UNDERGROUND WATER GALLERIES IN MIDDLE EAST AND CENTRAL ASIA
survey of historical documents and archaeological studies

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Summary

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The historical development and the engineering characters of hydraulic devices for the exploitation of surface waters are relatively well studied and documented. At the contrary underground water systems (wells and water galleries) rarely attracted archaeological studies so that their engineering features and history are badly known. The present paper provides a review of the history, diffusion, technical and social and cultural aspects concerning underground water galleries during the last 2700 years. The specific geo-morphological and geo-hydrological features of desert landscapes favoring their implementation are sorted out, with particular attention to 2 cases: the Iranian plateau and the Turkestan oasis at the piedmonts of the Big Karatau mountains (Kazakhstan).

1 - Surface and underground water systems in history

Water being a fundamental element for the existence of human communities, the evolution of the systems of water-use represents a process of the highest relevance for the understanding of human history. The presence of water determined favorable places for hunting, for collecting fruits and seeds, for localizing camps and more or less stable settlings. From the earliest times it has been used in all its forms: as surface water from rivers, lakes, and springs; as subsurface (underground) water reached by shallow pits and wells; as meteoric water collected in natural or artificial concavities.

Scarcity of water due to climatic changes or demographic expansion disturbed human communities and for thousands of years compelled adaptations just in the form of migrations to better watered places. But as soon as settled life became a habit and a productive economy substituted that of hunters and collectors, the problem of water scarcity could less and less be solved by human displacements and promoted instead technical improvements in the primitive ways of water collection. From that moment until the advent of commercial and industrial economies, the progressive realization of large water systems made most of the human population live within the orbit of irrigated areas; and determined by itself a total reshaping of the landscape. That huge process has been called "hydraulic civilization" (Wittfogel 1957).

The run-off of the precipitation waters from land to sea happens by 10% on the surface and by 90 % underground. Surface waters are constituted by rivers, springs, and lakes. Water-bearing underground zones are called aquifers, where water can be slowly moving or settled.

1.1 - Surface water systems

Quite known is the historical succession of techniques for transporting and storing surface water with the help of several sorts of canals and reservoirs. Simple radial canals can bring water from quiet streams into surrounding lower basins; or they can drain away excessive water from flooded areas planned for agriculture. A gravity fill of earth, stones and gravel can build an artificial basin and catch seasonal river floods; or, applied on the stream itself, constitutes a dam from where water can be diverted elsewhere by channels. The problem of water-lifting has been solved in history by the invention of several kinds of devices, from hand-lifting to stream or animal powered mechanical devices and finally electric pumps.

Small and simple systems and devices for water collection and diversion started to appear during Aeneolithic time (4th millennium BC) in Mesopotamia, built in a very changeable hydrological context by Sumerian people expanding from the inner river valleys to the alluvial plains of the Tigris and Euphrates. These plains were desertic lacustrine landscapes characterized by seasonal floods and rich lime soils: the newcomers transformed them into a large area of irrigated fields through the construction of sophisticated systems of catchments, channels, basins and fields, cisterns, and proto-towns. At first were implemented primitive flood catchment-and-basin systems that, around 2500 BC, were partly substituted by perennial reservoir systems. In 1750 BC, in Babylon, Hammurabi promoted the extensive use of water-lifting devices such as counterweights and animal powered wheels. In 1300 BC a rock-fill dam was built in Syria that still works today. Hydrological works had a significant development under the Achaemenid (550-331 BC) and Sassanid rule (224-602 AD). It is highly possible that Mesopotamia and the Iranian plateau are the regions where several kinds of water systems were first applied and then spread in every direction: Middle East, Kopet-Dag, Indo, Arabia, Greece and possibly Egypt (Spooner 1974)

In upper Egypt, drainage of Nile flood waters has been extensively done from 5000 BC; but it is with the end of the 4th millennium, possibly under the influence of Sumerian immigrants, that large irrigation works started to be built all over the delta; and in 2900 BC the construction is recorded of a masonry dam 15 m high across the Nile.

In China the first simple irrigation systems date back to 2000 BC, attributed to the mythical administrator Dayu who diffused agriculture and the art of making rice fields, ditches and channels. Attempts for taming big rivers through large irrigation systems started with the centralization of power realized by the mythical founder of the Chou dynasty (1040 BC). Techniques improved consistently during the second part of the 1st millennium BC, when the Dujiougyan irrigation district in the Sichuan province was built: it multiplied by 5 the crop production and is still in use today. The Han dynasty (2nd century BC – 2nd century AD) developed a wise water policy that raised the population number to 50 million; and, under the Tang dynasty (7th-10th centuries AD) the invention of waterwheel pumps permitted a huge reclamation of land and a further demographic expansion.

In Central America primitive irrigation works appeared during the 2nd millennium BC under the early Maya kingdoms (and possibly on the Peruvian dry coastal zones), but they developed into large systems only during the 3rd century AD, together with the centralization of the Maya political power. Around 300 BC simple irrigation works started among early settlers in the deserts plains of New Mexico. During the first half of the 1st millennium AD the Inca kings developed the hydrological systems of the coastal regions and imported them in the mountain zone totally reshaping the inland valleys.

Most probably simple techniques of surface water use were invented independently in several places of the world: everywhere they started on alluvial plains as devices for the diversion of seasonal floods from cultivable areas back to the river; and then evolved by directing the drainage channels across dry areas that, water-fed by the sides, were reclaimed to cultivation. The Mesopotamian plains and the Iranian plateau show a very early evolution, under the rule of centralized kingdoms, of complex flood basin systems and then perennial reservoir systems. The fact makes us suppose that from the 3rdmillennium BC onward these territories constituted the main point of application of surface water technology, and of their diffusion first all over Middle East and Egypt and then in all directions to Europe, India, Arabia and China (Downing 1974).

1.2 - Underground water systems

Less known is the history of human exploitation of *underground water*. Where an aquifer is present with a water table not too deep, with a quite soft water-bearing material, *wells* can be easily dug by hand: that is a method as old as man. The technique of digging wells definitely improved during the last millennia with the development of agriculture, the rise of big settlements, and the introduction of digging tools and of masonry constructions. Their improvements made it possible to reach aquifers tens of meters deep: brick lined wells are recorded in the Indo basin (Mohenjodaro) in 2500 BC; a well 500 m deep in China during the Han dynasty.

Another technology for the exploitation of underground water, as old as the one of digging shallow wells, was *tunneling* (i.e. the excavation of horizontal galleries in alluvial deposits and rocks) to increase the flow of a weak source. Bifurcating galleries in sedimentary and volcanic rocks can be found all over the Mediterranean and Middle East, dated back to the early Neolithic.

Welling and tunneling becomes the prototype of a more advanced technological step when it becomes a system that brings into existence a spring that didn't exist before. Such systems can eventually be of different kinds, but the only well documented is the tunneling to surface of aquifer waters by *underground galleries*. The first historical appearance of this tunneling scheme is generally considered to have happened in the context of mining works during the Urartu kingdom (North Iran, 8th century BC) as an expedient for drainage of underground waters. Water, when found in mining ditches among other mineral deposits, poses the problem of its drainage out of the pits. During the 1st millennium BC a good technical solution was the construction of underground galleries gently sloping (so that water can flow by gravity) from the aquifer to an opportune surface discharge point, provided along the way of vertical wells permitting uplift of excavated material, aeration and maintenance. That method could then be applied for the mining of water itself out of aquifers and for its transport to the surface in an area planned for irrigated cultivation. It is a fact that the Kurdistan mountains, with their rich ore deposits and the most ancient mining activities, provide also the first historical documentation of the existence of special systems of groundwater drainage galleries. The document consists in the account of the destruction in 714 BC, by the Assyrian king Sargon II, of the underground water systems feeding the town of Ulhu (today Ula), probably built one century before during the rule of Meinua, king of Urartu (800 BC) (Laessoe1951; Salvini 2001 pp 154-155).

Achaemenid rulers made the construction of drainage galleries the basic instrument for the diffusion of new settlements on arid lands of the empire, and a point of regal honor. Under their rule drainage galleries diffused in the upper Tigris valleys, in Media (Ecbatana) and on the Iranian plateau (Persepolis) where thousands of new villages have been established; and then in all Middle East and Arabia (Oman) (Bouchelard 2001 pp 157-184); as far as Egypt where, during the Persian domination, some abandoned oases (such as Douch-Ayn-Manawir, Kharga) were rehabilitated with the construction of over 100 underground devices (Wuttman 2001 pp109-136). Their existence during the second part of the 1st millennium BC is quoted by ancient historians such as Herodotus, Polybius, Diodorus Siculus (Briant 2001 pp 15-40). They were exported in North Africa under the Roman empire by Jewish colonies (118 AD) (Beaumont 1987). The Sasanides followed the Achaemenids policy of agrarian colonization by promoting irrigation schemes on alluvial plains and underground galleries on dry slopes. By that they developed the hydrological management of the territory to an unsurpassed excellence and under their rule the population of Northern Iraq grew to 15 million (40% higher than today). Under the Arabs, galleries spread from the Middle East to Cyprus, Sicily, Morocco, Spain, Canary Islands; under the Abassides from East Iran to Central Asia and Mecca. After the conquest of America the Spanish diffused them to Mexico and Peru (minas de agua), together with silver mines (minas de plata) (Bekman 1999).

Drainage galleries are called by different names in different parts of the world: qanat in Iran; karez in eastern Iran, Baluchistan, western and eastern Central Asia; falai in Arabia; foggara in Maghreb; rhettara in Morocco; pozeria or galeria filtrante in Spain; falaj, mambo or alcavor in Mexico; fuques or pukios in Peru; drainage galleries in English. These names all mean "device bringing ground water to the surface".

In the world 15 million ha (0.6% of all the irrigated land) are watered by underground galleries: almost half of them are situated in Iran, the others in Afghanistan, Pakistan, Turkmenia, Azerbaidjan, Tarim, Oman, Maghreb, Morocco, and Mexico. In fact during all periods up to now, the Iranian plateau has always been the region where drainage galleries represent the main if not the only type of water system, where a privileged class of specialized diggers exist (muqanni), and where such a technology is continuously ameliorated and exported. On that territory, until 1950, 38000 galleries (totaling 160000 km) were in use, supplying the total water necessities of towns such as Teheran, Qum, Nishapur, Yazd, Kirman, and of half of the irrigated lands (7 million ha of orchards and fields). Then, by the concurrence and the disruptive effects of modern devices such as deep wells and water pumps, 17000 were abandoned and 21000 are still functioning, constituting a major water source for the Iranian plateau and almost half of the drainage galleries in the world. The main concentration is found on the slopes of the Shir Khu mountains in the surroundings of medieval town of Yazd (Goblot 1962; Baillant 1992).

The durability and efficiency of techniques of exploitation of surface and underground water, in antiquity as in modern times, are dependent on changes of climate and of hydrological regimes. But also in absence of such natural forcing, the schemes of hydrological works are not always sustainable and can lead in a few decades or centuries to their own collapse. Excessive irrigation without proper drainage comports soil salinization; mismanagement of canals produces siltation and even the uplift of immense piles of silt alongside can contribute to plug the system. In the case of hydrological systems extended on very large territories, a centralized political structure is necessary for their management: social conflict can eventually break into pieces that political structure letting the water system go in progressive deterioration. Shallow wells can be exploited beyond the recharge rates of the surficial aquifer; and deep wells generally exhaust non rechargeable fossil deposits. So the history of mankind is marked not only by the gradual improvement of hydrological technology but also by the cyclical disasters caused by an unregulated exploitation of water resources. It is quite possible that the irrigation schemes of the Mesopotamian plains encountered the first big problems with floods and siltation as early as 3200 BC; they manifest clear signs of soil degradation and salinization first in south Iraq in 2400 BC, then along the Euphrates in 2100, and in north Iraq around 1300 BC. 1200 AD, with the help of the Mongols, signs the final collapse, after more than 4000 years, of the Mesopotamian irrigation systems.

But the Iranian plateau, with a water supply mainly based on underground galleries, didn't encounter major hydrological and pedological crises and it still uses ancient technologies. Apparently the historical fortune of water galleries in dry regions, still in use in spite of their high costs, is due on one side to their cautious use of water resources and structural sustainability; and on the other to their possibility of decentralized implementation and management by part of relatively small communities.

2 – Technical and social features of the karez of the Iranian plateau

Hidden underground waters are much more mysterious than the surface ones. Their diversion and exploitation needs more sophisticated exploration and devices, which are labor consuming and expensive; and so their maintenance. The amount of water that they can transport is quite small when compared with surface water systems of the same cost.

Drainage galleries, that further on we will call shortly *karez* (their denomination in East Iran and Central Asia, meaning in Persian "water uplift"), are an excellent example of the exploitation of underground water. The purpose of a karez is to collect some amount of underground water from an aquifer and to make it flow to the surface ground, as a kind of artificial spring, in a chosen area. Water will move by gravitation along a gently sloping underground gallery, provided all along with regular vertical wells for aeration and maintenance work (**Fig 1, 2).** The water is transported clean and cool, its evaporation and pollution is carefully avoided, and so eventual robbers.

Karez represent expensive engineering works for extreme arid conditions, capable of bringing into existence a spring and of building an oasis. Moreover they fix the localization and the plan of villages and fields; require a special social context for their construction, maintenance and use: briefly, they show a tremendous power in reshaping the arid landscape, the village (and town!) plans, the socio-economical relations, the mythology and the rituals of the oasis dwellers. This paragraph provides a general description of the technical, social and cultural aspects of the karez, and shows the strict interdependence existing between the three aspects.

The main technical elements of the system are the aquifer that provides the water, the engineering construction itself and the aerial areas (open canals lattice, orchards, fields and houses) developing after the daylight emergence of the waters.

2.1 - The aquifer

The run-off of the precipitation water from land to sea happens by 10% on the surface and by 90 % underground. Water-bearing underground zones are called aquifers and can be of 2 types. They are called "confined" when their water table is separated from the ground surface by a layer of impermeable material: this type of aquifer is generally hundreds of meters deep, thousands of km^2, of very ancient genesis and not rechargeable under current climatic conditions, out of reach of the karez technology. The "unconfined aquifers", most common, are those open to the atmosphere through permeable materials. They are the same hydrological phenomenon that, when the water table is high enough, manifests as a surface water pond or stream, with the speed of the flow increasing consistently from the underground bottom to the surface top: they always underlie active springs, lakes, streams (even when seasonally dried by the fall of the water table); they can underlie dry ancient basins and river courses. They get quite rich in water when:

- their bottom is sealed by impermeable materials with high clay content (shale or sandstone) or non-fractured rocks impeding a deeper percolation of water and favoring it horizontal expansion;
- when a suitable recharge rate is provided by rains on the recharge area (surrounding hills or mountains hundreds of km away);
- when the material saturated by water is very porous sand seam or fractured limestone, capable of holding an high volume of water per cubic meter (sand with 30% of porosity holds 10 liters of water per cubic meter) (Mass Aud Soc 1993, Internet 1).

In very dry areas, due the strong evaporation, unconfined aquifers, if well sealed and well recharged, represent the only existent accessible waters and can be exploited by the karez technology.

Water is caught, in an opportune point by a ditch at an average depth of 10-30m (up to a max of 100 m); and diverted with an opportune angle by underground tunnels to areas endowed with agricultural potential. When a well is dug into an aquifer, water will fill the ditch by gravity pressure, which depends on all the elements listed above: permeability and porosity of the material, depth and drift angle of the aquifer. Water will keep draining into the well as long as recharge rate of the aquifer will keep the level of the water table high enough. Eventually an excessive drainage speed would provoke, in the part of the aquifer surrounding the well, movements of small particles that will seal the pores and make impermeable the area of collection: a case that requires restoration work.

These characteristics mean that pebble beds and gravels at the bottom slopes of dry alluvial fans generally hide the aquifers the richest and the easiest to be transformed into open air sources by karez technology. These geomorphological and hydrological conditions are quite rare, and with them is rare the correspondent diffusion of the karez technology. Such landscapes with karez can be found, here and there, in North Africa and in the desert band cutting SW-NE the Eurasian continent (Bousquet 2001 pp185-190); and are quite characteristic of the Iranian plateau where correspondingly underground galleries have been used first and most extensively. Referring to Central Asia, such natural features are found on the northern slopes of the Kopet-Dag mountains (Turkmenia), the southern slopes of the Karatau mountains (south Kazakhstan), and in north Tarim (Western China). In Central Asia, up to now, karez, still in use or abandoned, are found only in these three regions (Anarbaev1981, pp71-94).

2.2 - The building of a karez

In few arid regions of the world ancient karez are still in use and new karez are under construction. It is on the Iranian plateau that today are found the biggest concentration of galleries (called qanat) and the most skilful diggers: their building methods, very traditional and using very ancient technologies, provide ethnographical material for the following account (English 1990, pp187-205; Internet 2):

In the building of a karez three phases can be distinguished **(Fig 3)**: a first phase of investigation and planning, a second of construction, a third of maintenance.

During the *first phase (planning)* an expert will try to locate the presence of an aquifer uphill from the land that is intended to be irrigated. He will survey the surroundings, searching for damp areas along the base of a cliff or escarpment, or the floor of a dry wash. A short karez will be normally built at the mouth of a dry alluvial fan, a long one on more various topographic settings. After the most profitable point has been individuated, a well (mother well) is first dug as collector of the aquifer waters: with shape opportune for catching a maximum of water, deep enough (average 50 m) to reach the water table and to filter an average of 2 m of water overnight. The depth between the level of the water table and the ground surface level is measured by a knot on a rope. Then the way of the future tunnel from the mother well to the emergence point is drawn: on average 3-4 km, exceptionally 50, in its first part intersecting the aquifer and then passing through its top into dry beds. On that way, at regular distances, the level of the water table relative to the new surface is calculated by the use of a primitive form of topographic instrument guaranteeing a horizontal precision (a kind of theodolite): a string stretched between two poles and some drops of water free to move along it. In that way the sloping gradient of the tunnel is planned: it must be significant enough to let the water flow down by gravity; and small enough to minimize speed, erosion and siltation. These operations are repeated all the way down to the point where the spring emerges in the atmosphere or at least flows at a depth not exceeding the 2 m (daylight well).

The *second phase (construction)* starts from the daylight well and proceeds uphill until the mother well. After the daylight well, a second well is dug 15-20 m uphill along the planned course, to the depth calculated by the topographic measures. Then, between the basis of the daylight well and that of the second well, a tunnel is excavated 1 m large and 1.5 m high (the optimal size for the work of a small boy with special instruments). The procedure is repeated further uphill at regular distances until the mother well is reached. The vertical wells that result provide openings for lifting out the excavated materials and for aerating the underground cavities and eventually, in case of deep wells, by pumping air into them. The straightness of the tunnel is ensured by 2 aligned lamps: the digging worker, just looking behind his shoulders and seeing the alignment of the flames, will be sure to proceed in a straight line **(Fig 3.1).**

Sometimes, in easy and well known conditions, first all the wells are excavated down to the planned depth, one every 15-20 m; and only then their bottoms are connected by an underground tunnel.

Generally, in order to increase the water flow to a required volume, not one but several mother wells are built, together with relative galleries bifurcating from the main one.

Some karez, when built parallel to seasonal streams, will bring ground waters to the surface during a dry period; and will provide filtered clean water out of the muddy flow during wet periods.
At the end of the 60's, in Kirman on the Iranian plateau, for the construction of a karez 1 km long with a mother well's water surface 50 m deep, was necessary a brigade of 4-5 specialized workers, 17 years of work and 10000 US$: that means that a brigade can produce 3-7 wells a year at the cost of $100-200 each.

Third phase (maintenance). After the karez is built, it will always be in need of maintenance, repairing and extension by new branches. The surface mouths of the wells must be kept closed by wood and bushes to impede evaporation. The mother well must be sealed when water is not needed. The galleries must be cleaned regularly, in particular after an abundant water flow: the cleaning operations accumulate ground around the mouth of the vertical wells, shaping the doughnut-like alignments that characterize the karez landscape. The vaults occasionally must be reinforced by wooden structures; and in sandy parts the tunnel walls must be covered by masonry (**Fig 3a**). The drainage into the mother well can diminish by movements of small particles inside the aquifer (in the cone of depression that gets formed around the mother well) and can end up in plugging the pores and stopping the water drainage: in that case the karez must be extended deeper into the alluvium, or a new mother wells must be dug nearby and then connected to the karez by bifurcations of the main gallery. Earthquakes, very wet transgressions or just antiquity can seriously damage the construction and compel the substitution of some segments by parallel galleries or the reconstruction the entirely system. Bats sleeping and nesting in the underground galleries must regularly be evacuated.

The karez stops functioning as soon as the water table falls under the drainage level of the mother well; and it restarts as soon the water level rises back over that point. So it constitutes a sustainable way of exploitation of water resources, with the geological and technical features of the mother well fixing and regulating the rates of drainage.

In the "Book of Qanat" (Kitab-I Qani, 9th century AD), a body of customs and laws concerning the social management of karez, the problem of their density is considered, and solved by forbidding the construction of a second karez parallel to an existing one at a distance less than 1 km.

2.3 - The aerial lattice of canals

The average amount of water carried to the open air by a karez can be 2 or 20 or 100 or more liters per second. A small karez can irrigate an area of 1/5 of hectare in 1 day and of 2x2 km in a year; and 4 of them are enough to feed the activities of a village of 500-1000 families.

The water ends up in being very expensive and the management of its aerial distribution is done with extreme care. The optimal ramification of the lattice of open air water channels is first planned, which will condition the localization and patterning of houses and fields.

The classic shape of the karez oasis is triangular, with the daylight well as upper vertex and a main channel running at the center. From this channel depart lateral bifurcations that broaden the watered area. Along these branches are located houses (provided of courtyards with central pool, canals, garden and orchard) so that the karez determines the village plan **(Fig 3.2)**. Further down the karez water feeds the fields, they too shaped and dimensioned by the karez: they are square and dimensioned by qasab, a unity of measure corresponding to an area of 9x9 meters.
In reality the qasab is not an absolute measure of space but is the measure of the duration of the water flow (in fact a measure of time) necessary to a specific karez to provide the amount of water necessary every day for the irrigation of 9x9 m of that specific land. Its value depends on the carrying capacity of a specific karez, the kind of soil, the kind of crops, so is slightly different in every case and village. The qasab is a practical tool: it is the basic principle for measuring the shares (sahms) of water and for managing the whole repartition in a specific village. Water is distributed to the different fields cyclically with periodicity going from once every 6 to once every 22 days. The management is done under the direction of a water supervisor: the partition is planned collectively; the water diversion is done with the help of weirs and sluices; the time measures are provided by a metal cup with a hole in the bottom put to sink in a water container.
It is near the daylight well that water is more abundant and perfectly clean: across the village water losses can reach 40% and the quality is reduced by pollution. This fact determines the functional distribution of buildings. In the upper part of the village are always located the public water storage (ab-anbar) (Internet 3), the public bath, and the pool of the mosque. Down-stream are successively located different pools: for domestic use and internal orchards, for animals, for construction; and finally the remnant water is diverted to the fields beyond the last houses. The localization of private buildings follows the socio-economical status: houses and orchards of the most prosperous landlords, religious leaders and karez owners are distributed along the primary stream at the top of the village; the ones of the poorer are downstream and in peripheral

areas of scarcity and pollution. (English 1990 p 196; Farooqi 1998 pp 99-101). Houses, eventually, are provided with 'air-conditioning' underground rooms on the karez shore.

In case there is more than one karez serving the same village and oasis or bringing clean water to a town, the settlement patterns spoken above will get more complicated, but the basic principles of the space interaction between water system and human activities will be respected: water is a limited resource and it costs, the waters of the daylight well are the best and most expensive, their further flow and use always happens in a scientifically planned lattice of canals.

Karez and villages or urban quarters are so interconnected that local people will communicate the home address by giving the name of the karez that feeds the house.

2.4 - Social and cultural aspects

The cost, time and skills necessary for building and maintaining a karez are very high. But in arid regions, when in function, the karez represents a kind of miraculous pure spring, capable of determining the survival of a whole village and so carrying an enormous economical, social and cultural impact. In fact the successful construction and utilization of a karez system doesn't just depend upon its technical and structural arrangements but also upon several social factors. On one side it has high costs, on the other it provides a unique mean for economical profits; on one sides depends from and on the other promotes social integration.

The preconditions of the functioning of a karez are the existence of slaves or of a very cheap class of workers supporting its material construction and maintenance; the commitment of kings, landlords, rich families, kinship groups promoting the construction; a class of skilful specialists that guarantee the technological aspects; and a perfect social cohesion. Any disharmony and conflict between or inside each of these protagonists will undermine the functioning of some parts of the system.

All dynasties in Iran trained slaves and captives in the construction of karez; and today labor costs are sufficiently low to provide the workers for keeping in function old karez and for building new ones.

The Achaemenid rulers gave incentive for their construction by allowing the entrepreneurs of new devices and their heirs to retain profits for 5 generations. In fact to build and manage a karez doesn't only give local privileges in the use of valuable water but represents also a profitable business. The ownership can be individual, or by kinship clan, or collective. In all cases part of the water is used by the owners and part is sold to other members of the village, eventually in exchange of corvйes for its maintenance. For example in the case of Mahan (Yazd), a village fed by 4 karez, the shares of the ownership of one of them are 6: 2 are the property of the priest of the shrine and 4 of 20 owners; the remnant of water is sold to 70 families (English 1990 p 201). An extreme case is documented where the water property is fragmented in such extent that the smaller share is reduced to 30 seconds every 12 days.

The karez gives an oasis to the people, to the owners it gives privileges and profits; but it is to the builders that goes honor and prestige. Most probably a cast of water-wizards existed from ancient times, which, cooperating first with the Urartian miners and then with the Achaemenid kings, developed the tunneling techniques into the almost perfect technology of the karez.

Today, in Iran the builders of karez are called *"muqanni"*. They are semi-nomadic kinship groups with secret hereditary transmission of knowledge. Their difficult and hazardous work encounters many problems and frequent death accidents: from very young age the muqanni risk their life in digging the underground tunnels, with the father helping and directing the operations from outside, so that only few of them reach an old age. The job requires skill, courage and a specific spiritual taint that attires honor and devotion. They are well paid and highly respected; they work only during favorable days and prayers are said over them by the villagers every time they descend in the pits; their instruments are treated as ritual tools **(Fig 4)**.

But the highest protagonist of the karez oasis is the karez itself. From being the cause, it becomes also the symbol and ritual mirror of the social cohesion. It deserves the physical and spiritual respect normally given to a spring, if not even higher. It is so appreciated, cared and beloved that songs, myths and legends flourish about it. A treasure is suspected to be hidden in the mother well. Every karez has its own name, its own gender (hard waters laden with metals are considered male, soft sweet waters female). It gets respected, personalized, spoken, presented with food offerings …and even introduced as a member of the human community by marriage.

A ritual is performed to improve the abundance of waters by mating the karez to a human partner. In case the karez has hard waters and masculine sex, a woman volunteer will be married and faithful to him during one year: it could be an old woman, or a widow or a virgin, depending on the character of the specific karez and the customs of the village. In case the karez is of feminine sex, the mate will be a young boy. A real marriage ceremony is performed at the daylight well with the participation of the whole village, with music and a

banquet, culminating in the bride (or the groom) bathing naked in the karez, a love-meeting that will be performed twice a week during one year (Internet 1).
Even the fish living in the underground galleries get their share of devotion: they are considered to be white, blind and immortal.

3 – Karez in Central Asia and Kazakhstan

Among the water supply systems of the medieval cities of Central Asia the karez are the most sophisticated and less investigated by ethnographical, archaeological and hydrological studies.
They are mainly constructed on gently sloped piedmonts in semi-desert areas, for the water supply of agricultural oases or cities. Such conditions are not rare in Central Asia but, in spite of that, up to now karez have been found only in a few sites, probably not just because of the difficulty of their implementation but because of the lack of accurate surveys. They exist on the northern slopes of the KopetDag mountains and on the Murghab delta (Turkmenia); on the Pamir and Tienshan piedmonts of Transoxiana and Ferghana (Uzbekistan); the southern slopes of the Karatau mountains (South Kazakhstan); northern Tarim (Turfan, West China).

In the Turkmenian KopetDag piedmont plains karez are still in use today in the regions of Izberzen, Ishan, Khankarez, Dev. They average a length of 2000 m, a mother well of 25 m, vertical wells every 50 m, and drainage of 20-150 liters per second (Akishev-Baipakov 1973 p 78; Nurgeldiev 1994, pp 62-64).
In Transoxiana alignments of a few hundred meters have been found on the Nurata range and on the foot-hills of the Ferghana valley (Khamraev 1948 p 27).

In Tarim (Western China) Karez are found in the Turfan depression and on southern slopes of the Barkol range north of Hami. In Turfan, in 1600 AD, they numbered one thousand with a total network of 5000 km: and most of them are still in use today. Their function and construction are described by the ethnographer G. E. Grum-Grzhimajlo in the following way: “In an area known to the locals as hiding a water layer not too deep under the surface, a “head pit” is dug, i.e. a narrow and deep well down to the water table; at the distance of 8 meters, a second well is dug, then the third, the fourth, the 100th, until the last one with a depth of less than 2 m; after that all these wells, starting from the last one, get connected each other by digging an underground gallery proceeding uphill deep into the water-bearing ground …Finally, along that main gallery, some other branches are dug for the purpose to increase the water drainage into the karez. Seen with the eyes of a flying bird, the earth surface will appear as pitted by a gigantic mouse, with the difference that the heaps of ground accumulated outside are not scattered in disorder but disposed in harmonious lines. This is a karez” (Grum-Grzhimajlo 1986).

Up to now, in Kazakhstan very few lines of wells have been found and only in the oasis of Turkestan, situated along the large alluvial slopes with the Karatau mountains on the NE and the Middle Syrdaria river on the SW. They are supposed to be karez and in this case they will be the signs of the most northern area of their distribution. Some of the wells were still in use at the end of the 19th century; today they are all abandoned; some are today the object of geo-archaeological study. By their big size they are more similar to the karez of Iran than to the ones found in Turkmenia and Uzbekistan.

4 - Karez of the Turkestan oasis (KZ)

4.1 - Historical documents and first archaeological studies: the karez of the medieval towns of Sauran and Turkestan

Most of the territory of the Turkestan oasis is characterized by very few permanent streams with limited water supply. Such hydrological conditions didn’t favor the development of large surface irrigation systems and eventually stimulated the development of wells and other hydraulic devices for the use of underground water.

Information about the existence of karez among the water supply systems in the oasis of Turkestan comes from several sources: from *historical documents*, from the toponomy of places and villages, from the testimony of some local elders, and from *archaeological surveys and research*.
Scientific surveys within the Turkestan oasis up to now have discovered karez in 5 sites: Sauran, Turkestan, Chernak, Babaikorgan and Karashik. The karez of Sauran and Turkestan have been spoken in historical documents or legends and have been found respectively in the 60’s and in 2002. The last 3 sites are slightly indicated by the toponomy of the area and have been discovered in the year 2002. In all cases the wells are aligned parallel to dry or seasonal rivers beds, on the bottom slopes of the desertic alluvial fans of the

Karatau range, where the drift rate doesn't exceed the 5 m per km **(Fig 5, Fig 6)**. They have all been found in areas today not interested by modern agriculture, a fact that permitted their easy aerial detection. But they are eventually present in cultivated areas and aerial surveys during early spring will eventually show anomalies in the colors of the vegetal cover that could witness the presence of wells and bring to new discoveries.

Sauran karez. The existence of karez near Sauran is reported by the 15th century Tadjik writer Makhmud Zainaddin Wasifi. In a passage of "Amazing Events", he says that the Muslim sheikh Mir-Arab offered to Sauran, his native town, 2 karez "similar to nothing that people traveling all around the world on land and sea had ever seen". They were built with the help of 200 Indian slaves. The bigger of them had the mother well one farsakh (7.5 km) from Sauran, a ditch 200 gyaz deep (1 gyaz = 0.6 m) with the water table at 50 gyaz (which seems largely exaggerated, see par 4.3). From there the water was channeled down to Sauran, but part of it was utilized in situ: it was lifted from the mother well by an animal powered water wheel (chigir) and used to irrigate an area well protected by walls and transformed into a garden with vineyards and buildings. Wasifi himself was committed by Mir-Arab to write the official document that made of this walled garden a wakuf, a site of popular religious use. (Lerkh 1870, pp14, 21, 31; Boldirev 1957 pp167-168; Barthold 1965 p147; Pischulina 1969 p 18)[1]

The first archaeological research of the old town of Sauran during the 50's didn't find in the immediate surroundings any remains of karez or of other hydraulic constructions (Ageeva-Patsevich1958, p 150). Only in 1969 remains of two lines of wells northwest and northeast of the old town respectively along the dry course of the Tastaksai and Maudaktal stream were discovered through the decoding of aerial pictures (Akishev-Baipakov 1973, pp76-78). During the following years the presence of a couple of karez in the vicinity of Sauran was considered an exotic phenomenon in the medieval history of the water devices of Kazakhstan, and the construction of such a complex hydraulic engineering construction an incidental fact.

In 1986 the IOUKKAE (South Kazakhstan Expedition, directed by V. A. Groshev) planned a detailed investigation of the karez system in the Sauran territory. It started making a topographical documentation of the karez and of their agro-irrigational settings. The average diameter of the outer ring is about 5 m and the distance between wells is 15 m. Three lines of wells have been detected north of the old town, possibly part of the same system. The first line of 20 wells is just 1 km north of the walls; a second line of 50 wells is clearly visible 3 km north of Sauran: it develops for 800 and at its northern end bifurcates into two short branches of 22 and 10 wells. A third line appears 1.5 km further north (Groshev1985, pp 96-97). These preliminary surface explorations hypothesized that the source of the karez could possibly be located in the area of the medieval town of Mir-Tobe, 7 km north from Sauran **(Fig 7)**. These ruins consist of a square platform (45x45m) surrounded by a perimeter 200 x 50 m of walls 3 m high, flanked with 10 towers and a gate in the middle of the southwest wall. The ceramics found in situ are dated to the 15th-16th centuries AD (Ageeva-Patsevich 1958 pp101-102)[2]. Thereafter the ruins of Mir-Tobe were identified as being the fortified mother well mentioned by the medieval historian Wasifi. Unfortunately, the work could not be carried on beyond the year 1988.

All these suppositions about the Sauran and Mir-tobe karez are far from convincing. Two wells of the first line 1 km north of Sauran have been excavated by Groshev. They have a diameter of 0.9 m and the upper mouth strengthened by rings of baked ceramics (17-20 cm high and 5 cm thick), but no underground gallery has been found. (Groshev1996, pp180-189). New surveys of the Mirtobe area implemented during 2002 revealed that the line of wells doesn't start from the walled town but 400 m northeast of it.

Concerning ***Turkestan*** town, several documents and legends quote the presence of underground galleries. An 18th century map shows the existence of 11 wells within the walls of the city, the underground gallery found north of the mausoleum being most probably a daylight well. Verbal accounts speak about some wells still visible at the beginning of the 20th century 3 km north of the town. One of the canals bringing water to the city of Turkestan is named Djuka-kyariz; and in the northern suburbs of the city there is a village called Kyariz (Groshev 1985, p101). Legends exist about mysterious underground galleries (roads, passages) under the city discovered by curious boys: the popular memory, burdened by the weight of conjectures and myths, even connects these galleries with the life and activity of Hodja Ahmed Yasawi, and suspect them to be underground roads connecting Turkestan with Otrar, Sairam, Tashkent, or even directly with Mecca[3]. More significant is the discovery by archaeological survey, during the restorations of the Muslim crypt of Aulie Kumchik-Ata of summer 2002, of some aligned wells 1 km south-east of the mausoleum of Hodzha Ahmed Yasavi, just at the periphery of the medieval city of Turkestan.

4.2 - Recent discoveries of new karez: Chernak. Babaikorgan, Karashik

During the years 2002 three aligments of wells formerly unknown have been discovered in the region of Turkestan: those of Chernak, Babaikorgan and Karashik. They have been found with the help of microlight aerial photos: from an altitude of 500-1000 m they manifest as lines of dark round spots corresponding to the rings of excavated material that surround the mouth of old wells filled by sediments **(Fig 8)**. Their discovery shows that the wells lines of Sauran are not an isolated phenomenon but part of an underground water catching system largely diffused in the region, adding new light about the historical development of water management devices in arid zones of Central Asia and about the managing skills of the early Kazakh khanates of South Kazakhstan.

Chernak karez. In June 2002, some specialists of the Kazakh project TAE (Turkestan Archaeological Expedition)[4], surveying the surroundings of the old town of Sidak, discovered a line of peculiar rings of piled ground paralleling the dry ravine of the Namanark seasonal stream. The line is situated 7 km north of the medieval town and 4 km north of the village of ***Chernak***, just northeast of the junction between the highway Turkestan –Kyzyl-Orda and the road to Babaikurgan, (N 43°25'40", E 68°04'20") **(Fig 8, Fig 9)**. The rings, consisting mainly of loam and sand and pebbles, have a heap 0.4-0.5 m high, external diameter of 10.5-11 m, and internal diameter of 3.5-4.0 m. They are laid in succession, at a distance of 15-20 m from each other, along a NNE direction. A main branch of 70 wells can be clearly seen, more than 1 km long. From the northern end of this branch two branches of 10-15 wells bifurcate respectively in the NW and NE direction toward two parallel dry river beds. The branch going NE ends up by dividing further in three final branches which seem to correspond to a main mother well **(Fig 9**). The soil of the area has been recently used for the culture of melons so that many wells have been partly destroyed.

In October 2002 a cooperation between the Kazakh project TAE and the international INTAS project "Geo-archaeological investigations of land use and irrigation works in Kazakhstan in present and historical times"[5] surveyed and photo-documented the karez of Sauran and Chernak; and explored the possibility of karez along other river courses of the Turkestan region, by field walking and aerial micro-light recognition. Clear traces of karez formerly unknown has been discovered and documented in 2 other localities: Babaikorgan and Karashik.

Babaikorgan karez. A line of a few wells has been found along the premountain segment of the same stream, 20 km north of Chernak, 2 km kilometers north-east of the village and walled medieval town of Babaikorgan, on the eastern side of the river bed (N 43°34'38.6", E 68°08'17.3"). The local population calls this area "Kirik-kuduk" (forty wells), in remembrance of the existence in situ of ancient wells. The line of wells stretches in a S-N direction for a length of three-hundred meters. The external features and the size of the rings are similar to those located near Chernak.

Both the hydraulic devices of Chernak and Babaikorgan are built on the same hydrological complex. The 2 streams of Aktobe and Koksarai and the waters of the spring Karabulak merge together in Babaikorgan forming the river known as Jankorganozen. Its upper course provides waters for irrigated cultures building an oasis 2-3 km long. Then it gets dry and intermittent changing as consequence several names: Tastaksai, Namanark and finally, south of Chernak, Ashasai. In the past, during more humid phase and different agricultural schema, the Jankorganozen river was a perennial stream flowing from the Karatau mountain zone down to the Syrdarya alluvial plains.

Karashik karez. A line of 50 karez with features similar to the ones of the systems spoken above has been detected by aerial survey on some desertic gentle slopes 12 km north of Turkestan, 7 km north of the village of Kyariz, 3.5 km north of the village of Karashik (N 43° 24' 20", E 68° 17' 30"). It catches the ground waters from the left bank of the Ashibulak stream and carries them somewhere down on the right bank of the Karashik river.

4.3 - Geo-hydrological considerations concerning the karez of the Turkestan oasis

If these systems of wells of the Turkestan oasis are interpreted as classic qanat-karez with galleries, then their possible engineering features can be approximately calculated on the basis of the geo-morphological and geo-hydrological features of the region, providing tentative models for the planning of further research.

The geological and hydrological maps of the Turkestan district[6] show that the floodplain comprised between the Syr-Darya river and the foothills of the Big Karatau range is constituted by upper quaternary deposits composed of layers 0-450 m thick of sand and loam on a sandstone basis. They are groundwater bearing with deep and surficial aquifers.

Referring to deep aquifers, the Karatau sub-artesian basin shows differences in water table levels of more than 200 m. In several areas water-bearing layers are alternated with waterproof layers of argil and slates in a way that pressured waters are already formed at the depth of 100 m.[7]
Referring to the surficial aquifers, the first water table is located at the average depth of 5-7.5 m. In the area of the city of Sauran the hydrological map shows 2 trial-wells, one near the town and the other 5 km NE, with water table respectively at 8.4 and 4.9 m; 2 other wells located 20 km NE from Sauran, have water tables at 3.4 and 6.4 m. After 10-15 m of sand and loam, the soil composition gets more clayed and the aquifer less rich.

All the karez of the Turkestan oasis are built parallel to dry river courses on the bottom slopes of desertic alluvial fans. By their location the karez found in the surroundings of the medieval city of Sauran seem to have been built with the purpose of carrying fresh water to the town. The karez found in the surroundings of Chernak, Babaikorgan and Karashik seem to be directed toward specific karez villages or just irrigated orchards.

Due to the conditions described above, in the region of Sauran the manual digging of a well deeper than 6-10 m would be difficult without the use of some kind of water pump. That makes totally impossible the case quoted by the historian Wasifi of a mother well 120 m (200 gyaz) deep, with water table at 30 m and an earthen column of water of 90 m. He probably mistakes by saying 200 gyaz instead of 20, which would mean a mother well of 12 m matching with the geo-hydrological features of the region.

The reconstruction of the possible engineering features of the Sauran karez confirms such a view. The 3 lines north of the town could be the remains of a system 7-8 km long going from Mirtobe (235 m asl) to Sauran (205 m asl) with optimal sloping rate of 1/1000. Its construction would require 500 vertical wells along the course and a mother well not deeper than 10-12 m at the top, largely enough for filtering an underground aquifer with water table between 3.4 and 8.4 m of depth.
Just one brigade of muqanni well equipped (4-5 persons) could have done the job in 40 years. The price could have been 5-7 kg of gold. In the karez is really buried a treasure…

Up to now archaeological excavations of karez wells in the region ***didn't find traces of underground galleries so that it is not excluded the presence of a hydraulic system of groundwater use of different and still mysterious nature.*** Moreover it is possible that the construction of the karez of the Turkestan oasis (with or without galleries), of which the implementation is attributed by historical documents to the 16th century AD under foreign impulse, could have started much earlier with simple schemes that developed for centuries by gradual improvements under local initiative. To solve this important question an extensive geo-archaeological survey is planned of the hydrological network of the Sauran region.

Notes

[1] See also the description of P.I. Lerkh, op cit, p.14,21,31; Pischulina, K.A., Prisyrdarynskie goroda I ikh znachenie v istorii kazakhskikh khanstv v XV-XVI AC. In: Kazakhstan v XV-XVIII vv, Alma-Ata, 1969, p.18

[2] E.I. Ageeva, G.I. Patsevich 1958 'Iz istorii osiedlik pasilenii i gorodov Iujnogo Kazakstana (About the history of the settlements and towns of South Kazakhstan)' *Works of IIAE AN Kaz.URSS*, Tome 5, p.101-102

[3] A local person, Dostanov, O., has been the richest reporter of popular legends

[4] In the research of the TAE participated: Smagulov J (archaeologist, MS sciences, Inst of Archaeology Almaty), Tuyakbaev, M.K. (archaeologist, scientific collaborator of the Museum Azret-Sultan), Erzhigitova, A.A. (archaeologist, post-graduate)

[5] The INTAS team was constituted of 4 specialists: Sala, R. (geo-archaeologist, principal investigator INTAS), Pachikin, K. (pedologist, doctor Inst of Soil Sciences); Deom, J-M. (historian, candidate Louvain University), Kuruzyan, Y. (microlight pilot)

[6] Hydrological map URSS. Scale 1:200000, K-42- II. Author: Salov, H.H. Scientifically approved by ЮКГУ committee, 1967.

[7] Formation and Hydrodynamics of the artesian waters of South Kazakhstan. Alma-Ata 1973, p. 7.

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