appear to date from about 1780.

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[4] W. E. Warne: Mission for Peace (New York, 1956), Chap. 31.

[5] Joseph Needham: Science and Civilisation in China, Vol. 1 (Cambridge, England, 1954), p. 236.

[6] Mildred Cable and Francesca French: The Gobi Desert (New York, 1944), pp. 184–185.

AFGHANISTAN AND PAKISTAN

Afghanistan has thousands of karez in the south and southeast, especially in the vicinity of Kandahar. The Royal Afghan Ministry of Mines writes[7] that the average karez has about 45 to 60 wells, and that each karez waters about 60 jeribs of land (one jerib = 2.47 acres). Humlum[8] describes the difference between rich and poor farmers in terms of the number of hours a week that they may use the water from the canal; well-to-do farmers own the privilege for 24 to 36 hours, the poor farmers for only one or two hours.

Karez are widespread in Baluchistan, where a 1903 census in the Administered Area showed 493. Many oases depend entirely on this supply, but, as is common elsewhere, the ruined karez may now outnumber those in operation. In the area around Quetta and Pishin, 66 per cent of the irrigated area, a total of 93,909 acres, is watered by karez.

IRAQ

The earliest qanat in what is now Iraq may have been constructed before 800 B.C. when Ashurnasirpal brought water to Calah from the Zab River through a tunnel that may have been a qanat.

Qanats are limited to the mountain foothills in the north and east. Ground-water surveys by the Ralph M. Parsons Company[9] list several dozen qanats, most of them abandoned except in the Kirkuk and Erbil areas, where lengths of one to five miles are common. The city of Erbil is thought to be one of the oldest inhabited sites on earth; one of the reasons for its continued prosperity may lie in the excellent supply of qanat water. The surrounding plain once had 365 qanats, but only 60 operate today. The yield for the principal qanat ranges from 200,000 to 315,000 gallons a day. The flow is steady from January through March, increases until the end of the rainy season in June, and then declines. The Kingerban qanat, south of Kirkuk, once had a flow of approximately 500 gallons a minute, but it is now much less.

South of the Sinjar Mountains, west of Mosul, several qanats have a length of 5 miles, and some abandoned systems measure as much as 25 miles. The measured flow of two qanats in the Sinjar area amounts to 20 to 25, and 250 to 300, gallons a minute. The city of Sulaimaniya, with a population of

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[7] Personal communication.

[8] Johannes Humlum: L'agriculture par irrigation en Afghanistan, *Comptes Rendus Congr. Internatl. de Géogr., Lisbon, 1949,* Vol. 3, Lisbon, 1951, pp. 318–328; reference on p. 322. See also his "Kushk-i-Nakhud, Map of the Oasis of Pirzada in Afghanistan" (Geografisk Institut, Aarhus, 1949).

[9] Ralph M. Parsons Co.: Ground Water Resources of Iraq (9 vols., Development Board, Baghdad, 1955–1956).

41,000, receives all its water supply from qanats, one of which is estimated to yield 200,000 gallons a day. A qanat at Chemchemal yields 20,000 gallons a day. The tunnel of a qanat surveyed near Kirkuk showed an average gradient of 1 in 315 over its 3-kilometer length, and slopes between 1 in 5000 and 1 in 534 near the exit, and 1 in 133 toward the source.

THE LEVANT

Most of Lebanon and Israel receives enough rainfall so that qanats are unnecessary, but a few are found farther inland in Jordan and Syria. Qanat systems supply the northern part of the Damascus oasis, and several short qanats are present east of the Jordan River near Shunat Nimrun. Discharge records for one of these, No. 9 (Figs. 4–9), some 400 meters long, show a flow that ranged from 75.6 gallons a minute in August, 1951, to 608.7 gallons a minute in August, 1943. Near the mouth of the qanat a weir divides the water into two canals, which in turn feed half a dozen laterals. The irrigated area covers about 75 acres. Local inhabitants report that the qanats are of Roman origin, since pottery of the Roman period is associated with them.

An underground aqueduct, with numerous shafts, leads into Solomon's pool in Jerusalem. This tunnel collects its water from an infiltration gallery but may not be a true qanat.

CYPRUS

Cyprus has numerous qanats, known locally as "chains of wells." The flow of one system, with 93 shafts, varies with the season between 400,000 and 3,000,000 gallons a day. The annual supply of water from all the qanats amounted to 9.25 billion gallons in 1950; new ones are expected to supply an additional 1.85 billion gallons. The usual dimensions of Cyprus qanats are three feet high by a foot and a half wide.

ARABIA

Arabia has few karez, since it has few mountains high enough to intercept much rain or to give rise to alluvial fans. However, some karez are present near Al Kharj, which is southeast of Riyadh, and at Qatif, north of Dhahran. At Qatif the tunnels pass through a sand-dune area, and the shafts are lined with cemented stones. As dunes advance and tend to bury the shafts, the stonework is built higher; where the sand has blown away, these towers stand like a line of chimneys. Here and on Bahrein Island some of the surface canals or aqueducts are roofed with slabs of stone to keep out the sand.

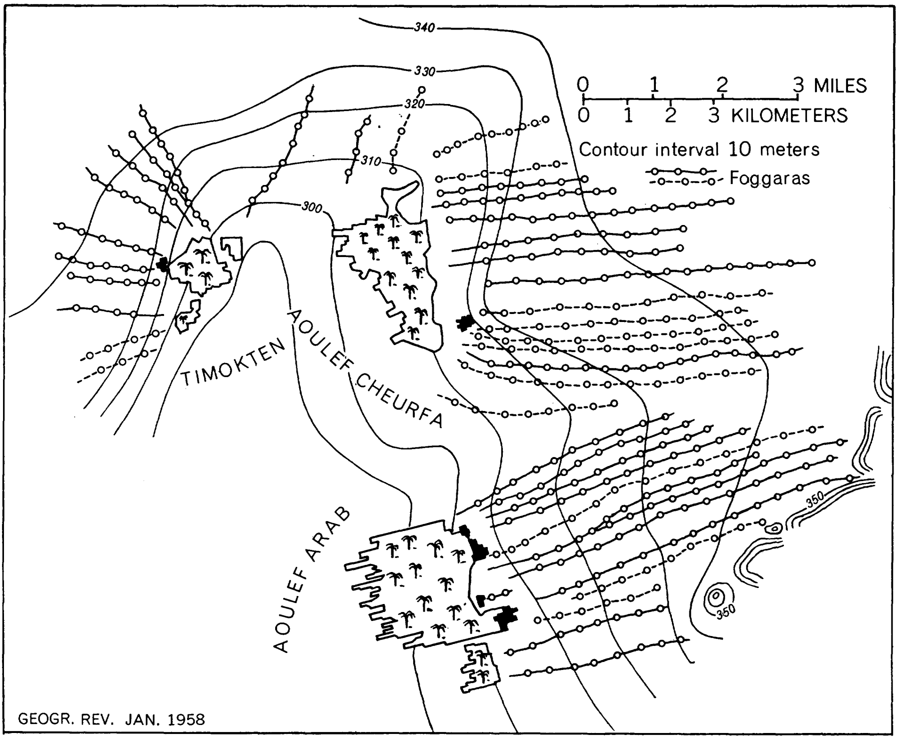

FIG. 11—Foggaras in the Timokten area, Algeria. Source: *Bull. Soc. de Géogr. et d'Archéol. d'Oran,* Vol. 29, 1909, Pl. 29.

Oman has underground infiltration galleries, locally known as *aflaj.* Similar structures are present in Yemen and the Hadhramaut, where they are known as *felledj.*

AFRICA

Foggaras are widely distributed across Northwest Africa. Modern pumps are replacing them in some areas, but there are occasional references to new construction. These foggaras are presumably of Arabic origin, but many local residents speak of them as Roman. In Morocco they occur on both sides of the Atlas Mountains. To the north they are especially well developed near Marrakesh, where they are also known as *khottara* or *rhettara;* about 85 systems supply much of the city's water. To the south they are found near Tafilalet.

Algeria contains many foggara systems along the western flanks of the Tademaït Plateau, especially in the districts of Gourara, Touat, and Tidikelt. The oasis of Aoulef, southwest of the Tademaït, with half a dozen settlements and three areas of palm trees, is supplied by 44 foggaras, many of them as much as 5 miles in length. In the Tamentit oasis of the Tuareg Sahara there are in all 25 miles of foggara tunnels, with ventilation shafts that reach 200 and 230 feet in depth at the head of the foggara.

Egypt has few, if any, true foggaras, but in the Kharga oasis infiltration galleries have been dug into soft sandstones in order to exploit the scanty yield of surface water. They presumably date from the fifth century before Christ, when the Persians under Darius I introduced these conduits into Egypt.

THE AMERICAS

The Arabs brought the foggara idea into Spain, and the Spanish brought it to the New World. In Chile there are 15 galleries near Pica, cut into soft piedmont deposits and ranging in length from 300 to 7750 yards, with a total length of 18 miles. The discharge totals 9.5 gallons a second, part of which is used for local irrigation and part to supply the city of Iquique. Similar systems are reported elsewhere in western South America.

Infiltration galleries are a well-known engineering measure for collecting ground water. The city of Los Angeles, for example, obtains a part of its water supply from tunnels beneath the bed of the Los Angeles River. These are regular tunnels, however, with no open wells and thus are not properly qanats. Similar water-collecting tunnels are present elsewhere in Southern California.

OTHER AREAS

Honolulu also obtains a good deal of its water from horizontal wells dug into the volcanic hillsides. These galleries are particularly effective where they penetrate vertical dikes that trap ground water.

Unconfirmed reports suggest that qanats may be present in Spain and in Italy, but details are lacking.

Qanats are thought to exist at the base of the mountains of Soviet Central Asia, but the available information is limited.