7th International Conference on Seismology & Earthquake Engineering
18-21 May 2015

SINGLE GRAIN OSL DATING OF MIAM QANAT SYSTEM IN NE IRAN AND SLIP RATE DETERMINATION OF DASHTEBAYAZE FAULT

Morteza FATTAHI
Institute of Geophysics, University of Tehran, Tehran, Iran
mfattahi@ut.ac.ir
School of Geography, University of Oxford, Oxford, OX1 3QY, UK
Morteza fattahi@ouce.ox.ac.uk

Richard T WALKER
Department of Earth Sciences, University of Oxford, OX1 3PR, UK
richard.walker@earth.ox.ac.uk

Morteza TALEBIAN
Geological Survey of Iran, Iran
morteza100@yahoo.com

Mohammad M KHATIB
Birjand University, Iran
m.khatibinia@birjand.ac.ir

Aydin AGHAZADEH
Institute of Geophysics, University of Tehran, Tehran, Iran
aydinagazade@ut.ac.ir

Robert A SLOAN
Department of Earth Sciences, University of Oxford, OX1 3PR, UK
als@earth.ox.ac.uk

Vasile ERSEK
Department of Earth Sciences, University of Oxford, OX1 3PR, UK
vasile.ersek@earth.ox.ac.uk

Keywords: Qanat, Osl Dating, Slip Rate, Dashtebayaze, Iran

ABSTRACT

In Iran many of qanat galleries were dug in the vicinity of, or directly upon, active faults. In some areas such as Dashte-bayze fault, line of craters are displaced by the activity of the fault, which lead to dry qanat stream, and consequently to dig new shafts by habitants. By means of measuring the offset between new shafts and old shafts, and considering qanat antiquity, the estimation of fault slip-rate - which is one of the prominent elements in hazard assessment - becomes possible. However, the direct dating of qanats has been problematic as no suitable method for determining the timing of construction and maintenance has yet been suggested. This article presents absolute age for a qanat system, obtained through optically-stimulated luminescence dating of grains in spoil heaps of Qanat wells. Feldspar single-grain dating of silt sediments that overlie construction spoil show that the Miam qanat was maintained until at least 1.6-2.6 ka. This age is the first absolute date of that advanced irrigation technologies existed in the NE

of Iran at least some hundred years earlier than previously thought. Combination of this age and the 10 meter displacement of Qanat line of shafts by Dashte-bayze fault provide a slip rate of 4-6 mm/yr for this fault.

INTRODUCTION

The qanat (also referred to as karez in Iran and other names in other countries) is a sustainable system of underground irrigation channels which use gravity in order to tap water in highlands from beneath the water table at its upper end and continuously distribute it through gently sloping tunnels often several kilometers long, to a ground surface outlet at tunnel lower end where it is needed for irrigation and domestic use. The Qanat design was so simple and effective that it was adopted in many other arid regions of the Middle East and around the Mediterranean. Along the length of the qanat tunnel, a series of vertical shafts were used for excavation of the tunnel at intervals of 10 to 140 meters to remove excavated material and to provide air circulation, lighting and access for maintenance (Fig. 1.). It can be marked on aerial photos by a line of circular craters (Fig. 2).

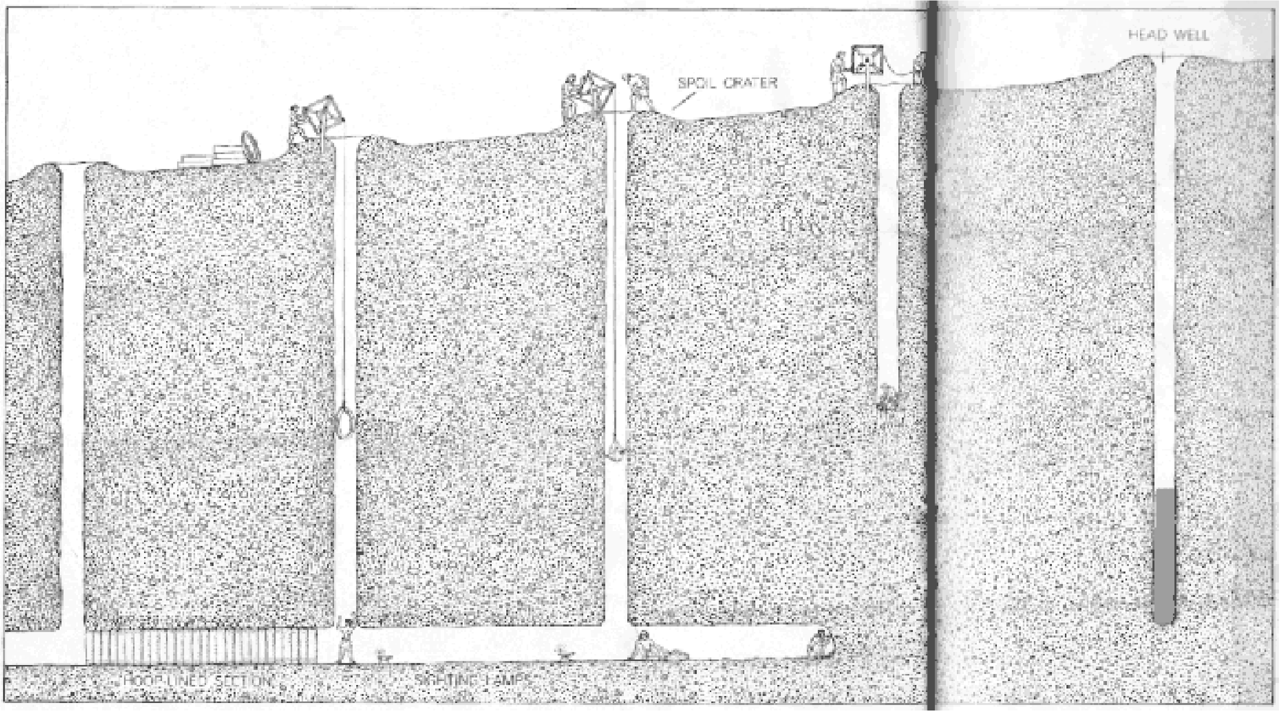

Figure 1. Schematic cross-section through part of a qanat system. Excavation of a qanat begins at the downhill end after a trial well (right) has successfully tapped the uphill water table. Where the gradually sloping tunnel passes through zones of loose earth (left) hoops of tile support the walls, but a tunnel generally lacks masonry except at the discharge point. Ventilation shafts are dug at intervals of 20 to 100 meters to provide air circulation, lighting and access for maintenance. Earth and rock excavated from the tunnel face are winched to the surface through the shafts. Sightings over a pair of oil lamps help to keep the tunnel diggers' progress on a straight line. A lamp flame that burns badly also gives warning of bad air. Before the tunnelers break through to the head well, men at the surface hail it dry. The main gallery taps elevated ground-waters beneath highlands and allows water to flow underground to low-lying agricultural regions, thus minimizing loss through evaporation (Wulff, 1968).

Figure 2. Example of a line of circular craters. Spoil from the excavation of the qanat, and from subsequent periods of maintenance, is piled around the vertical access shafts to provide a wall to protect the shafts and the tunnel below from erosional damage from the inflow of water during a heavy desert rainstorm (Wulff, 1968).

In most seismic regions, the earthquake faults are located at the boundary of plains and mountains where streams or qanats provide water and fertile soil for settlement and agriculture. As a result, it seems that the earthquakes often exactly target the human population centers. In some parts of Iran, such as Dashtebayze fault (Fig. 3), and North Tabriz fault (Fig. 4), the line of wells of the qanat systems have been displaced by faulting which lead to dry qanat stream and consequently to dig new shafts by habitants. For example in the case of Qanat that was displaced by North Tabriz fault, the new shafts and canal (A in fig. 4) was dug after the older canal (B in fig. 4) was offset right-laterally for about 11.7 m ± 0.5 (Hesami et al., 2003).

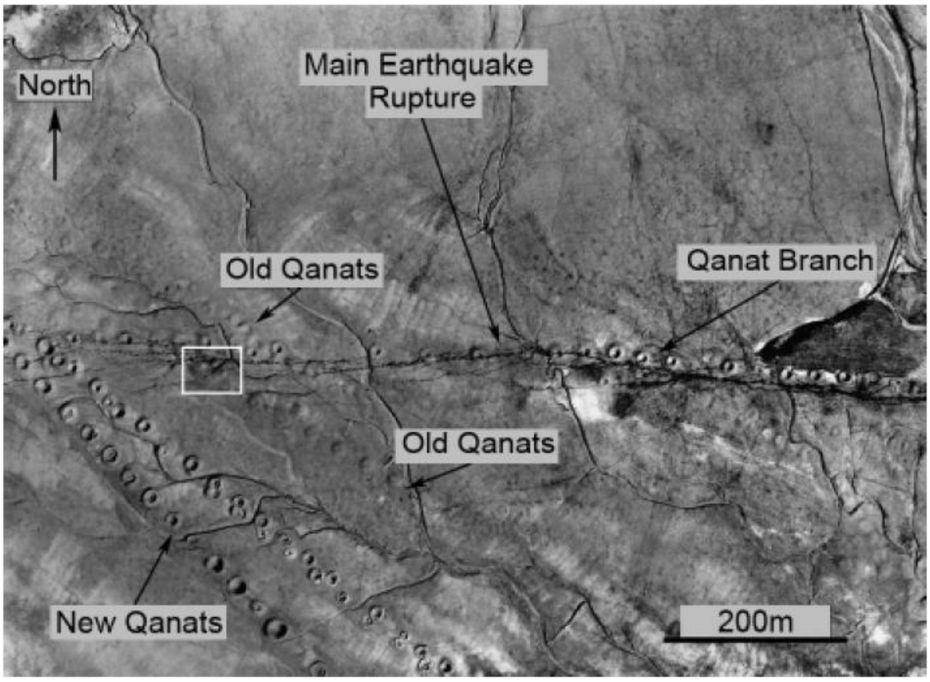

Figure 3. Air photo of Qanats in the Nimbluk valley, taken after the 1968 Dasht-e-Bayaz earthquake. The earthquake fault rupture runs east-west across the center of the picture and moved horizontally, with the north side sliding to the west. Multiple generations of Qanats are visible, the most recent were cut by the 1968 faulting, but these were replacements for earlier Qanats, whose lines of craters are now heavily eroded, that were presumably abandoned after earlier earthquakes. One Qanat follows precisely the line of the fault rupture, increasing the water flow into the main northwest-southeast Qanats by tapping an underground change in water-level, ponded by impermeable clay gouge on the fault (Ambraseys, N.N. and Melville, C.P. 1982). The white box shows the location of current sampling (Ambraseys and Tchalenko, 1969).

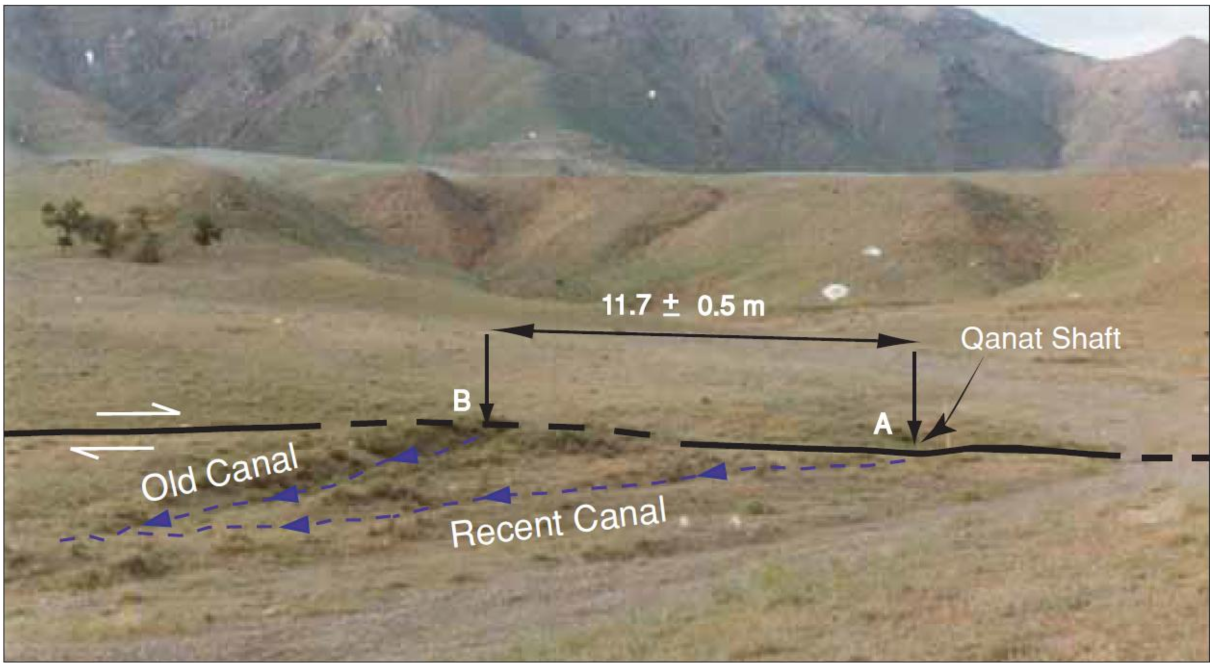

Figure 4. The North Tabriz Fault has displaced the old Qanat tunnel (looking north). The distance between old canal and its original position (*i.e.* the Qanat shaft) is 11.7 m. The new canal is built where the old canal used to be (From Hesami et al. 2003).

If we can date the age of qanat wells that are displaced by Earthquakes faults and measure the amount of offset, we can estimate the slip-rate of the fault, which is an important factor for Earthquake hazard assessment. However, the direct dating of qanats has been problematic as no suitable method for determining the timing of construction and maintenance has yet been suggested. The existing constraints on age of ancient qanats in Iran are circumstantial and are typically assigned from archaeological investigations of nearby habitation sites. The method of Qanat construction and maintenance has remained almost the same within last thousands of years. Vertical shafts dogged and material removed from underground during the construction or maintenance of the tunnel, and spread around the shaft to form the circular spoil heaps (upcast). This should have happened during the day time. A proportion of the grains in the spoil will have been reset by exposure to sunlight which makes it suitable for optically stimjulated luminescence dating. Fattahi et al. (2011) provided the first method for determining direct age of an ancient qanat system through luminescence dating of sediment grains within the circular spoil heaps. Their attempt to date spoils associated with Maiam qanat using quartz single aliquot OSL procedures were much earlier than expected.

This documemts explains the sampling site and the dating method. It will explain why the previous attempt to date spoils associated with Maiam qanat using quartz single aliquot OSL procedures were much earlier than expected, and how the new method has overcame this problem and present the slip rate of the Fault.

2. SAMPLING SITE

The Dasht-e-Bayaz left-lateral strike-slip fault in northeastern Iran is an important feature within the active tectonics of Iran. On the 31 August 1968, the western 80 km of the left-lateral Dasht-e-Bayaz fault in northeastern Iran ruptured in an earthquake of Mw 7.1 that killed an estimated 7000 to 12000 people (Ambraseys and Tchalenko 1969; Walker et.al. 2004). The Miam qanats were first noted following the 1968 Dasht-e-Bayaz earthquake. Detailed mapping of the rupture was facilitated by a post-earthquake aerial photographic survey (Ambraseys and Tchalenko, 1969), which also enabled the identification of several separate generations of qanat (Fig. 3.).

In the thirty years following 1968 the region has been subject to numerous further destructive earthquakes, including four events of Mw 5.5-6, four events of Mw 6-7, and a further two events of Mw 7.1.

The first of these two Mw 7.1 earthquakes, the Khuli-Buniabad earthquake of the 27 November 1979, ruptured the eastern 60 km of the Dasht-e-Bayaz fault. The second (the 10 May 1997 Zirkuh earthquake) ruptured the north-south right-lateral Abiz fault. Together, the sequence of destructive earthquakes within 30 years at Dasht-e-Bayaz forms one of the most outstanding examples of clustered large-magnitude seismic activity in the world (e.g. Berberian et.al. 1999; Berberian and Yeats 1999). Determining the slip rate and recurrence interval between large events on the Dasht-e-Bayaz fault is of importance for estimating the hazard posed by the fault to local populations and also for the more general issue of the clustering in time of large earthquake events.

The extreme antiquity of the oldest series of qanat mounds is inferred from their level of preservation, and also because they appear to be displaced left-laterally by 10 m across the Dasht-e-Bayaz fault, at a place where the 1968 displacement was only 3 m (Fig. 3). This observation indicates that they have been displaced by multiple earthquakes upon the fault. Modification of the land surface around Miam during the past few decades has eradicated most of the ancient qanat wells. However, it was possible to identify a short stretch of four consecutive mounds and to locate these four wells in the field.

A Short trenches was excavated through a circular spoil heaps (see figures 4 and 5 in Fattahi et al.2011). The central well was not excavated, dating of which would simply tell us when the qanat was abandoned, but instead focused on identifying the pre-construction land surface as well as observing the main sedimentary features of the spoil. Log of the north wall of the trench revealed four main sedimentary units. A lower unit (palaeosol) was composed of horizontally-bedded cobbles from which sample Gh1 was collected. This unit graded rapidly upwards into a thin, fine-grained, silty unit with a concentration of cobbles at its upper surface (no sample was collected from this unit). We infer that these two lower units represent the land surface immediately prior to construction of the qanat, with alluvial gravels overlain by a thin inflationary palaeosol, with partially developed desert armour at its surface.

The two upper sedimentary units exposed in the trenches consist of coarse gravel dipping at ~30° (Qanat spoil, gravel) overlain by a light-coloured, and predominantly silt unit (Qanat spoil, silt), with occasional sand and gravel clasts highlighting a dip of ~30°. We interpret these two units to represent stages in the construction and maintenance of the qanat. Initial excavation of the vertical well and underground gallery would have been through the same coarse gravel that is exposed in the lower unit (palaeosol), and the coarse gravel in the underlying spoil layers reflects this. Later maintenance, through the dredging of material accumulated within the gallery, yields spoil that is predominantly fine-grained. The occasional coarser lenses within the silty maintenance spoil may represent the repair of damage to the qanat gallery. Apart from the occasional gravel layers, there is an overall lack of structure within the fine-grained silt unit, and so we do not sub-divide it into individual maintenance events.

Moisture concentrates along the boundary between the spoil and underlying alluvium, and any organic matter that may have been present, and suitable for radiocarbon dating, has decayed. Instead, we sampled the main sedimentary units for OSL dating. Three light-protected samples were collected from the vertical trench faces by hammering in steel tubes. These represent the time of maintenance (Gh1), construction (Gh2) and the age of sediments underlying the pre-construction land surface (Gh3).

3. OSL DATING METHODOLOGY

Optically stimulated luminescence (OSL) dating determines the age of the last exposure to daylight of the sediment grains. When sediment is exposed to sunlight prior to deposition, the OSL acquired over geological time is removed. The luminescence “clock” is thus set to zero. After burial the luminescence clock starts and grains begin to accumulate a trapped-charge electron population that increases in response to the ionising radiation dose from environmental sources. Stimulating samples of buried quartz and feldspar grains in the laboratory releases the trapped electrons, along with photons of light (luminescence). The level of OSL observed in quartz and feldspar is dependent on the absorbed radiation dose. The burial age of grains that were well bleached by daylight at the time of deposition can then be calculated by dividing the equivalent dose De (which is the radiation level responsible for producing the luminescence signal) by the dose received per year (during burial).

The samples were treated in the laboratory as outlined by Fattahi et al., (2007) and Fattahi et al., (2014). The 90–250 μm size fractions were chemically pre-treated and quartz and feldspar were separated.

Purity of the quartz samples was checked by IR exposure and revealed feldspar contamination. Therefore, Quartz fractions were treated with hydrofluorosilisic acid for 2 weeks. Little amount of quartz from Gh1, Gh2, and almost none from Gh3 samples had remained. The dried samples were then, sieved further using 90 and 150 µm sieves.

The quartz and feldspar grains in eastern Iran are often very dim, with only small proportions of grains yielding any luminescence signal at all. Therefore, initially, standard large single-aliquot dating of the 90-150 µm quartz fractions of samples Gh1 and Gh2, and potassium feldspar of sample Gh3 was performed using standard protocols as outlined in (Fattahi et al., 2011). This provided the minimum ages of 15.8 ± 1.6ka and 22.1 ± 2.7ka for Gh1 and Gh2, respectively and average age of 9 ±1*ka* using Central age model for Gh3. The age of Gh3 is consistent with a quartz age of 8.7 ± 1.1*ka* calculated for a single sample of fine-grained fluvial silt that was collected from a depth of ~1.25*m* within the sediments in the surface of the Nimbluk plain (Walker and Fattahi, 2011), which is nearby and located just south of Khezri Dasht-e-Bayaz village. However, the application of the single aliquot OSL to date the deposition of spoils associated with this qanat in Iran provided pre-Holocene but consistent ages with the stratigraphy within the shaft, which were older than the estimated date of construction and maintenance (Fattahi et al.2011).

The first thing to note is that the age sequence of the single-aliquot analyses is stratigraphically inverted, with the younger age obtained from the deepest stratigraphic layer sampled (Gh3), and the maintenance (Gh1) yielding older age. The age inversion is expected. Material removed from underground during the construction or maintenance of the tunnel, and spread around the shaft to form the circular spoil heaps (upcast), may have had only brief exposure to sunlight. A proportion of the grains in the spoil will have been reset by exposure to sunlight, whereas others will be only partially bleached, or not bleached at all. Standard single-aliquot methods provide the luminescence response of large numbers of grains, with many retaining significant inherited signal. Standard single-aliquot methods, are hence likely to provide ages that are older than the deposition of the construction or maintenance spoil unit. Even when the minimum age model is applied, the ages of each single aliquot are still an average signal of many grains ranging from unbleached to fully bleached grains. If the number of fully bleached grain in aliquots is limited, the calculated ages can greatly overestimate the true probable age. By performing single-grain measurements, it is possible to separate out those grains that were fully bleached by exposure to sunlight. In order to determine the timing of construction and maintenance of the two excavated wells we used single-grain analysis of the luminescence signal.

First, quartz single-grain analyses (grain sizes of 150-250 µm) were performed, with subsequent statistical analysis of the equivalent dose (De) distributions to help identify the true deposition age. The quartz grains were very dim and despite of many measurements, quartz single grain method could not provide a meaningful D_e for none of the samples. Following single grain measurements, no quartz grain remained from Gh1 and Gh2 samples.

The potassium feldspar fraction was therefore employed for single grain measurement of samples Gh1 and Gh2. As the number of completely bleached grains was expected to be limited, large numbers of measurements was required for single-grain dating of feldspar (for Gh1 and Gh2). The feldspar grains were also very dim and less than 2% of grains produced any signal. Therefore, the experiments were carried out in 2 steps. In the first step, natural and test dose signal was measured. In the next step, the rest of SAR was carried out only for grains which had produced sufficient amount of signal for the test dose.

A total of 20000 grains of Gh1and Gh2 were measured, of which less than 1% of single-grain analyses were successfully used for De determination and passed the SAR method acceptance criteria (Wintle and Murray, 2006; Jacobs et al., 2006). Figure 5 show the De value of samples from paleosoil. Dose-rates were calculated based on the method outlined in Fattahi et al (2011).

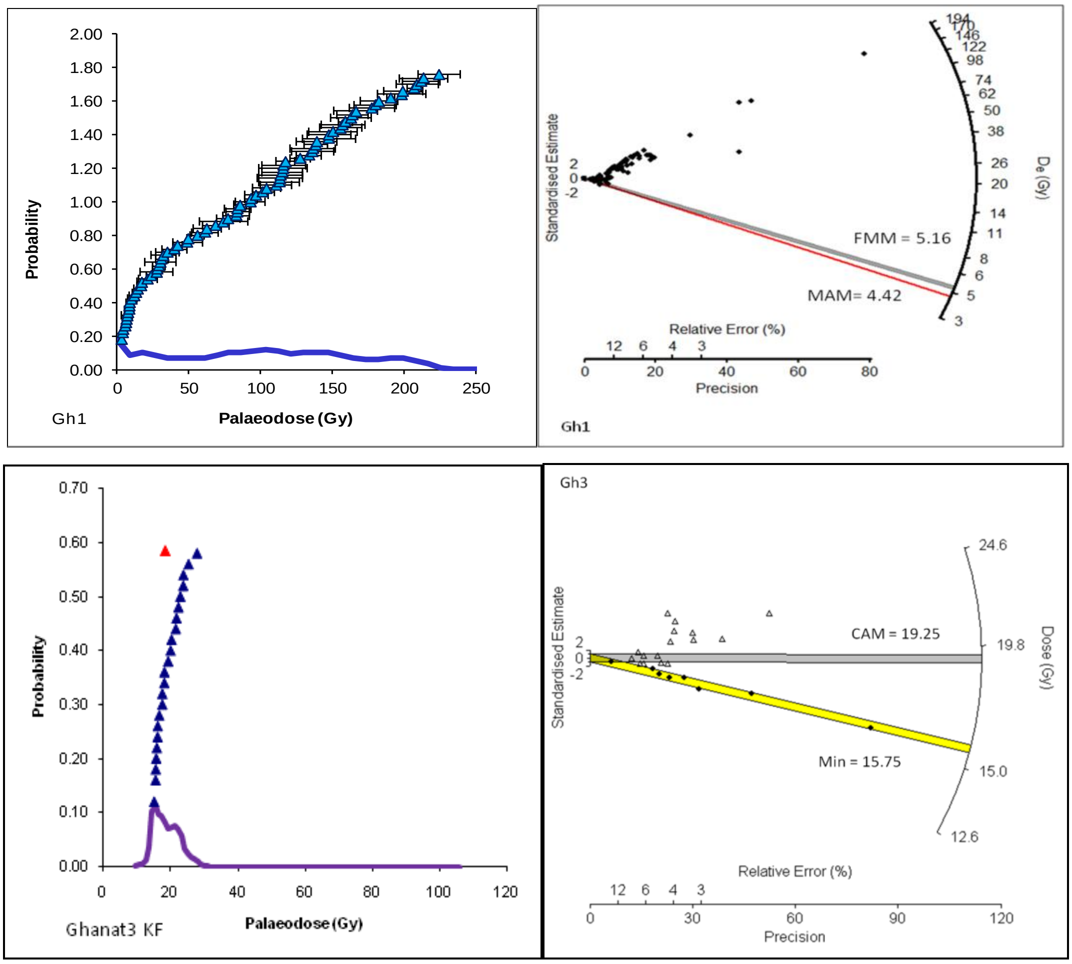

Figure 5. The De value of samples from paleosoil, representative probability and radial plots of 'mixed and scattered' large single-aliquot De distributions of samples Gh1 and Gh3. The grey bands shows values of 2 standard deviations from the De CAM estimates cantered on the reference value. The solid yellow line shows the Minimum De to compare.

CONCLUSIONS

This study provided the first direct age of an ancient qanat system through optically-stimulated dating of feldspar sediment single grains within the circular spoil heaps of Miam Qanat which is displaced by Dashte-Bayze fault. This method can also be used for dating wells and handmade ditches and canals.

Our feldspar single grain OSL dating thus gives the ages of last maintenance of these wells at 1.6-2.6. Combination of this age and the 10 meter displacement of Qanat line of shafts by dashtebayaze fault provides a slip rate of 4-6 mm/yr for this fault.

ACKNOWLEDGEMENTS

The first author would like to acknowledge the financial support of University of Tehran for this research under grant number 6201002/1/10 for OSL dating. The Leverhulme Trust, is thanked for the financial support of the research field work. We also would like to thank the Geological Survey of Iran, and the mayor and people of Khezri/Dasht-e-Bayaz for their long-term support of our work in the area. Hamideh Amini kindly helped for sample preparation.

REFERENCES

Ambraseys NN and Tchalenko JS (1969) The Dasht-e-Bayas (Iran) earthquake of August 31, 1968: A field report, Bull. Seism. Soc. Am., 59, 1751–1792

Ambraseys NN and Melville CP (1982) a History of Persian Earthquakes, Cambridge University Press, UK

Berberian M and Yeats RS (1999) Contribution of archaeological data to studies of earthquake history in the Iranian Plateau, Journal of Structural Geology, 23, 563-584

Berberian M, Jackson JA, Qorashi M, Khatib MM, Priestley K, Talebian M and Ghafuri-Ashtiani M (1999) The 1997 May 10 Zirkuh (Qa'enat) earthquake (Mw 7.2): faulting along the Sistan suture zone of eastern Iran. *Geophysical Journal International, 136, 671-694*

Fattahi M, Walker RT, Khatib MM, Dolati A and Bahroudi A (2007) Slip-rate estimate and past earthquakes on the Doruneh fault, eastern Iran. *Geophysical Journal International,* 168, 691-709

Fattahi M, Aqazadeh A, Walker RT, Talebian M, Sloan RA and Khatib MM (2011) Investigation on the Potential of OSL for dating qanat in the Dasht-e Bayaz region of north-eastern Iran using the SAR protocol for quartz. *J. Seismology and Earthquake Eng.* 13, 65-75

Fattahi M, Walker RT, Talebian M, Sloan RA and Rasheedi A (2014) Late Quaternary active faulting and landscape evolution in relation to the Gowk Fault in the South Golbaf Basin, S.E. Iran. Geomorphology 204:334–343

Hessami K, Pantosi D, Tabassi H, Shabanian E, Abbassi M, Feghhi K and Solaymani S (2003a) Paleoearthquakes and slip rates of the North Tabriz Fault, NW Iran:preliminary results. Annales Geophysicae 46, 903–915

Jacobs Z, Duller GAT and Wintle AG (2006) Interpretation of single grain De distributions and calculation of De. Radiation Measurements 41, 264e277

Walker R and Fattahi M (2011) A framework of Holocene and Late Pleistocene environmental change in eastern Iran inferred from the dating of periods of alluvial fan abandonment, river terracing, and lake deposition. Quaternary Science Reviews. 30, 9–10, 1256–1271

Wintle AG and Murray AS (2006) a review of quartz optically stimulated luminescence characteristics and their relevance in single aliquot regeneration dating protocols. Radiation Measurements 41, 369–391

Wulff HE (1968) The Qanats of Iran," Scientific American, April, p. 94-105