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Underground Irrigation Canals in the Arid Regions through the High-resolution Satellite Images and Field Works

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Abstract: Underground irrigation canals in the arid region are discussed through the high-resolution satellite images, Corona, which cover whole of a single canal system and its surroundings, in addition to the terrestrial conditions. Among the karez canals in Turpan Basin, China, the reverse "J" plan pattern at the alluvial fans is distinctive. Mother wells of this pattern were moved up-stream, extending oblique to the slope, to manage lowering of groundwater. In Yazd area, Iran, qanat systems develop along the bottom of the longitudinal valley reflecting the basin and range landform which can collect groundwater from the both side. This terrestrial condition seems to have produced 300 m deep and 80 km long qanat. Some qanats are found nearly along the contour line at the lowest margin of a small pediment, like frontlet. The same type is constructed in the valley of Bamian, Afghanistan. At the northern piedmont alluvial fans of Qilian Mountains, China, there are underground irrigation canals with ventilation ducts dug in the upper part of the river terrace cliff and horizontal aqueduct water is flowing directly from the river channel. This system is connected to underground irrigation canals with vertical ventilation ducts.

Key Words: Corona, Terrestrial condition, Turpan, Underground irrigation canal, Yazd

1. Introduction

Professor KOBORI Iwao promoted researches on the underground irrigation canals, consisted of vertical shafts and nearly horizontal tunnels, called qanat, karez and so on. They spread all over the world, especially in the arid region (Kobori, 1996). It is rather difficult to catch the whole system by the ground-level view. Previously, researches on qanat were restricted within a relatively small area, mainly focused on the usages along a single or small numbers of them. However, introduction of the high-resolution satellite images, such as Corona and QuickBird, made possible to recognize debris heaps of shafts of underground irrigation canals in the large area from the great altitudes. Consequently, we could get the whole images both of a single canal system and neighboring ones, in addition to the terrestrial conditions, namely landform and landscape. Based on the interpretation of Corona images, maximum ground resolution about 3 m, following characteristics of underground irrigation canals are identified.

2. Study area

Studies were conducted on underground irrigation canals (karez) of the Turpan Basin, China, the Yazd area (qanat), Iran and the Bamian area, Afghanistan, and the underground irrigation canals at the Zhangye district, Gansu, China (**Fig. 1**). Except the last one in the semi-arid region, others are situated in the arid region. Among them, the field survey was conducted only at the Turpan Basin.

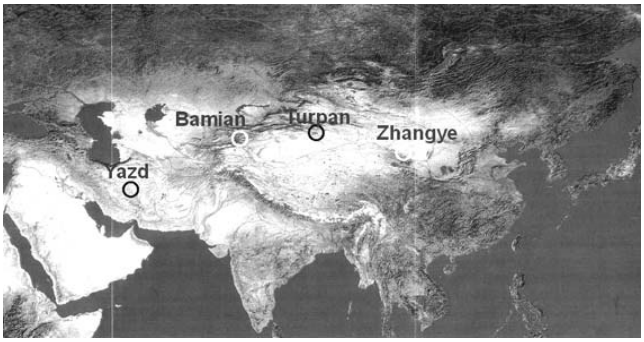

Fig. 1. Study area (Modified from Research Center for Silk Roadology, 1996).

3. Results

3.1. Turpan Basin

Many karez systems distribute in the Turpan Basin, (International Conference On Karez Irrigation, 1993). Based on the interpretation of Corona images, debris heaps of karez systems are easily recognized as the dots. Therefore, alignments of them correspond to the karez system. Their distributions are classified as follows; on the alluvial fan of the gravel desert of the northern and southern piedmonts of Flaming Mountain and on the mud desert of the lower margin of the latter, and this classification is nearly same as Yang (1993) and a little bit different from Liu (1993).

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Fig. 2. Distribution of karez systems at the northern piedmont of the Flaming Mountain (Lower marginal parts of the alluvial fans from the Tianshan Mountains).

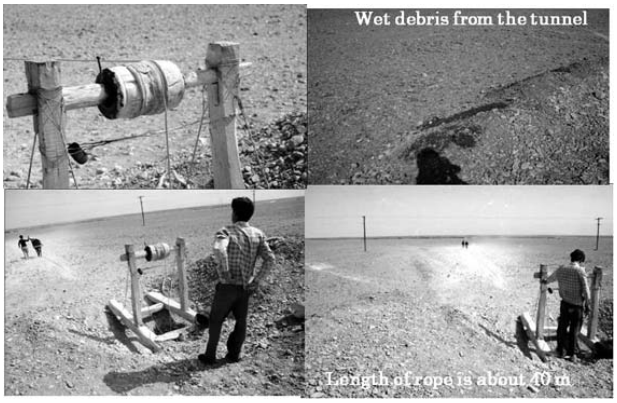

Fig. 3. Karez repairing in the Turpan Basin.

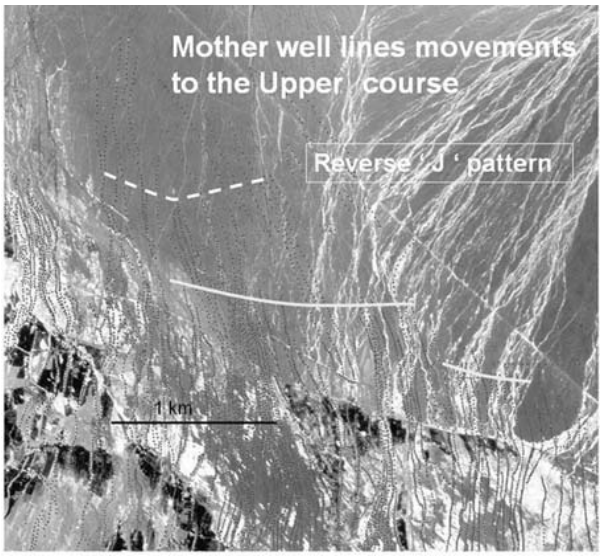

Fig. 4. Upward movements of the mother well lines (Southern piedmont of the Flaming Mountain). Data available from U.S.Geological Survey, EROS Data Center, Sioux Fall SD.

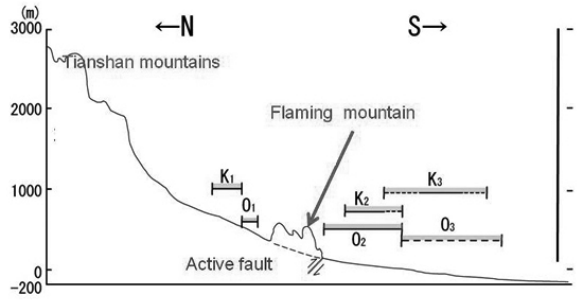

Fig. 5. Distribution of karez and oases along the profile in the Trupan Basin. K: karez O: oasis

Figure 2 shows the most typical karez systems in the Turpan Basin, namely, the shaft alignment of the parallel pattern, development at the lower marginal part of the alluvial fan and the length of the shaft alignment around 2 km (Sohma, 2002). Generally speaking, based on the consideration of the grain sizes of the deposits, it will be severely hard to construct the shafts or tunnels of the karez systems at the upper or middle reaches of the alluvial fan by the primitive methods, namely without machine assistances.

During the research with professor Kobori in 1999, we encountered repairing of one karez, in the gravel desert of the south-western part of the Flaming Mountain. The depth of the vertical shaft was more than 40 m (**Fig. 3**) and it was very deep. This deep aquifer level was concordant with remarkable decrease of karez systems in number at Toksun area, western part of the Turpan (Kimoto *et al.*, 1991).

Shaft patterns aligned in the reverse "J" shape of the upper part of the karez systems developed at the southern piedmonts and the western parts of Flaming Mountain, but did not develop at the mud desert areas. **Figure 4** suggests, at least, two step movements of the mother well lines, linked line of the neighboring mother wells, to the upper course against the subsidence of the groundwater level, and the reverse "J" shape pattern was dominant at the upper most mother wells areas in Figure 4.

Based on the above, shafts alignment of the reverse "J" shape is considered to manage lowering of groundwater level.

Based on the Corona images taken in 1966, the distributional relationship between the karez systems and oases along the profile in the Turpan Basin is summarized as **Figure 5**. Electrically-powered pumping wells were not popular in this basin in 1966. Figure 5 suggests distribution of oases in this basin closely related with the karez systems

3.2. Yazd area

Yazd area is well known as one of the oldest areas where the underground irrigation canal system, qanat, was entered in use (for example, Kobori, 1996). In addition, there is a qanat reached to 80 km in the length of horizontal tunnel (Yazdi, 2011, personal communication), and a qanat of 300 m in depth

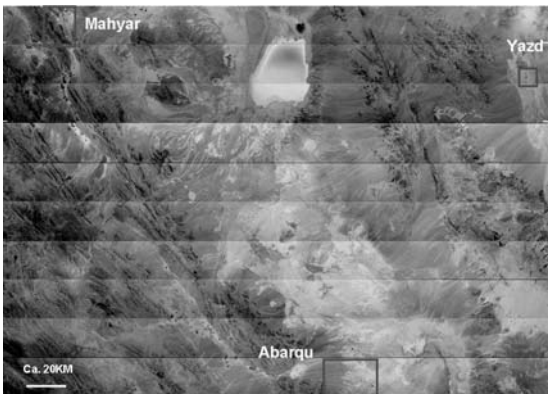

Fig. 6. Index map of the Yazd area. Data available from U.S.Geological Survey, EROS Data Center, Sioux Fall SD.

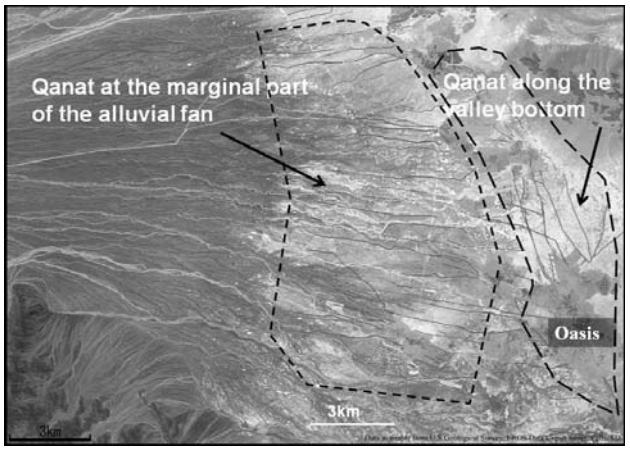

Fig. 7. Two types of Qanat at Abarqu (Location is shown in Fig. 6).. One is at the lower marginal part of the alluvial fan and the other stretched along valley bottom.

(Kobori, 1996).

Yazd and surrounding areas are characterized by the "basin and range" landforms of the Iranian plateau, and without glaciers on the mountains. Annual precipitation is more than 100 mm/yr with mainly in the winter season.

Figure 6, collected of 10 sheets Corona images in the mosaic style, is the index map of the Yazd area. Each Corona images are about 18 km wide and were taken on May 25 1970.

In Figure 6, narrow nearly straight lines running in NW-SE with shadows on the both sides are mountains and between them are basins or valleys reflecting the "basin and range" landforms.

3.2.1. Abarqu

Abarqu is located about 130 km southwest of Yazd. There developed two different types of qanat; one is nearly along the slope at the lower part of the alluvial fan from the west, and the other is at the bottom of the valley along the southwestern flank of the mountain running NW to SE (**Fig. 7**).

Qanat systems at the marginal part of the alluvial fan have the same terrestrial condition with those of the Turfan Basin, and this type is most common in the underground irrigation canals. Qanats constructed at the valley bottom are connecting oases and groundwater of this type come from both side of the valley reflecting the basin and range landform.

3.2.2. Yazd

Figure 8 is the Corona image of a part of Yazd which developed at the longitudinal valley of the basin and range landform. In Figure 8, individual debris heaps of the qanat are recognized as each dots and their alignments show qanat systems.

From Figure 8, followings are apparent; 1) there are clear differences in the dot sizes showing those as the debris heap sizes and those in the amount of debris brought from the underground, 2) distances of the each debris heaps of a qanat are roughly classified into six groups ranging from 10 m to 15 m, 25 m to 30 m, around 50 m, 60 m to 75 m and 100 m, 3)

Fig. 8. Qanat systems in Yazd (Location is shown in Fig. 6).

some qanat lines cross each other.

Above mentioned 2) and 3) suggest difference in the depth of the horizontal tunnels, and 3) also suggests difference in digging stages.

Based on the above, it is clear that qanat systems in Yazd are dug at the longitudinal valleys changing in depth and in magnitude for a long period. This terrestrial condition of the longitudinal valleys, related with the basin and range landform, permits to construct qanat systems such as 80 km in the length of horizontal tunnel and as 300 m in depth.

3.2.3. Mahyar

Mahyar is situated at about 250 km from Yazd to the WNW and at about 45 km from Esfahan to the south. There

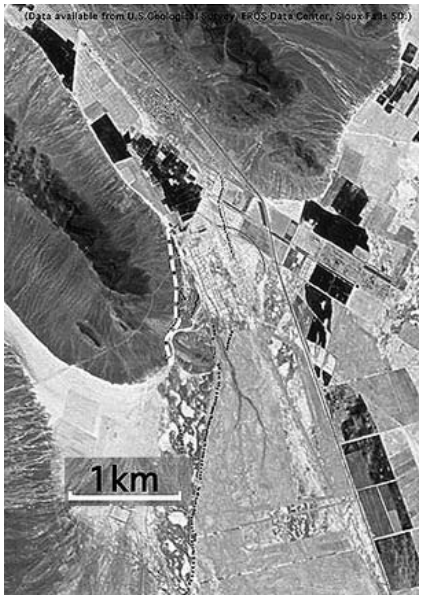

Fig. 9 Qanat along the frontlet of the pediment (Near Mahyar). Qunat: white broken line.

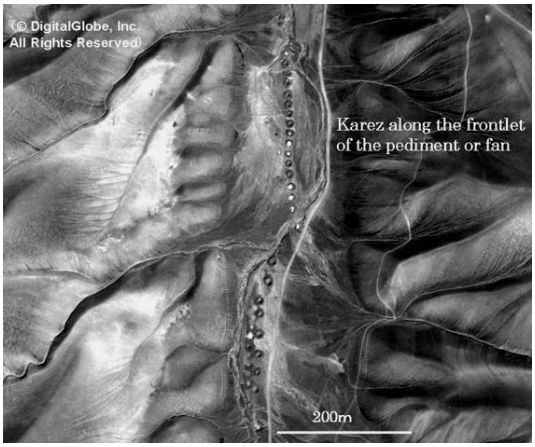

Fig. 10. Karez of frontlet type at the southern part of Bamian, Afghanistan (Sohma, 2008).

developed a qanat system along the southeastern piedmont of the low hill (**Fig. 9**). The horizontal tunnel of this qanat did not dig in the direction of the inclination of the hill slope, but nearly the right angle to it, intending to gather groundwater at the piedmont part of the hill.

We call this qanat system as the frontlet type.

Figure 10 is the QuickBird image, resolution about 61 cm and taken on Feb. 1 2003, of the southern part of Bamian, Afghanistan. There is a valley flowing to the north and small alluvial cones from the both side develop at the bottom part of the valley. There are two karez systems of the frontlet type at the lower parts of alluvial cones and distances of the debris heaps are about 10 m (Fig. 10; Sohma, 2008): Distances of each shaft are around 10 m. These karez systems which are nearly impossible to recognize in the Corona taken in 1965 are considered to have been constructed around 2000 as a part of the reconstruction plans for Afghanistan.

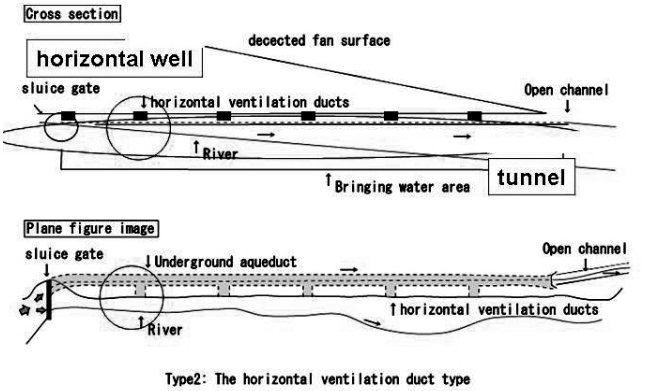

Fig.11 Horizontal ventilation duct type, at the northern piedmont of the Qilian Mts. (Watanabe *et al.*, 2006)

3.3. Zhangye district

There is other type of the underground irrigation canals; horizontal ventilation ducts type (**Fig. 11**; Watanabe *et al*., 2006), at the northern piedmont alluvial fans of Qilian Mountains, Zhangye district, Gansu, China (Fig. 1). Their terrestrial conditions are the head parts of the large confluent alluvial fans and climate is semi-arid.

Ordinary underground irrigation canals have vertical ventilation ducts, or vertical shafts, from which debris from the horizontal tunnel are removed outside of the systems. But the ventilation ducts of the underground irrigation canals at Zhangye district were dug at the upper part of the river terrace to the underground aqueduct in horizontal directions. Moreover, water flowing into underground aqueduct does not originate from the groundwater but from river channels.

Though the ventilation ducts of this system can not be recognized in the high resolution satellite images such as the Corona image, the outlet part of it is recognized connecting to debris heaps of the underground irrigation canal of the vertical ventilation ducts type. This suggests the origin of this system is closely related with the vertical ventilation ducts type.

Anyway, this type underground irrigation canal has been constructed under the intention of transport water for agricultural irrigation where water is hardly available, same as underground irrigation canal of the vertical ventilation ducts types.

5. Concluding remarks

In this paper, based on the interpretation of high resolution satellite images such as Corona and QucikBird, we described underground irrigation canals constructed in the arid regions of Asia.

Based on the historical documents, this type underground irrigation canal was constructed in the Ming Dynasty (Watanabe *et al*., 2006).

Table 1. Comparison between Trupan and Yazd.

	Yazd	Trupan
Climate	More than 100 mm/yr (winter precipitation)	Less than 20 mm/yr
Landform	Basin and range landform without glacier	Tianshan mountains with glacier and Flaming mountain at the front
Distribution of underground irrigation	Along the bottom of longitudinal valley, alluvial fan margin and frontlet of the pediment	Alluvial fan margin and succeeding mud desert
Plan pattern of underground irrigation	Parallel, crossing with different depth and very long, and frontlet	Parallel, oblique, reverse 'J'

First of all, not only QuickBird images but also Corona images are very effective to capture the whole image of a single underground irrigation canal, in addition to the ter restrial conditions around it.

Underground irrigation canals are well developed in Turpan Basin and Yazd area (**Table 1**). Especially, in the former case, the reverse "J" plan pattern in the alluvial fans is distinctive.

By this pattern, the horizontal tunnel were extended oblique to the slope to acquire more water within limited distances, and the mother wells were moved up-stream to manage lowering of groundwater level.

In the latter case, systems were developed along the bottom of the longitudinal valley reflecting the basin and range landform where groundwater can be collect from the both sides. This terrestrial condition seems to have produced 300m deep and 80km long qanat. In addition, the frontlet type qanat extending nearly along the contour line at the lowest margin of the small pediment is also characteristic.

At the northern piedmont alluvial fans of Qilian Mountains, Zhangye district, Gansu, China, there exist the ventilation ducts of the underground irrigation canals dug in the upper part of the river terrace cliff and horizontal aqueduct water is flowing directly from the river channel. This system continues to underground irrigation canal of the vertical ventilation ducts types.

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