New Evidence for Irrigation Systems in Kashgar

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Abstract

The importance of Kashgar has been associated with its position on the Silk Road. It is located in a physical bottleneck between the Pamir Mountains to the south and the Tianshan Mountains to the north. It is very much a crossroads, with both northern and southern Silk Routes passing through, with historical evidence for destinations for the caravans that passed through to Central Asia, India, Pakistan, Persia, and China. Most importantly, it was an oasis in the midst of the vast desert of the Tarim Basin, with its irrigated fields producing a wealth of goods and livestock.

The basis for that wealth, that agricultural wealth, and for all that made Kashgar important in trade and as a hub on the Silk Road, was the system of irrigation. This paper adds to our knowledge of that system by identifying previously unknown evidence for *karez* in Kashgar. While this is an important addition, it is only an initial investigation, and indicative of the value of the work which remains to be done. A more exhaustive analysis of satellite images is required, and fieldwork is needed to proof what is seen and provide further evidence for construction and chronology.

Introduction

Over several millennia, the water supplies of the Kashgar oasis have provided its inhabitants with a secure and productive basis for settlement. The sustainability of such settlements on the edge of one of the most arid and unproductive deserts in the world, the Taklamakan, can be almost exclusively credited to the seasonal water ingress from melting glaciers in the Tianshan mountains to the north and the Pamir Mountains to the south. Regular water supply from river systems, springs and irrigation has enabled this fertile oasis of alluvial and loess soils to support cultivation of corn, rice, wheat, fruit, and recently, cotton. This has, in turn, supported a sizeable population which also benefited from Kashgar's significance as a trading centre. Its strategic location, bottlenecked by mountains north and south and surrounded by deserts, meant that it was one of the most important points along the Silk Road, a point where the northern and southern Silk Routes crossed, and where traders from antiquity onwards chose to travel east to China, west to Central Asia, south to the Indus and towards India, or north to the steppe. It is not surprising that Kashgar is one of the oldest continuously inhabited cities in the world.

Understanding settlement in the Kashgar region thus requires an understanding of the geohydrological environment in which it is situated, and the mechanisms used by its inhabitants to exploit that environment. This means studying the snow and glacial melts in the mountains around Kashgar, examining agriculture within the Kashgar region, and researching the irrigation and water management systems that support it. As a first step towards this, we have recorded snow coverage in the mountains around Kashgar across a range of chronological points from the mid-twentieth century onwards, mapped the extent of agriculture since this was first done in the early 20th century, and undertaken a preliminary prospection for indications of canals, wells, and underground channels (*karez*).

Snow And Sustainable Agriculture

Using satellite photographs from the CORONA series of declassified images from 1960 to 1972, and LANDSAT images from 1973 onwards, it was possible to map snow coverage and agricultural land in the late 20 and early 21st centuries starting with 1964, figure 1., 1975, figure 2 and 1989, figure 3.

This was continued in figure 4, 1999 and figure 5, 2009

Not all of the snow-covered mountains shown are in the Kashgar-Yarkant watershed. The extent of the watershed is delineated in the map below, figure 6.

Nevertheless, the variations in snow covered areas during late summer periods between 1964 and recent years is demonstrable in figure 7.

While the historical decrease in snow cover indicates that water supply to the Kashgar oasis has diminished during the last century, the area devoted to agriculture in the region has increased substantially. Using the same CORONA and LANDSAT images that allowed the mapping of snow cover, areas under cultivation were mapped from 1965 to 2020 in figure 8. In addition, the maps published by Sir Aurel Stein were used to show areas under cultivation at the time of his surveys in 1906-7 and 1914, figure 9 (Stein, 1921, 1928).

It is of considerable interest that the area under cultivation has increased at a steady rate, apparently unimpeded by major historical events such as war with Japan, the changes imposed by the Communist Party after 1949, the Great Leap Forward, and the Cultural Revolution. The rate at which land was brought under new cultivation increased markedly after the year 2000, and that rate of increase has shown no sign of abating in the past two decades. The fact that this is possible when water supply, according to area under snow, has been decreasing, indicates the extent of the resources available, a point which should be considered when investigating agriculture in this area in the past. In other words, it is important to remember there has been an abundant water supply from glacial and snow melts for millennia, but that water management and irrigation technology have been the primary drivers of productivity of the region, rather than absolute water supply itself.

In this world water was the mainstay of economic life. A complex system of canals and drainage channels drew on the mountain streams and irrigated the loess soil, making up for the mere 2 inches of rain that fell each year. Wherever water could be brought to the soil there was an amazing fertility. Canals and country lanes ran between lines of willow and poplar. Low farmhouses built of mud bricks, each with its tree-shaded courtyard and veranda, were dotted between fields of corn and cotton. Every-where there was an abundance of vegetables and fruit trees. In the fruit season the stalls of Kashgar overflowed with peaches, melons, pomegranates and grapes, which could all be bought by the trayful for the equivalent of a few coppers. Food of every kind was plentiful and cheap. Even the climate suited the Arcadian scene. Although the temperature went down to zero in winter and the ground froze to a depth of 18 inches there was little snow and the sun shone nearly every day of the year (Nightingale & Skrine, 2013, pp. 16–17).

Such fecundity relied heavily upon the water supply and upon systems of irrigation and drainage. This is of particular interest considering the loess soils mentioned in the above. The loess soils of Kashgar are the key to both the fertility and to the irrigation systems, since loess is “among the most fertile [soil] in the world, principally because the abundance of silt particles ensures a good supply of plant-available water, good soil aeration, extensive penetration by plant roots, and easy cultivation and seedbed production” (Catt, 2001, p. 213). There are, however, drawbacks to loess soils. If clay content is low, then these soils suffer from rapid loss of organic matter and structural instability of the surface soil causing crusting, poor water penetration, poor germination, and erosion. In simple terms, loess retains water and nutrients exceptionally well, but water can, under some circumstances, pool on the surface and fail to penetrate more than a few centimetres. The same “crusting” effect will result in low nutrient value to plants sown in such soils (Lóczy & Szalai, 1995).

The apparent consensus regarding loess fertility is illusory, since the loess soils of the so-called “Loess Plateau” of central China, the periglacial loess deposits of Europe, and the rich loess soils of North America do not find an equivalent in the nutrient poor soils of desert loess, such as that of the Negev desert in Israel (Avni et al., 2006; Bruins, 1976; Dan et al., 1981; Yaalon & Dan, 1974) nor does the high water penetration and nutrient-rich loess of the prairies equate to those of Xinjiang.[1] This is apparent in the areas of surface water, the evidence of water runoff in the form of fans from the mountain river outlets, the saline crusting of large areas, and the patterns of erosion. All these indicate a loess layer that allows little natural water penetration and low nutrient value without fertilisation, similar to that of the loess horizon of the Negev desert.

This is supported by the soil maps produced by the Chinese Academy of Sciences, figure 10, which describe the loess soils of the area as “ □□ ” (Mò tǔ) “desert soil” as opposed to the “ □□ “ (Huángtǔ) “loess” of the famous “Loess Plateau” of central China (“ □□□□ “ Huángtǔ gāoyuán) which has much superior qualities of fertility and permeability.

Nevertheless, the loess soils of the Kashgar and Yarkant oases have been worked for thousands of years and, in the well-irrigated areas, have become classified in maps such as the one above as “alluvial farming soil” or “ancient farming soil”, attesting to the capacity of the loess soil to become a nutrient-rich mixture ideal for cultivation. The loess soil that surrounds these irrigated fields remains, however, very much like that of the Negev: lacking in nutrients, allowing little natural water penetration, and prone to water pooling and salt encrustation at the surface. This regional system, featuring well-cultivated, water-permeable loess distributed in tandem with hard-crust loess areas, has particular significance for the development of irrigation systems in the region.

Karez, Wells, and Canals in the Kashgar Area

1. Description

Canals.

The region of Kashgar receives very little rainfall, typically only 70mm per annum. Agriculture and human settlement are therefore impossible without irrigation supplied by the glacial and snow melts from the Tianshan and Pamir mountains to the north and south. As Golab wrote in 1951, "owing to the scarcity of rains in the lowlands…this belt of arable soil is in itself no more than arid steppe" and cultivation in the oases is only made possible by careful water management systems which conserve runoff from the spring/summer melts, making that water available throughout the year (Golab, 1951, p. 188). When the melts are at their height, water is available in the streams that flow down out of the mountains and out into the plain, being then diverted into man-made irrigation canals. However, during the drier months of the year groundwater is accessed by means of *karez* and wells. Thus, irrigation is a complex multi-component system designed to make maximal use of much-needed water from both canals and *karez/wells*.

The first part of this system is the canal. These are usually built to take water from the permanently flowing rivers, but the smaller streams which flow only during the melts are also redirected: "the largest of these… [such as] the Kashgar, are only tapped and part of their waters drawn off but the smaller ones are entirely diverted into canals" (Golab, 1951, p. 190). Golab states that the mid-century canal systems of Kashgar and "Kaldja" (Ghulja, Yining County) are the most extensive, including larger canals of considerable antiquity, and describes in detail the method of their construction (Golab, 1951, pp. 188–194). In contrast to the rigid grid pattern of much of the present Kashgar oasis, pre-modern canals were designed to follow, to some extent, the contours of the terrain, and naturally occurring flow channels were incorporated into the canal system. This can be observed in the oasis of Ustun-Artush (Shang'atushixiang), just to the north of Kashgar city; here, satellite images from 1968 show canals following natural channels in the terrain, but a grid emerges by the 1970s and is certainly completed by the turn of the century.

Major canals from the Kashgar river can be seen in historical satellite images such as those shown directly to the south-east of Kashgar, mainly now overbuilt, figure 11, figure 12, figure 13, figure 14.

Karez

The second component of the irrigation system involves accessing groundwater through networks of wells and *karez*. The latter of these, *karez,* are slightly sloping channels dug horizontally into (usually) an alluvial fan, which are accessed by a series of horizontal well shafts. These are thought to have originated in Persia or Arabia (English, 1968; Tikriti, 2002); *karez* is a Farsi word describing what are often known as *qanat* or *falaj* in Arabic, which are underground channels used for transporting water over distances, usually in hot, arid climates, figure 15.

The channel accesses ground water enters the channel, which flows down the slope and is directed to the cultivated areas where it is required. Construction of these channels requires that vertical shafts are excavated at regular intervals along the length, a method which supports both the initial construction of the *karez* and its continued maintenance. Such shafts also allow access to the water supply along the length of the *karez*, if it is required. The underground *karez* therefore have numerous advantages as an irrigation technology: distribution of groundwater to fields under cultivation, minimization of evaporation, prevention of silting of the channel by wind-borne dust, and distribution of ground water access along the length of the *karez*.

As noted above, this technology is thought to have its origin in Iran, or possibly eastern Arabia, in the first half of the first millennium BC and was brought to Central Asia along the Silk Route (Goblot, 1963; Wulff, 1968).There is some suggestion, usually dismissed, that it may have been developed locally (Trombert, 2008). It is an understandable notion, since anyone who watches the meltwater emerge from a glacier, only to watch it disappear in the scree and re-emerge sometimes at a great distance downslope, often a matter if kilometres, may consider means of channelling and controlling such a resource. However, a unique factor in the region of Kashgar may be of importance: the layer of loess soil.

Loess in the Kashi and Pishan area is up to 8–10 m thick (Li et al., 2015, p. 5/16), and is characterised by poor water penetration. Therefore, groundwater mainly travels under the loess layer, rather than through it. In traditional *karez* construction, it is thus necessary only to dig through the loess layer to reach a water table, which simplifies the construction process by allowing a mother-well to be dug at any point, such as in the figure 16 below.

All sources describe *karez* as being built on an alluvial fan. Indeed, studies in Kazakhstan have shown that “all the karez of the Turkestan oasis are built parallel to dry river courses on the bottom slopes of desertic alluvial fans” (Sala, 2008). This is a natural means of water access from streams that “send swift currents down out of the mountains, but disappear in the sands or the salt marshes soon after leveling off onto the plain” (Golab, 1951, p. 189).

However, the above demonstrates how these channels can be built at any point where groundwater is sufficient. This process has been described:

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 to 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-Grzhimailo, 1896)

There are also descriptions of *karez* in the Kashgar oasis which do not seek groundwater sources but create a source in the system of canals in the form of a reservoir, which is then tapped using *karez*. The opposite is also true: *karez* are built to bring water to a reservoir from which water is distributed by canals to fields, figure 17.

Recourse is had to subterranean systems or karyz (Turkish for "underground canal"). There are a number of small streams which have a continuous flow in their upper reaches, but …disappear into …a substratum…a layer of impervious clay underlies …these areas, often at a depth of but a few yards. Some of the water, following the incline of the clay stratum, may reappear above ground in the form spring…. A technique has been developed for gathering and bringing it to the surface where wanted, either as large springs or as flowing streams. To accomplish this, vertical shafts are dug here and there within the area where the underground water is thought to be …. If the indications are favourable, a reservoir is hollowed out of the earth …[and] from this basin one or more canals with eventually be dug to deliver the water to the oasis. When the reservoir is ready, work begins on a whole system of vertical shafts and connecting tunnels throughout the water-bearing area….The whole system sometimes stretches out a mile or more. If the water is plentiful, side tunnels with corresponding shafts are sometimes sent out from the main tunnels. (Golab, 1951, p. 194)

2. Identification

Di Castro, Vicziany and Zhu have studied the physical environment of the Kashgar oasis and identified systems of tanks, wells, uncovered canals, underground and covered canals or karez/qanat and the underground water wells (also called karez locally) (Di Castro et al., 2019). They noted several important points: that there were many similarities and clear connections between the irrigation systems of Kashgar and those of other areas (such as those of the Jingjue Kingdom at Loulan on the far eastern side of the Tarim Basin and of Gandhara in Afghanistan and Pakistan), the probable importance of the Tuntian system (Luo et al., 2017), and the clear association between Buddhist sites and water management systems (Di Castro, 2008). They also identified the first evidence for *karez* in the Kashgar area, in the vicinity of the Mori Tim stupa (Vicziany & Di Castro, 2016, 2019, p. 117). Since the publication of their work, further research has been undertaken for evidence of *karez* in the Kashgar region, and clear evidence has been located.

Since the 1960s, with papers by Paul English and Hans Wulff (English, 1968; Wulff, 1968), the method used to identify and illustrate *karez* has been to publish aerial photographs or satellite images, such as those in figure 18, figure 19, figure 20 and figure 21 below.

The tell-tale mounds of earth from the *karez* shafts, more or less regularly spaced, indicate the line of the underground channel. These have been found at various locations around the oases of Kashgar.

3. Distribution

The distribution of the *karez* thus far identified is limited to sites on the periphery of the cultivated areas, clearly designed to channel water to those areas, as can be seen in figure 22 below.

The preliminary investigations which have identified *karez* in the area around Kashgar consist of an initial survey of Google Earth images and closer examination of the higher resolution U.S. intelligence satellite images, predominantly from the KH-4 Corona mission, in the public domain. It is the intention of the author to carry out much deeper investigation and map all remains of past and present *karez* in the Kashgar and Yarkant oases.

It may prove significant that all *karez* identified in early stages of research have been located on the slopes and alluvial fans that lead towards the irrigated fields of the region. There is no evidence for water being brought to towns nor for the sort of long distance "engineering feats" of 50km *karez* such as those mentioned by English in Iran (English, 1968). All *karez* appear in environments which show evidence of flood water surface erosion.

4. Construction

Most sources which describe *karez* describe the construction of these channels in some detail; all sources identify three phases: planning, construction, and maintenance. (English, 1968; Golab, 1951; Khan & Nawaz, 1995; Sala, 2008; Wulff, 1968).

After identifying the proposed endpoint of the *karez*, the fields to be irrigated, a rough plan is made which considers slope, water supplies, and soil conditions. Then the second phase begins in which the source is dug, which can be a reservoir, a spring, or most commonly, the so-called "mother well" (see figures 15 and 16 above). Starting from the endpoint, shaft and channel is then dug, one after another, until the mother well is reached. Naturally, this is difficult and dangerous work and is usually undertaken by specialists. In Iran these are called *muqannis*, in other areas experts use other names, although their expertise is clearly acknowledged in all sources. Golab states that the surveyors of *karez* construction are known as *duzliq baši* ("master of the horizontal"). The third phase, maintenance, is seen as ongoing and onerous: *karez* are always in need of repairing, extension, cleaning, and the prevention of collapses. Often the mother well will be sealed when water is not needed. The underground channels are, naturally, prone to collapse and sometimes must be reinforced by what in modern mining is called "ground support" – a particularly difficult undertaking in the friable, fine loess soils of Kashgar.

In every description of the construction of *karez* a place is found for a discourse upon the "social and cultural aspects" of *karez*. Recent scholarship has taken for granted the necessity for a highly structured society and an organisation of *karez* construction and maintenance based upon landlords and authority.

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 (Sala, 2008, p. 7)

This would appear to owe much to the influence of Karl Wittfogel and his 1957 work, *Oriental Despotism* (Wittfogel, 1957), in which he postulated, among other things, that irrigation systems required substantial and centralized control. Wittfogel's Marxist analysis of Weber, influenced by Marx's very anachronistic concept of an Asiatic mode of production and coupled with an equally dated idea of a "hydraulicbureaucratic official-state" in India, led Wittfogel to believe that the control of the agricultural basis of “oriental” societies invariably leads to an absolutist managerial state. This idea, so attractive in 1957 in the west, has shown a certain tenacity as far as irrigation systems are concerned, since Wittfogel made the connection between irrigation and the state central to his thesis. However, there is little evidence to support the theory in Kashgar, or in many other places.

In Balochistan, for example, there is explicit testimony that *karez* are built and maintained in cooperative ventures (Khan & Nawaz, 1995). Even in Iran, the very home of this system of irrigation, initial state-sponsored construction has not resulted in such irrigation remaining in the hands of the powerful: there has been “fragmentation of qanat ownership” resulting in “the ownership of qanats [being] widely diffused throughout the population….Many qanats have as many as two or three hundred owners and the water…divided into 10,000 or more time shares” (English, 1968, p. 179). Golab indicates that the state, at least before the declaration of the People’s Republic of China, had little to do with irrigation projects in Xinjiang: “A new irrigation project …is generally left for the *lung kuan* and the headmen to decide, the mandarins and irrigation officials receive written orders and the necessary authorizations from the higher authorities to get the project underway. Beyond these preliminaries the government does nothing[3]” (Golab, 1951, p. 199).

5. Comparanda

Detailed published accounts of *karez* are few, however, comparisons of those available show similarities. The *karez* identified in this study, for example, show that shafts, visible by the mounds of excavated material around them, have a separation that is by no means uniform. *Karez* such as that of Figure 19 have shafts 20 meters apart, while those of Figure 21 are 50 meters apart. Some of the many and varied *karez* shafts of Figure 20 are separated by as little as 10 meters, while those around Mori Tim are 15 meters apart. Such variation does not appear abnormal, since Golab mentions a separation of 150 feet which is close to English’s 50 meters, but quite different from Khan & Nawaz’s 30 meters and Sala’s 15 to 20 meters. It is not unreasonable to assume that such variability reflects different ground conditions.

It is not possible to compare the channels themselves, since this information will have to wait for excavation in the Kashgar region. Similarly, the length of the *karez* in the Kashgar area does not appear unduly long, with most in the north being a few hundred meters long, the *karez* near Mori Tim at about one kilometre, and the longest in the south at about 12 kilometres. None of this compares with the 50 kilometre distances possible in Iran, or in some other locations (English, 1968, p. 171). However, further study and fieldwork is necessary to confirm the extent of these structures in the Kashgar region.

6. Function

The function of *karez* is related to its perceived benefits. No power supply is required; neither that of the modern pump nor of human or animal muscle power. The flow of water is proportionate to the supply from the original source; as long as the source (here snow and glacial melts) is unaffected and the *karez* maintained, the water for irrigation is secure. Most importantly, water is moved over distances without evaporation or the silting up of channels by dust and surface erosion. Thus, a secure, reliable, and accessible water supply for irrigation is the result.

There is, however, another possibility: necessity. *Karez* may, in fact, be the only means for transporting water in some circumstances. Desert loess soils, as has already been mentioned, can be characterized by very low water penetration. This is most obvious when water pools at the surface and when there is high evaporation: salt flats can be the result. However, water moving through loess deposits as groundwater can also be limited. When access to groundwater becomes difficult, the problem can be solved by using the mother well to gain access early, up slope, and then transporting the water through *karez* to reach the irrigated fields.

This problem will have ceased to exist with the advent of mechanical drilling equipment and diesel pumps in the 20th century. These enable deep wells to be drilled safely and easily, and water pumped from depths that may have been prohibitive or uneconomical in the past (Fletcher & Carter, 2017, p. 462). By these means, water tables well below the loess layer can be accessed and the *raison d'etre* for many *karez* may have been removed. A single well could replace an entire complex of *karez* shafts.

7. Chronology

There would appear to be no secure means of knowing, at this stage, the chronology of *karez* in the Kashgar region. However, a study of the information available suggests that they are not a recent introduction.

Buddhist rituals are known where Chinese farmers use *karez* (Golab, 1951, p. 199). Although Islam prohibits such practices, nevertheless, Golab points out that there is a likelihood that certain traditions are celebrated by the Uighurs of Xinjiang and are related to pre-Muslim rituals honouring water deities: “the slaughter of sheep, especially at the beginning and again at the completion of the canal, as well as on the occasion of the annual canal clean-each spring, may well be a survival of such observances” (Golab, 1951, p. 199). While this is no proof of the antiquity of *karez*, as these practices relate to all kinds of irrigation systems, the fact that they were celebrated for the construction of *karez* suggests a pre-Muslim date for their introduction to the region.

The proposition that *karez* cannot predate the 19th century, based upon Chinese sources, should be dismissed. A thorough analysis of Chinese Qing Dynasty sources by Éric Trombert points out that no records exist about such irrigation until late in the Qing period. However, this assumes that Qing dynasty officials were involved in the construction and maintenance of these systems, which can be shown to be unlikely. Golab describes all work being done by “natives” or the non-Chinese inhabitants, what English called “Turki labourers” (English, 1968, p. 177; Golab, 1951, p. 192), which almost certainly means the Uighur people of Xinjiang. All terminology appears to have been in Persian or Uighur, even if there is no evidence for familiarity with the wider body of custom and law that was codified in the *Kitabi Qani* or *Book of Qanats* which is said to have been in existence by the 8th century. Golab continues:

The country has no written law embodying these regulations, but only an unwritten tradition sanctioned by long observance. Special officers of the water administration are charged with the enforcement of these regulations. The Chinese call them lung kuan *(dragon watchmen), the Turks refer to them as* aryk agsakal *(canal supervisors). These officials are not appointed by the provincial government, as are the dau and district mandarins and the village headman, but are selected by the people* (Golab, 1951, p. 197).

Only proper archaeological investigation of undisturbed *karez* in situ can resolve the question of *karez* chronology in the Kashgar region. The use of microwave satellite data can identify disused *karez*, which can then be excavated and dated. Numerous cases will be necessary in order to give the highest chance of discovering the clearest chronological picture.

[1] In loess regions with reasonable rainfall a serious concern is erosion, which in the case of the North American loess deposits can result in the removal of the nutrient rich levels and the exposure of underlying infertile loess deposits. See, for example, (Weaver & Bruner, 1948)

[3] Golab's "*lung kuan*" is □□ (*long guan*, dragon official), an irrigation official. In China, popular religion has dragons closely associated with water, weather, and naturally, irrigation.

Declaration

Data availability

The datasets analysed during the current study are available in Google Earth and from the U.S. Geological Survey dataset: *Earth Explorer* (https://earthexplorer.usgs.gov/).

References

1. Avni, Y., Porat, N., Plakht, J., & Avni, G. (2006). Geomorphic changes leading to natural desertification versus anthropogenic land conservation in an arid environment, the Negev Highlands, Israel. Geomorphology, 82(3), 177–200. https://doi.org/10.1016/j.geomorph.2006.05.002
2. Bertrand, A. (2012). Water Management in Jingjue Kingdom: The Transfer of a Water Tank System from Gandhara to Southern Xinjiang in the Third and Fourth Centuries CE. Sino-Platonic Papers April: No. 223, 1-81.
3. Bruins, H. J. (1976). The origin, nature and stratigraphy of paleosols in the loessial deposits of the NW-Negev (Netivot, Israel), M.S. thesis. Hebrew Univ. of Jerusalem.
4. Catt, J. A. (2001). The agricultural importance of loess. Earth-Science Reviews, 54(1), 213–229. https://doi.org/10.1016/S0012-8252(01)00049-6

5. Dan, J., Makhon le-ḳarḳa u-mayim (Israel), & International Conference on Aridic Soils. (1981). Aridic soils of Israel: Properties, genesis, and management: Guide book to the excursions. Division of Scientific Publications, Volcani Center.
6. Di Castro, A. A. (2008). The Mori Tim Stupa Complex in the Kashgar Oasis. East and West, 58(1/4), 257–281. JSTOR.
7. Di Castro, A. A., Vicziany, M., & Zhu, X. (2019). The Kashgar Oasis in Buddhist and Pre Buddhist Times: The Archaeological and Environmental Record. In The Cultures of Ancient Xinjiang, Western China: Crossroads of the Silk Roads (pp. 143–170). Archaeopress Publishing Limited; /z-wcorg/. https://www.jstor.org/stable/10.2307/j.ctvwh8c04
8. English, P. W. (1968). The Origin and Spread of Qanats in the Old World. Proceedings of the American Philosophical Society, 112(3), 170–181. JSTOR.
9. Fletcher, R. N., & Carter, R. (2017). Mapping the Growth of an Arabian Gulf Town: The case of Doha, Qatar. JESHO, 60, 420–487.
10. Goblot, H. (1963). Dans l'ancien Iran, les tech-niques de l'eau et la grande histoire. Annales: Economies, Sociétés, Civilisations, 18(3), 499–520.
11. Golab, L. W. (1951). A Study of Irrigation in East Turkestan. Anthropos, 46(1/2), 187–199. JSTOR.
12. Grum-Grzhimailo, G. E. (1896). Opisanie puteshestviia v Zapadnyi Kitai / sostavleno G.E. Grum-Grzhimailo; pri uchastii M.E. Grum-Grzhimailo. Tipografiia S.M. Nikolaeva.
13. Khan, M. F. K., & Nawaz, M. (1995). Karez irrigation in Pakistan. GeoJournal, 37(1), 91–100. https://doi.org/10.1007/BF00814888
14. Li, Y., Song, Y., Yan, L., Chen, T., & An, Z. (2015). Timing and Spatial Distribution of Loess in Xinjiang, NW China. PLOS ONE, 10(5), 1–16. https://doi.org/10.1371/journal.pone.0125492
15. Lóczy, D., & Szalai, L. (1995). Assessment of loess as parent material for agroecological potential. GeoJournal, 36(2), 275–280. https://doi.org/10.1007/BF00813185
16. Luo, L., Wang, X., Liu, J., Guo, H., Lasaponara, R., Ji, W., & Liu, C. (2017). Uncovering the ancient canal-based tuntian agricultural landscape at China's northwestern frontiers. Journal of Cultural Heritage, 23, 79–88. https://doi.org/10.1016/j.culher.2016.04.013
17. Nightingale, P., & Skrine, C. P. (2013). Macartney at Kashgar: New Light on British, Chinese and Russian Activities in Sinkiang, 1890-1918. Taylor & Francis. https://books.google.com.au/books?id=Bbr5AQAAQBAJ
18. Sala, R. (2008). Underground Water Galleries in Middle East and Central Asia: Survey of historical documents and archaeological studies. Laboratory of Geoarchaeology, Institute of Geological Sciences, Academy of Sciences of Kazakhstan.
19. Sala, R. and J-M. Deom (2008a). The 261 Karez of the Sauan Region (Middle Syrdarya). Transoxiana: Journal Libre de Estudios Orientales 13: August, viewed on 2 April 2019, <http://www.transoxiana.org/13/sala_deomkarez_sauran.php>.

20. Shaw, J. (2000). Sanchi and its archaeological landscape: Buddhist monasteries, settlements & irrigation works in Central India. Antiquity 74 (286): 775-776.
21. Shaw, J. and J. Sutcliffe (2001). Ancient irrigation works in the Sanchi area: an archaeological and hydrological investigation. South Asian Studies 17: 55-75.
22. Shaw, J. et al. (2007). Ancient irrigation and Buddhist History in Central India: Optically Stimulated Lumines and Dates and Pollen Sequences from the Sanchi Dams. Asian Perspectives 46 (1): 166-201.
23. Shaw, J. (2009). Stūpas, Monasteries, and Relics in the Landscape: Typological, Spatial, and Temporal Patterns in the Sanchi Area in A. Shimada and J. Hawkes (eds) Buddhist Stūpas in South Asia: Recent Archaeological, Art-Historical, and Historical Perspectives: 114-145. New Delhi: Oxford University Press.
24. Shaw, J. (2016). Buddhist Landscapes in Central India. Sanchi Hill and Archaeologies of Religious and Social Change, c. Third Century BC to Fifth Century AD. London: The British Association for South Asian Studies/The British Academy 2007 Edition republished by Routledge: ProQuest Ebook Central, viewed on 19 May 2019, <http:// ebookcentral.proquest.com/lib/monash/detail. action?docID=1921163>.
25. Stein, A. (1921). Serindia: Detailed Report of Explorations in Central Asia and Westernmost China, Carried Out and Described Under the Orders of H. M. Indian Government. Clarendon Press. https://books.google.com.au/books?id=w-RdCPGhq24C
26. Stein, A. (1928). Innermost Asia: Detailed report of explorations in Central Asia, Kan-Su and Eastern Iran. Clarendon Press.
27. Tikriti, W. Y. A. (2002). The south-east Arabian origin of the falaj system. Proceedings of the Seminar for Arabian Studies, 32, 117–138. JSTOR.
28. Trombert, É. (2008). The Karez Concept in Ancient Chinese Sources Myth or Reality? T'oung Pao, 94(1/3), 115–150. JSTOR.
29. Vicziany, M., & Di Castro, A. A. (2016). The Hidden Treasures of Buddhist Kashgar. TAASA Review The Journal of the Asian Arts Society of Australia, 24, 14–17.
30. Vicziany, M., & Di Castro, A. A. (2019). The Kashgar Oasis: Reassessing the Historical Record. In The Cultures of Ancient Xinjiang, Western China: Crossroads of the Silk Roads (pp. 113–142). Archaeopress Publishing Limited; /z-wcorg/. https://www.jstor.org/stable/10.2307/j.ctvwh8c04
31. Weaver, J. E., & Bruner, W. E. (1948). Prairies and Pastures of the Dissected Loess Plains of Central Nebraska. Agronomy & Horticulture - Faculty Publications, 495.
32. Wittfogel, K. A. (1957). Oriental Despotism: A Comparative Study of Total Power. Yale University Press. https://books.google.com.au/books?id=INcPAQAAMAAJ
33. Wulff, H. E. (1968). The Qanats of Iran. Scientific American, April, 94–105.
34. Yaalon, D. H., & Dan, J. (1974). Accumulation and distribution of loess-derived deposits in the semi-desert and desert fringe areas of Israel. Z. Geomorphol., 20, 91–105.

Figures

Figure 1

Snow and agriculture September 1964

Figure 2

Snow and agriculture September 1975

Figure 3

Snow and agriculture September 1989

Figure 4

Snow and agriculture September 1999

Figure 5

Snow and agriculture September 2009

Figure 6

Watershed for the Kashgar-Yarkant oasis (made using NASA DEM and ArcGIS).

Figure 7

Snow coverage calculated from above maps

Figure 8

Agriculture in the Kashgar-Yarkant oasis (made using CORONA and LANDSAT and ArcGIS).

Figure 9

Cultivation coverage calculated from above maps

Figure 10

Soil map of the Xinjiang Uighur Autonomous Region, 1965 (ISRIC Wageningen).[2]

[2] This soil map has no date printed upon it. However, M. Van Liedekerke at the European Soil Data Centre suggests a date of 1978 (personal communication), while Stephan Mantel, Senior Soil Scientist at ISRIC, which holds the map, believes it is from a 1965 publication [illegible]. [illegible]. [illegible]:[illegible], 1965 (personal communication).

Figure 12

U.S. intelligence satellite image from 1968 of Ustun-Artush (KH-4 Corona mission)

Figure 13

U.S. intelligence satellite image from 1980 of Ustun-Artush (KH-7 mission)

Figure 14

GeoEye's OrbView-3 satellite image from 2005 of Ustun-Artush

Figure 16

Proposed *karez* structure in the loess soils of Kashgar

Figure 17

Karez in Golab's description of irrigation in Xinjiang

Figure 18

Paul English's photographs of "qanats located south of the city of Kirman, Iran" (English, 1968, pp. 172–173)

Figure 19

Tell-tale mounds of earth from karez wells, 5 km to the west of Ustun-Artush 2004. Google Earth

Figure 20

Karez wells, 10 km to the southwest of Ustun-Artush and 10km northeast of Kashgar, 2002. Google Earth

Figure 21

Karez wells, 20 km to the Yengisar (Yangi Hissar), 2010. Google Earth

Figure 22

Distribution of *karez* thus far identified