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In 1990 it was estimated that the kārēz technique supplied water to around 1.5 million hectares of the planet's total irrigated surface area, which constituted only the minor portion of approximately 0.6 percent (Balland, 1992a, p. 1). The technique has largely remained a phenomenon specific to the Iranian lands, where its role continues to be of primary importance. In Iran itself underground water channels are the most widespread, with a total length of about 80,000 km for the channel network, of which 18,400 channels have been measured. In the 1970s and 1980s their overall outflow was estimated to be 239 m3/sec (Balland, 1992b, p. 109, following Ehlers; Behnyā, 1988). Moreover, the applications of the kārēz technique to non-agricultural uses have been the most considerable in Iran, where they have often been maintained up to the present day. Example are the operation of water mills (Papoli-Yazdi, 1992) and the water supply to cities—Tehran was still exclusively supplied through kārēz up to the 1920s—for drinking and domestic uses.

For Afghanistan the available statistical data of the great agricultural survey of 1967 were not particularly reliable, and sometimes even excessive. In 1990 an approximate and more or less plausible estimate for about 6,000 kārēz, with a total network length of some 12,000 km, was an overall outflow of around 100 m3/sec (Balland, 1992b, p. 109). Such an outflow could have irrigated around 160,000 hectares, which equals about 7 percent of Afghanistan's irrigated land.

The only country outside the central Iranian lands where underground water channels are indispensable for farming is Oman, which is located very close to Iran and was long under its political influence. In the 1970s the number of Omani kārēz was estimated to be about 11,000, of which 4,000 were major channels with a continuous outflow (Costa and Wilkinson, p. 55; Weisgerber, p. 69). Their overall outflow was assessed to be some 45 m3/sec (Dutton, pp. 217-19).

Although data are rarely gathered together and the resulting statistics are less than precise, it is still possible to conclude that in other geographical areas the yields obtained by the underground channel technique are far smaller: 3.6 m3/sec for the central and western Sahara (Bisson, 1992, p. 10); 5.059 m3/sec for the Haouz of Marrakesh (Pascon, 1977); and 16.5 m3/sec for Turfan and Komul, where 1,231 channels irrigated 21,860 hectares in 1990 (Liu, p. 67). In these regions the channels can be regarded as marginal, although their local importance is great for certain oases.

The useable worldwide outflow of the kārēz in 1990 must not have exceeded 450 m3/sec and was probably much closer to 400 m3/sec, with a distribution of 60 percent in Iran, 25 percent in Afghanistan, and about 10 percent in Oman. It is only for these three countries that the evolution of the technique and its continued use in agriculture constitutes a macroeconomic problem of the first importance in the near future, because in general the reliance on kārēz technique in agriculture is declining.

The rapid and quite widespread decline of the kārēz in the second half of the 20th century has affected more or less all of the pertinent geographical areas from the Sahara to China. Although it is impossible to precisely quantify this decline, an approximate evaluation is possible. At the end of the 1970s the combined outflow of all kārēz worldwide was estimated to be 700-800 m3/sec (Goblot, 1979, p. 193). Even if this figure was probably exaggerated, it is very instructive to compare it with the much more reliable figure for 1990, given

above. Moreover, some of the data available for specific countries are more convincing. In Iran the total outflow went from 574 m3/sec in 1954 to 224 m3/sec in 1977 (Bonine, 1989, p. 120). In China, at Turfan and Komul the outflow was measured to be 24.6 m3/sec in 1963 (Liu, p. 67), and in the following three decades it was diminished by about one-third. These statistics can be considered plausible and of general applicability, because all the local observations agree and the symptoms of decline are everywhere in evidence. Many kārēz have recently been completely abandoned or are no longer being repaired, even if they still function with reduced outflow, so that their impending demise is a given. Others have been completely modified in their uses and are no longer used for transporting water to irrigate agricultural areas below their outlets. Openings along the courses of kārēz are reduced to a series of wells used by the local populations (Dupaigne, 1977).

The causes of this decline are complex, but by far the principal reason is the development of a rival technique, which consists of wells with motorized pumps (Goblot, 1979, pp. 194-95; Beaumont, 1989, pp. 28-30; Ehlers and Saidi; Haimiti; Mantimin). Sinking these wells is much less costly than the construction of new kārēz. For example, in 1976, in the Asadābād basin, in the heart of the Zagros in Hamadan province, the cost of excavating one kārēz of 2 km length with a mother well of 16 m depth and 57 openings was estimated to be 600,000 tomans, to which annual maintenance cost of several thousand tomans must be added. In contrast, a well with a motorized pump that is sufficient for the cultivation of an equivalent area could be obtained for 175,000 tomans, but the annual maintenance cost for power, clearing, etc. was about 20,000 tomans (Ehlers and Saidi, p. 105). Furthermore, the motor-pump wells are far more adaptable in their use. Since the motor-pumps are only running during the growing season, they completely eliminate the waste of water in the winter, which from the economic point of view is the fundamental weakness of the kārēz system. Lastly, the much simpler technique almost completely eliminates the dangers and accidents that are often inevitable in the excavation and maintenance of the underground water channels. Under these circumstances it should not be surprising that in Iran the construction of new kārēz practically ceased in the 1950s. The most recent underground channel projects were reported for China in the 1980s, when the People's Republic was still a very poor country (Kobori, 1989, p. 35).

Apart from their role as competitor, the multiplication of motor-pump wells had disastrous effects for the water economy of the kārēz, because they lead to

a drastic lowering of the water tables. Since almost always the motor-pump wells are dug in the neighborhood of kārēz, both take the water from the same subterranean sources, which in turn are usually overexploited (Bonine, 1982, pp. 148, 158). But the number of active kārēz diminishes proportionally less quickly than their average output, even though the competition of the motor-pump wells and the lowering of the water tables are two major factors in the decline of the kārēz technique. In Iran the number of underground water channels declined between 1954 and 1977, from about 21,060 to about 18,700 (Bonine, 1989). While these figures suggest a decline of only a little more than 10 percent in the number of kārēz, their overall outflow diminished by more than 60 percent during the same period. In other words, the kārēz remain a characteristic feature of the agricultural landscape, even if their role has lost much of its importance.

Other factors may also contribute to the decline of the kārēz system, although they seem comparatively quite minor. The number of trained channel workers (for *moqanni* see ii (5), above) is declining, since this very difficult, though poorly paid, occupation has been disparaged with the increased standard of living, and thus the maintenance of the kārēz system has become much more random, leading rather often to a channel's ruin and progressive abandonment. In Iran, during the agrarian reform of the 1960s, the dispossession of the great landowners may have brought an end to a few kārēz, whenever village communities failed to independently organize the channels' maintenance. Yet these situations seem to have been rather rare, and most often the social system proved to be sufficiently flexible so that the village communities were able to maintain their channels (Kielstra).

Despite the undeniable decline of the kārēz system, the technique itself is not doomed, and the underground water channels should not be written off as relics of the past (Balland, 1992a, pp. 3-4). The kārēz are a "soft" technique, which is much more respectful of the water supply, as provided by the groundwater table, than the "hard" technique of motor-pump wells, whose damage to the environment is considerable. Moreover, the underground water channels constitute an immense infrastructural capital, built up over generations and therefore impossible to abandon. In the last two decades of the 20th century, once the first infatuation with the great novelty of motor-pump wells had passed, it was realized that the existing kārēz network should be used to its full capacity, since the construction of new channels had more or less ceased. Just about everywhere governments were henceforth preoccupied

with promoting the clearing, as well as sometimes the extension, of channels, the repair or reinforcement of their openings, and even, as observed in Oman (Owen, p. 114), the return to service of networks which had fallen into disuse. This change in attitude has been particularly noticeable in Afghanistan, where reconstruction programs, after years of war and decades of disinterest, have made kārēz repair a top priority.

Occasional innovations and advances testify that this millennia-old technique can be adapted to the 21st century. It is perfectly conceivable to combine underground water channels with motor-pump wells. A lifting motor could be used at an already existing opening to reduce the cost of digging, or a new well near a kārēz could use a motorized pump to immediately benefit from the underground channel's outflow. Both options could be used to increase the value of the network, because they allow for the irrigation of new areas very far from the channel's outlet at high elevation (Bisson, 1989, p. 190; 1992, pp. 18-21). The safety of the workers can be considerably improved, if more resistant and cohesive materials like cement conglomerate or blocks, or even iron frameworks, are used for the channel walls. If the floors are lined with cement, virtually all infiltration can be stopped, while the yield will be considerably increased (Wessels). Furthermore, urbanization holds surprising possibilities for renewal. Tehran gets its water from mountainous areas, some of which are quite far away, and from the 1960s onwards the infiltration of Tehran's wastewater significantly increased. Because of the topography of the piedmont south of the city, the increased waste water infiltration led to a very noticeable elevation of the water table level, which, in turn, strongly augmented the kārēz outflow throughout the area and as far as the plain of Varāmin (Beaumont, 1989, p. 30).

In sum, the kārēz keep all of their value whenever the physical and social conditions are favorable. The strength of a community's social structure determines whether kārēz maintenance and water distribution are managed in a satisfactory manner, and it is thus essential that local populations be determined to support the preservation of their kārēz systems (Wessels, pp. 259-60). In a world where the problem of water resources will soon become particularly distressing in all arid and subarid regions, the kārēz will continue to make a precious contribution to its solution.

BIBLIOGRAPHY

Abbreviations.

EC = Daniel Balland, *Les eaux cachées: Etudes géographiques sur les galeries drainantes souterraines*, Publications du Département de Géographie de l'Université de Paris-Sorbonne 19, Paris, 1992.

IDA = Pierre Briant, ed., *Irrigation et drainage dans l'antiquité: Qanats et canalisations souterraines en Iran, en Egypte et en Grèce—Séminaire tenu au Collège de France*, Paris, 2001.

PICKI = Jianzhong Lai, ed., *Proceedings of International Conference on Karez Irrigation*, Urumqi, 1993.

QKK = Peter Beaumont, et al., eds., *Qanat, Kariz and Khattara: Traditional Water Systems in the Middle East and North Africa*, London, 1989.

WESDASZ = *First International Conference on Water, Ecosystems and Sustainable Developments in Arid and Semi-Arid Zones*, 9-15 October 2006, held in Urumqi and organized by Xinjiang University, the University of Tehran, and the EPHE; the proceedings were distributed in 2009 on CD-Rom; cf. the conference history given online: http://watarid.aquitaine.cnrs.fr/spip.php?article107 (accessed 4 August 2010).
WQ = K. Grewe, ed., *Wasserversorgung aus Qanaten: Qanate als Vorbilder im Tunnelbau—Internationales Frontinus Symposium 2.-5. Oktober 2003, Walferdange, Luxemburg*, Schriftenreihe der Frontinus-Gesellschaft 26, Bonn, 2005.

Studies.

Niyaz Alim, "Rock Drawing: The Testimony for the Research on the Karez Origin," in *PICKI*, pp. 80-81.

Daniel Balland, "Introduction," in *EC*, 1992a, pp. 1-5.

Idem, "La place des galeries drainantes souterraines dans la géographie de l'irrigation en Afghanistan," in *EC*, 1992b, pp. 97-121.

Daniel Balland and Michèle Brognetti, "Une forme nouvelle: Les *kārēz* de

montagne du Hazārajāt (Afghanistan central),” in *EC*, pp. 123-27.

Marcel Bazin and Ashgar Nazarian, “La limite des galeries drainantes souterraines dans le Nord-Ouest de l’Iran,” in *EC*, pp. 79-86.

A. Bazzana et al., “L’hydraulique agraire dans l’Espagne médiévale,” in *L’eau et les hommes en Méditerranée*, ed. André de Réparaz, Paris, 1987, pp. 43-66.

Peter Beaumont, “Qanats on the Varamin Plain, Iran,” *Transactions of the Institute of British Geographers* 45, 1968, pp. 169-79.

Idem, “Qanat Systems in Iran,” *Bulletin of the International Association of Scientific Hydrology* 16/1, 1971, pp. 39-50.

Idem, “A Traditional Method of Ground Water Extraction in the Middle East,” *Ground Water* 11/5, September-October 1973, pp. 23-30.

Idem, “Water Resource Development in Iran,” *Geographical Journal* 140/3, 1974, pp. 418-31.

Idem, “The *qanat*: A Means of Water Provision from Groundwater Sources,” in *QKK*, pp. 13-31.

P. Beckett, “Qanats in Persia,” *Journal of the Iran Society* 1/4, 1952a, pp. 125-33.

Idem, “Qanats around Kirman,” *Royal Central Asian Journal* 39/2, 1952b, pp. 47-58.

ʿA. K. Behnyā, “Ketāb-nāma va maqāla-nāma-ye qanāt,” *Našr-e dāneš*, 1362 Š./1983-84, 4/1, pp. 68-75 and 4/2, pp. 64-69.

Idem, *Qanāt-sāzi va qanāt-dāri*, Tehran, 1367 Š./1988.

R. Biscione, “The Crisis of Central Asian Urbanization in II Millenium BC and Villages as an Alternative System,” in *Le Plateau iranien et l’Asie Centrale des origines à la conquête islamique: Leurs relations à la lumière des documents archéologiques*, ed. J. Deshayes, Colloques internationaux du CNRS 567, Paris, 1977, pp. 113-27.

Jean Bisson, *Le Gourara: Etude de géographie humaine*, Mémoires de l’Institut de recherches sahariennes 3, Algiers, 1957.

Idem, “The Origin and Evolution of *foggara* oases in the Algerian Sahara,” in *QKK*, pp. 179-94.

Idem, “Les foggara du Sahara Algérien: Déclin ou renouveau,” in *EC*, pp. 7-26.

Frank Bliss, *Die Oasen Bahriya und Farâfra: Bestimmungsfaktoren und Folgen des sozialen und wirtschaftlichen Wandels in zwei Oasengesellschaften in der westlichen Wüste Ägyptens*, Bonn, 1983; orig., Ph.D. diss., Universität Bonn, 1982.

Michael E. Bonine, “From *Qanāt* to *Kort:* Traditional Irrigation Terminology and Practices in Central Iran,” *Iran* 20, 1982, pp. 145-59.

Idem, “*Qanats*, Field Systems and Morphology: Rectangularity on the Iranian Plateau,” in *QKK*, pp. 35-59.

R. Boucharlat, “Les galeries de captage dans la péninsule d’Oman au premier millénaire avant J. C.: Questions sur leur relations avec les galeries du plateau iranien,” in *IDA*, pp. 157-84.

Idem, “Iron Age Water-Draining Galleries and the Iranian ‘Qanat’,” in *Archaeology of the United Arab Emirates: Proceedings of the First International Conference on the Archaeology of the U.A.E. in Abu Dhabi in 2001*, ed. D. Potts et al., London, 2003, pp. 162-72.

Cornel Braun, *Teheran, Marrakesch und Madrid: Ihre Wasserversorgung mit Hilfe von Qanaten—Eine stadtgeographische Konvergenz auf kulturhistorischer Grundlage*, Bonner Geographische Abhandlungen 52, Bonn, 1974; orig., Ph.D. diss., Universität Bonn, 1973.

Pierre Briant, “Polybe X.28 et les qanats: Le témoignage et ses limites,” in *IDA*, pp. 15-40.

M. A. Butler, “Irrigation in Persia by Kanats,” *Civil Engineering* 3/2, February 1933, pp. 69-73.

Pan Cai and Chao Jiang, “The Relation of the Karez Systems of Xinjiang and the Central Plains of China,” in *PICKI*, pp. 23-32.

Robert Capot-Rey, *L’Afrique blanche française: II—Le Sahara français*, Paris, 1953.

M. Chauveau, “Les qanats dans les ostraca de Manawir,” in *IDA*, pp. 137-42.

Peter Christensen, *The Decline of Iranshahr: Irrigation and Environments in the History of the Middle East 500 B.C. to A.D. 1500*, tr. from the Danish by Steven Sampson, Copenhagen, 1993.

Huaizhen Chu, “General View of the ‘Karez Culture’ as Seen from the Excavated Documents as well as from the Archaeology,” in *PICKI*, pp. 104-6.

A. Cornet, “Essai sur l’hydrogéologie du grand erg occidental et des régions limitrophes: Les foggaras,” *Travaux de l’Institut de recherches sahariennes* 8, 1952, pp. 71-122.

Paolo M. Costa and T. Wilkinson, “The Hinterland of Sohar: Archaeological Surveys and Excavations within the Region of an Omani Seafaring City,” *Journal of Oman Studies* 9, 1983, pp. 11-238.

G. B. Cressey, “Qanats, Karez and Foggaras,” *Geographical Review* 48, 1958, pp. 27-44.

Jean-Marc Deom and Renato Sala, “The 261 Karez of the Sauran Region,” in *WESDASZ*, pdf-file of 15 pages; cf. their article with the same title in *Transoxania* 13, 2008, available on the internet at http://www.transoxiana.org/13/sala_deom-karez_sauran.php (accessed 4 August 2010).

Jean Despois, *Mission scientifique du Fezzan, 1944-45: III—Géographie humaine*, Paris, 1946.

Bernard Dupaigne, “Du Karez aux puits dans le Nord de l’Afghanistan,” *Revue Géographique de l’Est* 17, 1977, pp. 27-36.

R. W. Dutton, “Aflaj Renewal in Araqi: A Village Case Study from Oman,” in *QKK*, pp. 237-56.

Jean-Claude Échallier, *Villages désertés et structures agraires anciennes du Touat-Gourara (Sahara algérien)*, Paris, 1972.

Eckart Ehlers, *Iran: Grundzüge einer geographischen Landeskunde*, Wissenschaftliche Länderkunden 18, Darmstadt, 1980.

Eckart Ehlers and Abbas Saidi, “Qanats and Pumped Wells: The Case of

Assad'abad, Hamadan," in *QKK*, pp. 89-112.

Paul W. English, *City and Village in Iran: Settlement and Economy in the Kirman Basin*, Madison, Wis., 1966, esp. pp. 135-40.

Idem, "The Origin and Spread of *qanats* in the Old World," *Proceedings of the American Philosophical Society* 112, 1968, pp. 170-81.

Idem, "The Qanats of Mahan," in *QKK*, pp. 113-18.

Ahmed Fakhry, *The Oases of Egypt: II—Bahriyah and Farafra*, Cairo, 1974; repr., Cairo, 2003.

Zili Fan, "The Preliminary Studies on the Origin of Karez in Turpan Basin, Xinjiang," in *PICKI*, pp. 43-46.

C.-G. Feilberg, "Qanaterne: Irans underjordiske vandingskanales," in *Øst og-Vest: Afghandelinger tilegnede Professor Dr. phil. Arthur Christensen*, ed. K. Barr and Hans Ellekilde, Copenhagen, 1945, pp. 105-13.

Robert James Forbes, *Studies in Ancient Technology: II—Irrigation and Drainage, Power, Land Transport and Road-Building, the Coming of the Camel*, Leiden, 1955.

P. Gentelle, "Quelques observations sur l'extension de deux techniques d'irrigation sur le plateau iranien et en Asie centrale," in *Le plateau iranien et l'Asie centrale des origines à la conquête islamique: Leurs relations à la lumière des documents archéologiques*, Colloques internationaux du CNRS 567, Paris, 1977, pp. 249-62.

Georg Gerster, *Paradise Lost: Persia from Above*, ed. M. Sachs, London, 2008.

Henri Goblot, "Dans l'ancien Iran, les techniques de l'eau et la grande histoire," *Annales* 18/3, 1963, pp. 499-520.

Idem, *Les qanats: Une technique d'acquisition de l'eau*, Industrie et artisanat 9, Paris, 1979; orig., Ph.D. diss., Ecole des hautes études en sciences sociales, 1973.

T. Gonon, "Les qanats d'Ayn Manawir (Oasis de Kharga, Egypte): Techniques de creusement et dynamique de l'exploitation d'une ressource épuisable de la Première Domination Perse au IIe siècle de l'Ere Commune," in *WQ*, pp. 39-57.

K. Grewe, “Wasserversorgung aus Qanaten: Qanate als Vorbilder im Tunnelbau,” in *WQ*, pp. 9-24.

Yunchang Ha, “The Origin and Development of Karez in Turpan Basin,” in *PICKI*, pp. 86-89.

Kimiti Haimiti et al., “Karez Water Conservancy Characteristics and Development in Turpan,” in *WESDASZ*, pdf-file of 8 pages.

W. B. Henning, “A List of Middle-Persian and Parthian Words,” in *BSOS* 9, 1937, pp. 79-92.

M. Honari, “Qanats and Human Ecosystem in Iran,” in *QKK*, pp. 61-85. Shengzhang Huang, “Re-Expound the Source and Development of Xinjiang Karez,” in *PICKI*, pp. 17-22.

A. Humbert, “Une galerie drainante dans le bassin de l’Ebre à 42 degrés de latitude Nord,” in *EC*, pp. 27-31.

Johannes Humlum, “Underjordiske Vandingskanaler: Kareze, qanat, foggara,” *Kulturgeografi* 16, no. 90, 1964, pp. 81-132.

Ellsworth Huntington, *The Pulse of Asia: A Journey in Central Asia Illustrating the Geographic Basis of History*, Boston, 1907.

C. Jentsch, “Die Kareze in Afghanistan,” *Erdkunde* 24, 1970, pp. 112-20. “Ḳanāt,” in *EI*^{2} IV, 1978, pp. 528-33.

Moḥammad b. al-Ḥasan al-Karaji, *La civilisation des eaux cachées: Traité de l’exploitation des eaux souterraines*, tr. and comm. Aly Mazahéri, pref. Charles Morazé, Institut d’études et de recherches interethniques et interculturelles—Etudes préliminaires 6, Nice, 1973; tr. of *Ketāb enbāṭ al-meyāh al-ḵafiya*, written 1071 CE.

N. O. Kielstra, “The Reorganisation of a *qanat* Irrigation System near Estehbanat, Fars,” in *QKK*, pp. 137-49.

H. Kinzl, “Die altindianischen Bewässerungsanlagen in Peru nach der Chronik des Pedro de Cieza de Leon (1553),” *Mitteilungen der Österreichischen geographischen Gesellschaft*, 1963, pp. 331-39.

H. Klaubert, “Kanate in Selb/Bayern und Umgebung,” *Wasser und Boden* 18,

May 1966, pp. 148-50.

Idem, “Qanats in an Area of Bavaria-Bohemia,” *Geographical Review* 57, 1967, pp. 203-12.

Idem, “Wasserstollen im bayerisch-böhmischen Grenzraum,” *Heimatkalender für Fichtelgebirge und Frankenwald* 1, 1973, pp. 35-43.

Iwao Kobori, “Some Notes on Diffusion of Qanat,” *Orient: The Reports of the Society for Near Eastern Studies in Japan* 9, 1973, pp. 43-66.

Idem, “Notes on *Foggara* in the Algerian Sahara,” *Bulletin of the Department of Geography, University of Tokyo* 8, 1976, pp. 41-55.

Idem, “Comparative Studies on the Formation of Qanat Water System,” *Bulletin of the Institute of Social Sciences, Meiji University, Tokyo* 12/1, 1989, pp. 1-40.

I. Kobori, ed., *Qanawat Romani of Taibe Oasis*, Tokyo University Scientific Mission for the Comparative Study of the Foggara Oasis in the Arid Zone of the Old Continent, Report 1, Tokyo, 1980.

Idem, ed., *Case Studies of Foggara Oases in the Algerian Sahara and Syria*, The Tokyo University Scientific Mission for the Comparative Study of the Foggara Oasis in the Arid Zone of the Old Continent, Report 2, Tokyo, 1982.

Philip L. Kohl et al., *L’Asie centrale des origines à l’âge du fer*, Paris, 1984; with English and French contributions.

Rajab ʿAli Labbāf Ḵāneki, “Barrasi o šenāsā-ye qanāvat-e gonābād,” *Gozāreša-ye bāstān šenāsi* 1, 1997, pp. 271-98.

A. K. S. Lambton, *Landlord and Peasant in Persia: A Study of Land Tenure and Land Revenue Administration*, London, 1953.

Idem, “The Origin, Diffusion and Functioning of the *qanat*,” in *QKK*, pp. 5-11.
Idem, “The *qanats* of Qum,” in *QKK*, pp. 151-75.

Jørgen Læssøe, “The Irrigation System at Ulḫu, 8th Century,” *Journal of Cuneiform Studies* 5, 1951, pp. 21-32.

Ferdinand Friedrich Carl Lehmann-Haupt, *Armenien einst und jetzt: Reisen und*

Forschungen—II/1: Das türkische Ost-Armenien, in Nord-Assyrien, Berlin, 1926.

Yide Liang, "Discussions on the Research of Textual Origin of Karez in Xinjiang, China," in *PICKI*, pp. 84-85.

Gorislava N. Lisitsyna, *Stanovlenie i razvitie oroshaemogo zemledeliya v Yuzhnoĭ Turkmenii* (Formation and development of irrigation agriculture in South Turkmenia), Moscow, 1978.

Chifei Liu, "The Source and Utilization of the Xinjiang Karez," in *PICKI*, pp. 54-67.

Capitaine A. Lô, "Les foggaras du Tidikelt," *Travaux de l'Institut de recherches sahariennes* 10/2, 1953, pp. 139-79 and 11/1, 1954, pp. 49-77.

Maria Macuch, *Rechtskasuistik und Gerichtspraxis zu Beginn des siebenten Jahrhunderts in Iran: Die Rechtssammlung des Farroḫmard i Wahrāmān*, Iranica 1, Wiesbaden, 1993.

N. E. McClymonds, *Shallow Groundwater in the Zamin Dawar Area, Helmand Province,* U.S. Geological Survey Open-File Report, n.p., 1972.

Keith McLachlan, "The *kariz* in the Herat Basin, Afghanistan," in *QKK*, pp. 257-66.

Idem, *The Neglected Garden: Politics and Ecology of Agriculture in Iran*, London, 1988.

Monique Maillard, *Essai sur la vie matérielle dans l'oasis de Tourfan pendant le Haut Moyen Age*, Arts Asiatiques—numéro spécial 29, Paris, 1973.

B. Mantimin et al., "The Traditional Technology for Optimum Subterranean Water Used in the Cold Desert of Northwest China," in *WESDASZ*, pdf-file of 10 pages.

J. P. de Menasce, "Textes pehlevis sur les qanats," *Acta Orientalia* (Budapest) 30, 1966, pp. 67-75.

Adam Mez, *Die Renaissance des Islams*, ed. H. Reckendorf, Heidelberg, 1922.

Joseph Needham, *Science and Civilisation in China*, Vol. IV. *Physics and Physical Technology*, Pt. 3. *Civil Engineering and Nautics*, in collaboration with Wang

Ling and Lu Gwei-Djen, Cambridge, 1971.

J. A. Neely, “Sassanian and Early Islamic Water-Control and Irrigation Systems on the Deh Luran Plain, Iran,” in *Irrigation’s Impact on Society*, ed. T. E. Downing and M. Gibson, Anthropological Papers of the University of Arizona 25, Tucson, 1973, pp. 21-42.

E. Noël, “Qanats,” *Journal of the Royal Central Asian Society* 31, 1944, pp. 191-202.

H. S. Nyberg, ed., *Frahang i Pahlavīk*, ed. from the posthumous papers . . . by B. Utas, Wiesbaden, 1988.

Eugen Oberhummer, *Die Insel Cypern—Eine Landeskunde auf historischer Grundlage: Quellenkunde und Naturbeschreibung*, Munich, 1903.

S. Okazaki, “The Japanese *qanat* (mambo): Its Technology and Origin,” in *QKK*, pp. 267-79.

Jocelyn Orchard and Gordon Stanger, “Third Millenium Oasis Towns and Environmental Constraints on Settlement in the Al-Hajar Region,” *Iraq* 56, 1994, pp. 63-100.

Idem, “Al-Hajar Oasis Towns Again,” *Iraq* 61, 1999, pp. 89-119.

T. Owen, “Oman,” *Middle East Review* 15, 1989, pp. 113-17.

Ünal Öziş et al., “Tunnelstrecken in Qanatbauweise: Der [sic] Kenchrios-(Değirmendere)-Fernwasserleitung nach Ephesus,” in *WQ*, pp. 293-300.

Antonino Pagliaro, “Pahlavi *katas* ‘canale’ gr. ΚΑΔΟΣ,” *Rivista di Studi Orientali* 17, 1938, pp. 72-83.

M. H. Papoli-Yazdi, “Āsyābhāʾi ke bā āb-e qanāt kar mikonand,” *Majalla-ye Dāneškada-ye adabiyāt o ʿolum-e ensāni-e Dānešgāh-e Ferdowsi* 18, 1364 Š./1985, pp. 3-30.

Idem, “Une technique méconnue: Les *qanāt* à moulins du désert iranien,” in *EC*, pp. 87-96.

Paul Pascon, *Le Haouz de Marrakech*, 2 vols., Rabat, 1977; orig., Ph.D. diss., Université de Paris VII, 1975.

Paul Pelliot, note about kārēz in the “Séance du 16 Avril 1920,” *JA*, ser. 11, 15, 1920, p. 261.

Idem, “L’édition collective de l’oeuvre de Wang Kouo-Wei,” *T’oung Pao* 26, 1929, pp. 113-82.

Xavier de Planhol, “Les galeries drainantes souterraines: Quelques problèmes généraux,” in *EC*, 1992, pp. 129-42. I

dem, “Réflexions sur l’identité iranienne,” *Mondes et cultures* 66, 2006, pp. 261-69.

Idem, “Le *kārēz* et la luzerne: Une première revolution agricole en Iran,” *Stud. Ir.* 39/1, 2010, pp. 11-26.

X. de Planhol and Pierre Rognon, *Les zones tropicales arides et subtropicales*, Paris, 1970.

S. Radojicic, *Water Resources Development Prospects for the Water Supply of Rural Population in Ghazni Province*, multigraph, UNICEF/WHO Assisted Rural Water Supply Project, Kabul, 1978a.

Idem, *A Note on Hydrogeological Reconnaissance of Deh-Sabz BHC and Qala-i-Bakhtyar in the Kabul Vicinity*, UNICEF/WHO Assisted Rural Water Supply Project, Kabul, 1978b.

Fereydoun Rahimi-Laridjani, *Die Entwicklung der Bewässerunglandwirtschaft im Iran bis in sasanidisch-frühislamische* [sic] *Zeit*, Beiträge zur Iranistik 13, Wiesbaden, 1988; orig., Ph.D. diss., Universität Tübingen, 1988.

Susan Roaf, “Settlement Form and *Qanat* Routes in the Yazd Province,” in *QKK*, pp. 59-60.

Zvi Ron, “Development and Management of Irrigation Systems in Mountain Regions of the Holy Land,” *Transactions of the Institute of British Geographers*, N.S. 10, 1985, pp. 149-69.

Idem, “*Qanats* and Spring Flow Tunnels in the Holy Land,” in *QKK*, pp. 211-36.

Idem, “Qanats and Spring Flow Tunnels in the Holy Land,” in *EC*, pp. 33-55 (a more complete and abundantly illustrated version of the preceding article).

Jawād Safi-Nežād, *Neẓāmhā-ye ābyāri-e sonnati dar Irān*, Entešārāt-e moʾassasa-ye moṭālaʿāt o taḥqiqāt-e ejtemāʿi 88, Tehran, 1359 Š./1980.

Idem, "De la pierre à l'eau: Nouvelles observations sur les *qanat* d'Iran," *EC*, pp. 57-78.

Emmanuel Salesse, ed., *Las galerías de captación en la Europa mediterránea: Una aproximación pluridisciplinar—Coloquio Internacional 4-6 de junio de 2001*, Madrid, forthcoming.

Mirjo Salvini, "Pas de qanats en Urartu!" in *IDA*, pp. 143-55.

Mansur Seyyed Sajjadi, *Qanat/Kariz: Storia, tecnica construttiva ed evoluzione,* Quaderni della sessione archeologica dell' Istituto italiano di cultura 1, Tehran, 1361 Š./1982; the Persian orig., *Qanāt/Kāriz: Tārik̲ča, saḵtamān va čegunagi-ye gostareš-e dar jahān*, was published in parallel as a separate volume.

Fred Scholz, "Die physisch- und sozialgeographische Ursachen für die Aufgabe und den Erhalt der Kareze in Belutschistan," *Die Erde* 103, 1972, pp. 302-15.

Idem, "Falaj-Oasen in Sharqiya, Inner-Oman," *Die Erde* 115, 1984, pp. 273-94.

Anthony Smith, *Blind White Fish in Persia*, London, 1954; tr. as *La Perse et ses mystères: A la recherche du poisson blanc aveugle*, by François Boësse, Paris, 1957.

Robert Payne Smith, *A Compendious Syriac Dictionary*, Oxford, 1903.

G. Stratil-Sauer, "Kanats, Persiens künstliche Bewasserungsanlagen," *Die Umschau* 40, no. 271, 1937, pp. 271-75.

Maximilian Streck, "Ḳanāt," in *EI*[1], Eng. tr., II, 1927, pp. 708-9.

Hori Sunao, "The Origin of the Karez in Turpan: Reasons for its Spread," in *PICKI*, pp. 82-83.

K. Suter, "Die Foggara des Touat," *Vierteljahresbericht der Naturforscher in Zürich* 97, 1952, pp. 145-80.

Nur Moḥammad Tarah'ki (Taraki), "Awzāʿ-e zarāʿati o fallāḥati-e Moqor," *Majalla-ye Eqteṣād* (Kabul) 1319 Š./1940, pp. 621-23.

Richard Thoumin (Thoumin-Lodoïs), *Géographie humaine de la Syrie centrale*, Tours, 1936; orig., Le Ghab, Ph.D. diss., Université de Grenoble, 1936.

C. Troll, "Qanat-Bewasserung in der Alten und Neuen Welt," *Mitteilungen der Österreichischen Geographischen Gesellschaft* 105, 1963, pp. 313-30.

Eric Trombert, "The Karez Concept in Ancient Chinese Sources: Myth or Reality?" in *WESDASZ*, pdf-file of 18 pages.

W. Wagner, *Grundlagen und Empfehlungen für eine Perspektivplanung zum regionalen Entwicklungsvorhaben Paktia/Afghanistan: Grundwasser (Grundwasserpotential)*, Planungsteam Paktia, n.p., 1972.

Hermann-Josef Wald, *Landnutzung und Siedlung der Pashtunen im Becken von Khost (östliches Afghanistan)*, Opladen, 1969; orig., Ph.D. diss., Universität Freiburg, 1967.

Binghua Wang, "The Ancient Irrigation Works as Seen in the Xinjiang Archaeological Investigation," in *PICKI*, pp. 94-103.

Shouchun Wang, "The Study of Historical Geography on the Origin of the Kerez of Turpan," in *PICKI*, pp. 47-53.

G. Weisgerber, "The Impact of the Dynamics of Qanats and Aflaj on Oases in Oman: Comparisons with Iran and Bahrain," in *WQ*, pp. 61-97.

J. Wessels, "Criteria for Renovating and Using Ancient Qanats in Syria: Case Studies," in *WQ*, pp. 249-62.

Jacques Weulersse, *Paysans de Syrie et du Proche-Orient*, Paris, 1946.

J. C. Wilkinson, *Water and Tribal Settlement in South-East Arabia: A Study of the Aflāj of Oman*, Oxford, 1977.

Idem, "The Origins of the Aflāj in Oman," *Journal of Oman Studies* 6/1, 1983, pp. 177-94.

A. Wilson, "Foggara Irrigation and Early State Formation in the Libyan Sahara: The Garamantes of Fezzan," in *WQ*, pp. 223-34.

H. E. Wulff, "The Qanats of Iran," *Scientific American* 218/4, 1968, pp. 94-105.

M. Wuttmann, “Les qanats de ʿAyn-Manāwīr (oasis de Kharga, Egypte),” in *IDA*, pp. 109-36.

Xinjiang Water Conservancy Bureau and Xinjiang Hydraulic Engineering Society, “Studies on Xinjiang Karez,” in *PICKI*, pp. 33-42.

Xiru Zhang, “The Conditions of the Formation of ‘Karez’ in Xinjiang and the Theories about their Origin,” in *PICKI*, pp. 68-75.