Offsets along the Doruneh fault; implications for dating sampling sites and slip rate determination

Hamideh Amini[1],*, Morteza Fattahi[1], Mohammad Reza Ghassemi[2]

1- Physics of Earth Science Group, Institute of Geophysics, University of Tehran, Iran.

2- Research Institute for Earth Sciences, Geological Survey of Iran, Tehran, Iran.

* Corresponding Author: hiamini@ut.ac.ir; h.amini@iiees.ac.ir

Received: 28 March, 2016 / Accepted: 05June 2016 / Published online: 07June 2016

Abstract

The Doruneh fault is one of the longest and most prominent faults in Iran. However, only two recorded historical earthquakes with magnitudes more than 7 might be related to this fault. For getting more information on this fault more investigation in different fields are required. Fault displacement is one of the most important parameters needed to explore the fault activity. In this study, with the help of Landsat and Quickberd images of this region, several locations near Bardaskan, Khalil-Abad, Kashmar and Rezg-Abad are suggested for field measurement and OSL sampling to improve the information on this fault.

Keywords: Displacement, Earthquake, Sampling, Doruneh Fault.

1- Introduction

Most of the deformation in the Iranian Plateau is principally related or created by strike-slip faults (e.g. Talebian and Jackson, 2002; Walker and Jackson, 2004; Solaymani Azad et al. 2011; Ritz et al. 2006; Regard et al. 2005; Le Dortz et al. 2009; Shabanian et al. 2009b; Farbod et al. 2011). Shortening in Zagros and Alborz mountains are recently localized with 5-9 mm/yr (Hessami et al., 2006) and ~7 mm/yr (Djamour et al. 2010; Shabanian et al. 2012) respectively.

The left-lateral strike-slip fault Doruneh [called by Wellman (1966)], also known as Great Kavir Fault [called by Stoclin and Nabavi (1973)], is located in the N-E of Iran (Figure 1). This is the second longest fault system of this region after the Zagros Fault system. The length of this fault is reported to be ~600 to 900 km, from the Afghanistan-Iran border to the Dasht-e-Kavir desert of central Iran (e.g., Fattahi et al., 2006; Javadi et al., 2013).

The geomorphology of the Doruneh fault contains numerous indications of cumulative left-lateral slip over various scales. Most of the information of the Doruneh Fault is provided by its morphotectonic features. These include offset terrace rivers, alluvial fans and displaced river channels (e.g. Sieh and Jahus, 1984; Keller and Pinter, 2002; Talebian and Jackson, 2002; Walker and Jackson, 2002; Fattahi et al., 2006). According to the geometric arrangement and trend of this fault it is possible to consider three western, central and eastern sections for this fault. These are extended in NE-SW, E-W and NW-SE orientations respectively. Kinematic evidences of the Doruneh fault system indicates a left-lateral slip rate of ~2.4±0.3 mm/yr (Fattahi et al., 2006; Tavakoli, 2007) in the central part of this fault on the Northern margin of the central Iran.

The oldest study on the Doruneh fault was done by Wellman (1966). He employed arial-photos and studied geomorphology of the region. He presented 75m and 200m left-lateral displacement of the rivers on this fault. In 1975 and 1977 Ambraseys and Moinfar who were concentrating on Kashmar earthquake

(1903.09.25) and Kaj-Drakht earthquake (1923.05.25) studied the seismotectonic and geomorphology of the region. Walker and Jackson (2004) suggested the involvement of a vertical axis clockwise rotation of the Doruneh fault which is transmitting to the Dasht-e-Bayaz fault. Zare (2000) and Nabavi (1976) proposed that this fault had right-lateral movements before left-lateral movement.

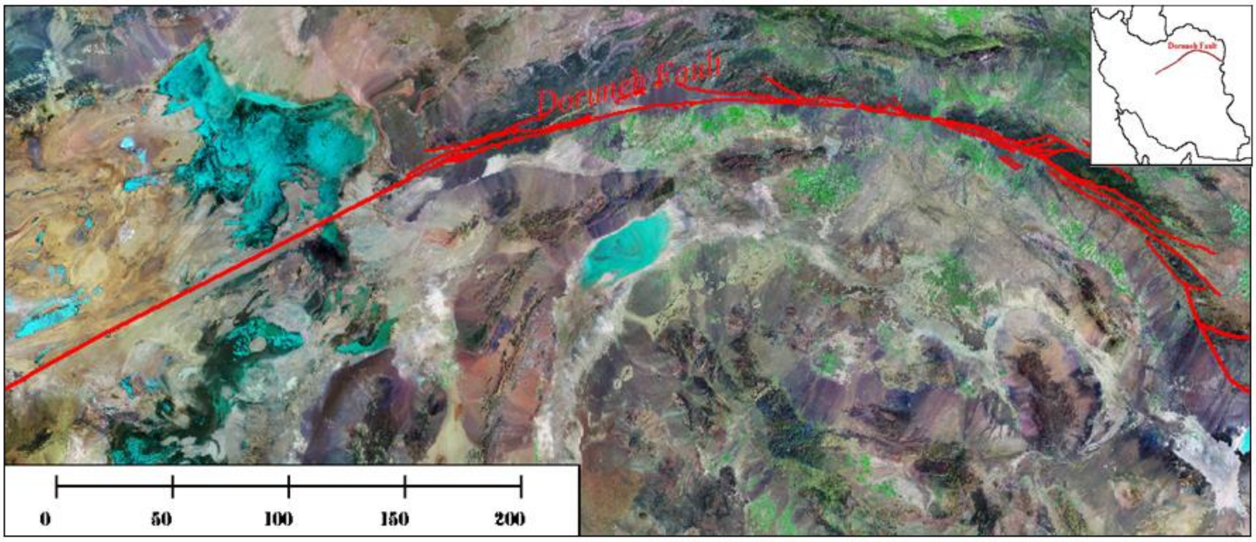

Figure 1) Location of Doruneh fault in Iran region.

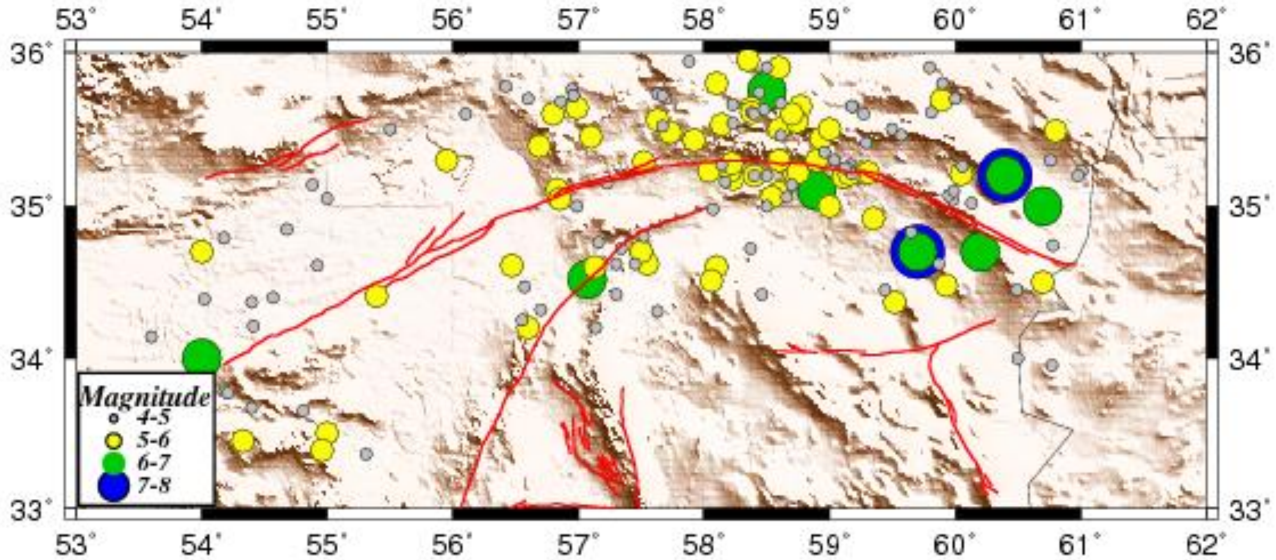

Figure 2) Reported earthquakes around Doruneh fault; earthquakes are separated with different color of magnitude.

Fattahi et al (2006), Tavakoli (2007), and Javadi (2007) estimated the slip rate of the central part of this fault by using OSL dating, GPS and applying tectonic and geological information respectively.

Recent geomorphological studies by Farbod et al. (2011; 2012) proposed models for the Doruneh fault system defining three distinct segments (the western, central and eastern fault zone) characterized by different kinematic regime. The eastern part of the Doruneh fault displays an imbricate reverse fault zone and is involved in a NNWtrending dextral shear zone between Central Iran and Eurasia. This implies that the eastern part forms a complex right-lateral trans-perssional relay zone between the Eastern and Northeastern Arabia-Eurasia convergence boundaries. The central part of Doruneh fault shows exclusively a left-lateral strike-slip motion. The western part of the

Doruneh fault shows instead evidence of transpressional local tectonics in agreement with the kinematics of the NEtrending branching Dahan-Qaleh left-lateral strike-slip fault.

The kinematics of the fault is controlled by various interplaying factors. These include the present-day regional stress state structural complexities and geometries of the fault as well as the kinematic interactions between the fault and other intersecting fault zones (Farbod et al., 2012). More investigations on this fault are published by Farbod et al. (2011), Pezzo et al. (2012), Shabanian et al. (2012), and Javadi et al. (2013; 2015).

There are several branches near each part of this fault which can be considered as a fault system. Remote sensing could help us to get more information on this fault. In this study the displacements on the rivers and the geological layers by the Doruneh fault are investigated using the geological map (in different scales), aerial photos, Landsat 7, and Quickberd images. Finally, some locations with their displacements are suggested for field study, sampling and dating to estimate the slip rate of the faults in these regions.

2- Geology and seismicity

2.1- Geology

Most of displacements on the Doruneh fault are concentratedon the rivers which are in Quaternary deposits. If there are any displacements on the geological layers they are observed on the Paleogene, Neogene and Quaternary layers (Amini *et al*., 2014).

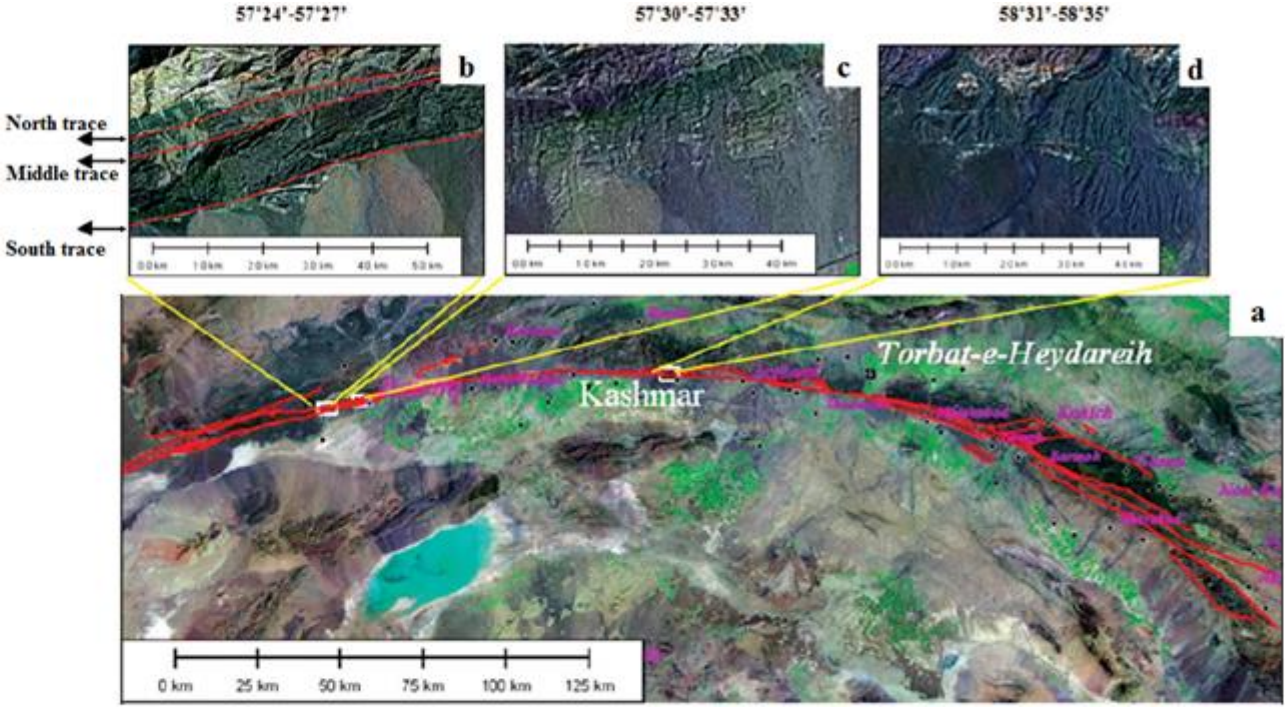

Figure 3) Three examples of Doruneh fault with their main traces.

According to Farbod *et al*. (2011) the Doruneh fault system is a structural assemblage with a complex history of tectonic evolution along which there is clear evidence in two distinct periods of faulting. The first period is the Cenozoic which is an initial vertical fault controlled by the northern margin of the subsiding Neogen sedimentary basin located on the southern side of the fault. The second is the Quaternary strike-slip movements affecting post-Miocene geological structures and geomorphic landforms.

Along the western part the fault segments mostly show a left-stepping arrangement whereas to the east a parallel fault arrangement is dominated. The central part of this fault is more complex than the other two parts.

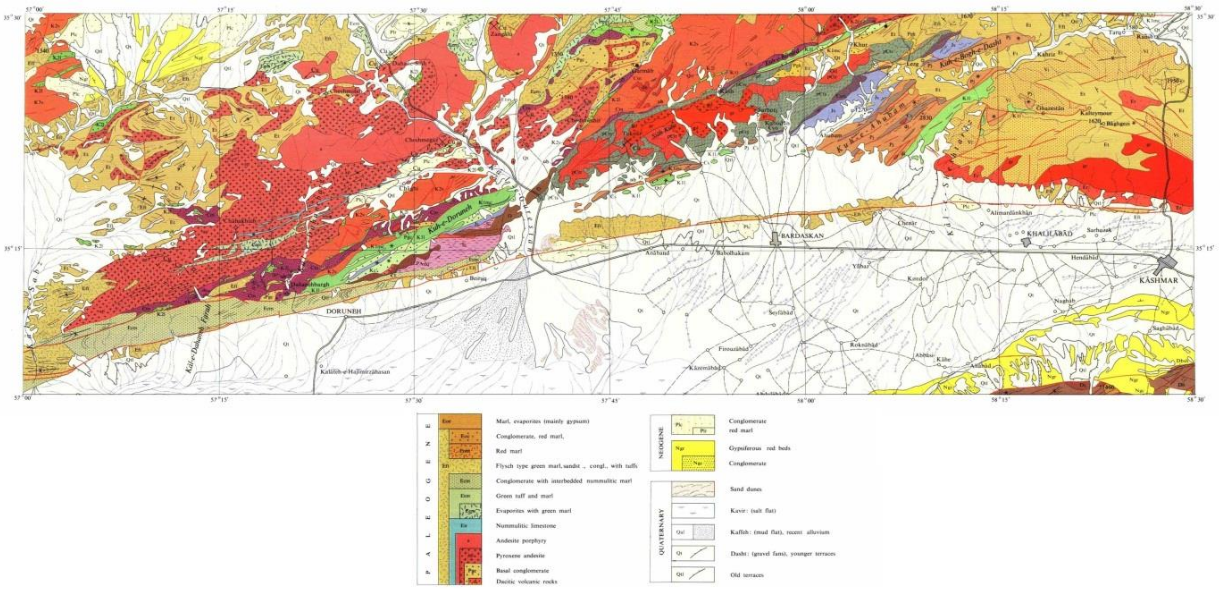

Figure 4) Geology map of central part of Doruneh Fault with the geological layers in scale 1:250,000.

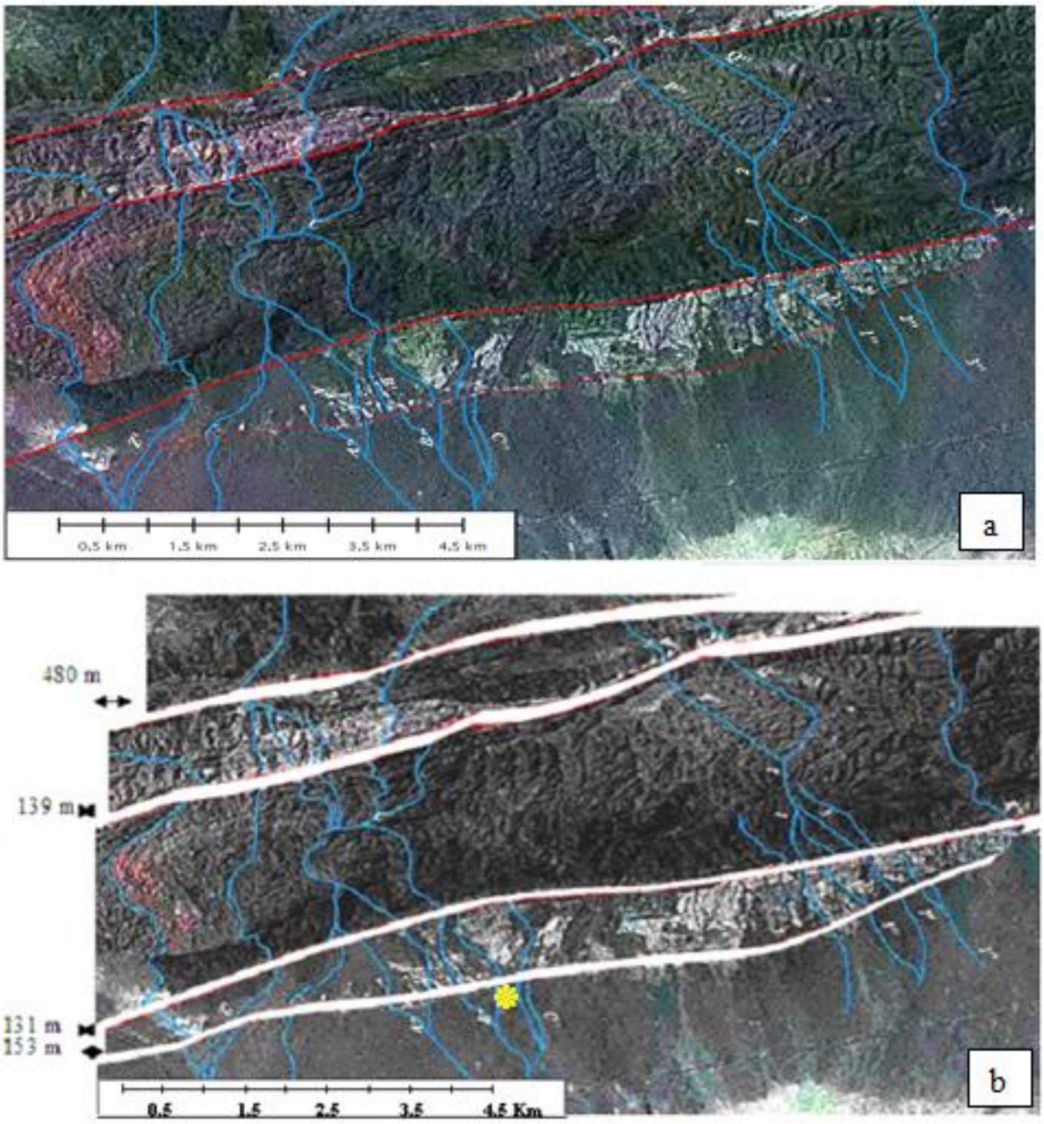

Figure 5) Location of longitude between 57˚02΄ and 57˚10΄; a) without considering displacements, b) with considering 480, 139m left-lateral displacement, 131m right-lateral displacement, and 153m left-lateral displacement, respectively from top to down. The location explained in the text is shown with star.

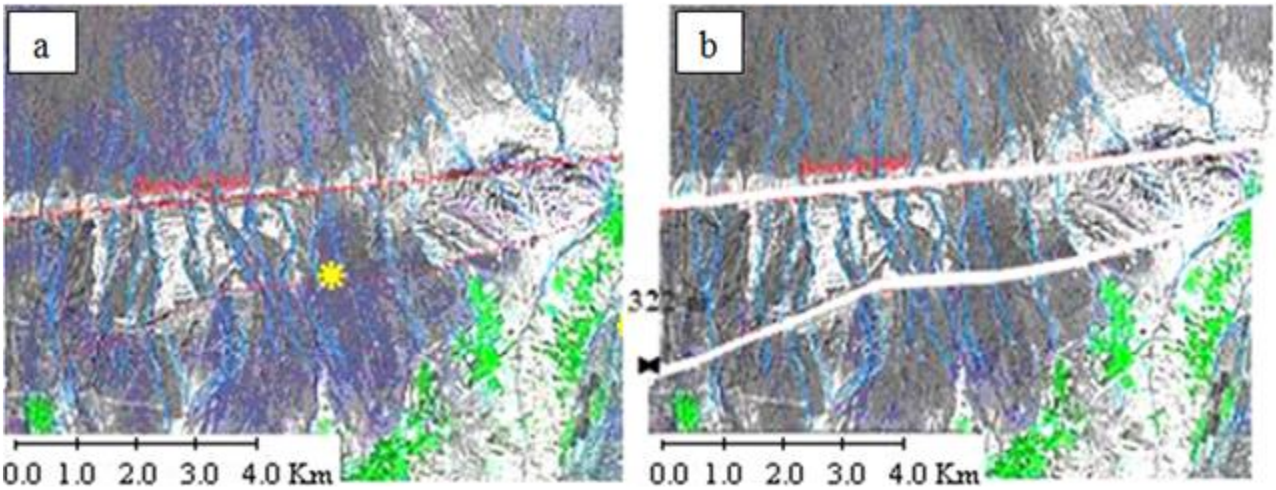

Figure 6) Location of longitude between 57̊ 59´ and 58̊ 04´; a) without considering displacements, b) with considering maximum 322m left-lateral displacement. The location explained in the text is shown with star.

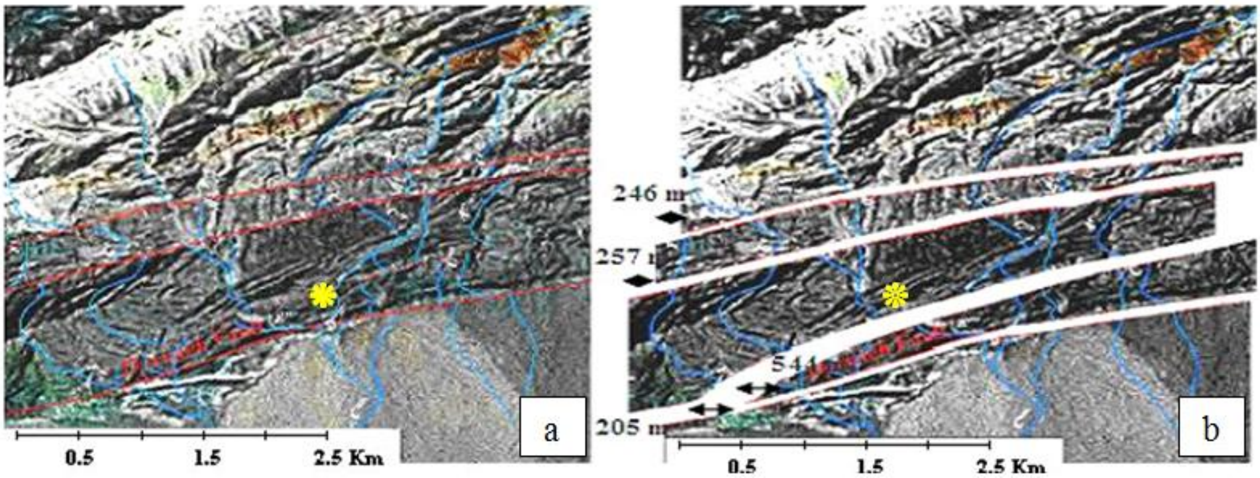

Figure 7) Location of longitude between 57 ˚ 24́ and 57 ˚ 27́; a) without considering displacements, b) with considering 246, and 257m left-lateral displacement, 544m right-lateral displacement and 205m left-lateral displacement, respectively from top to down.

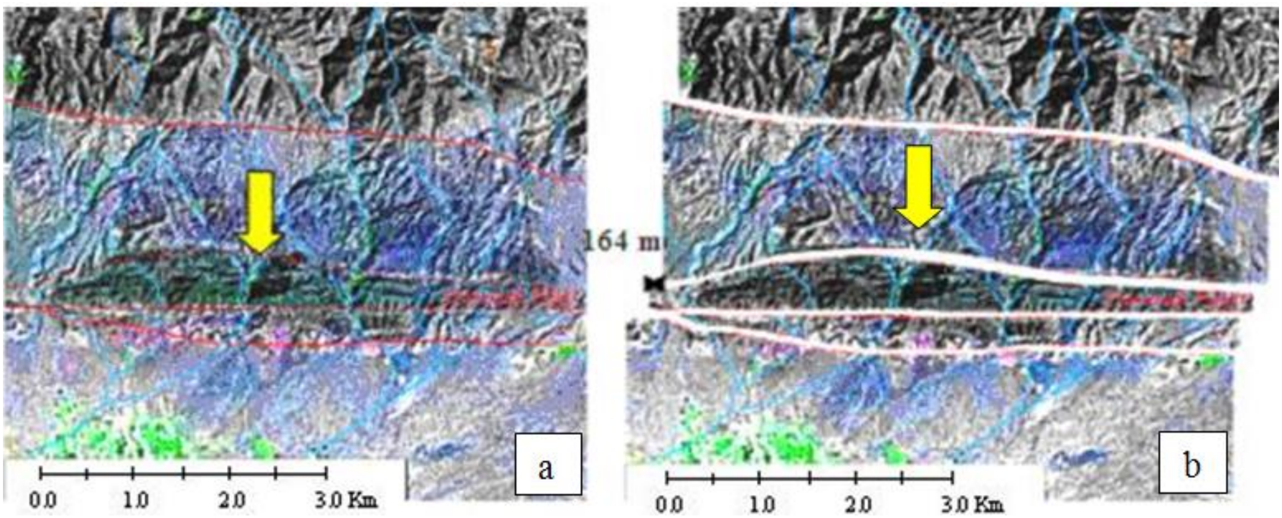

Figure 8) Location of longitude between 58 ˚ 23́ and 58 ˚ 27́; a) without considering displacements, b) with considering maximum 164m left-lateral displacement.

2.1- Seismicity

The active tectonics of Iran are moving northwards with respect to Afghanistan at ~15mm/yr (Vernant *et al*, 2004); accommodated on right-lateral strike-slip fault systems on both western (Gowk-Nayband fault system) and eastern (Neh and Zahedan fault systems) margins of the aseismic Dasht-e-Lut desert (Walker and Jackson 2004; Regard *et al*., 2005).

Despite the very clear expression of Doruneh fault in the geomorphology and its apparent major role in accommodating N-S right-lateral shear across eastern Iran relatively few earthquakes have been recorded in this region (Ambraseys and Melville, 1977). The low rate of seismicity on the Doruneh fault is in contrast to the neighboring Dasht-e-Bayaz region.This region appears to play a similar role in the regional tectonics (Walker *et al*., 2004) but has suffered from many earthquakes recorded both instrumentally and historically (Berberian and Yeats, 1999, 2001; Walker *et al*., 2004). Along this fault and in nearby areas the historical (Ambraseys and Melville, 1982) and instrumental (Jackson and McKenzie, 1984; Fattahi *et al*., 2006; Javadi, 2007) earthquakes report indicate moderate seismicity for the region.

Figure 9) Location of proposed situations for sampling on Doruneh Fault.

The catalog of earthquakes with magnitude more than 5, collected from Engdahl, ISC, Harvard, IRSC, IIEES centers, and Zare *et al*. (2014) are presented in Appendix (A). This catalog consists of historical and instrumental earthquakes with magnitude 5≤ Mw <7.6 and for period of 765 to 2015 (Figure 2).

According to Ambraseys and Melville (1982) two historical earthquakes with magnitude more than 7 was occurred;the Khaf earthquake (in 1336.10.21 with 7.6) and Torbat-e-Jam earthquake (in year 765 with 7.5). Also, 7 historic earthquakes with magnitude between 6-6.5 recorded before 1940 (start of installation WWSSN around the world).They reported to be near this fault but not exactly on the fault (Appendix A; Figure2). There are no recorded earthquakes with magnitude greater than 6 after

1940 around this fault. According to this information, and also Fattahi *et al*. (2006) and Farbod *et al*. (2011) such low seismicity might be either because of incompleteness of historical data or a long recurrence interval for the largest earthquakes.

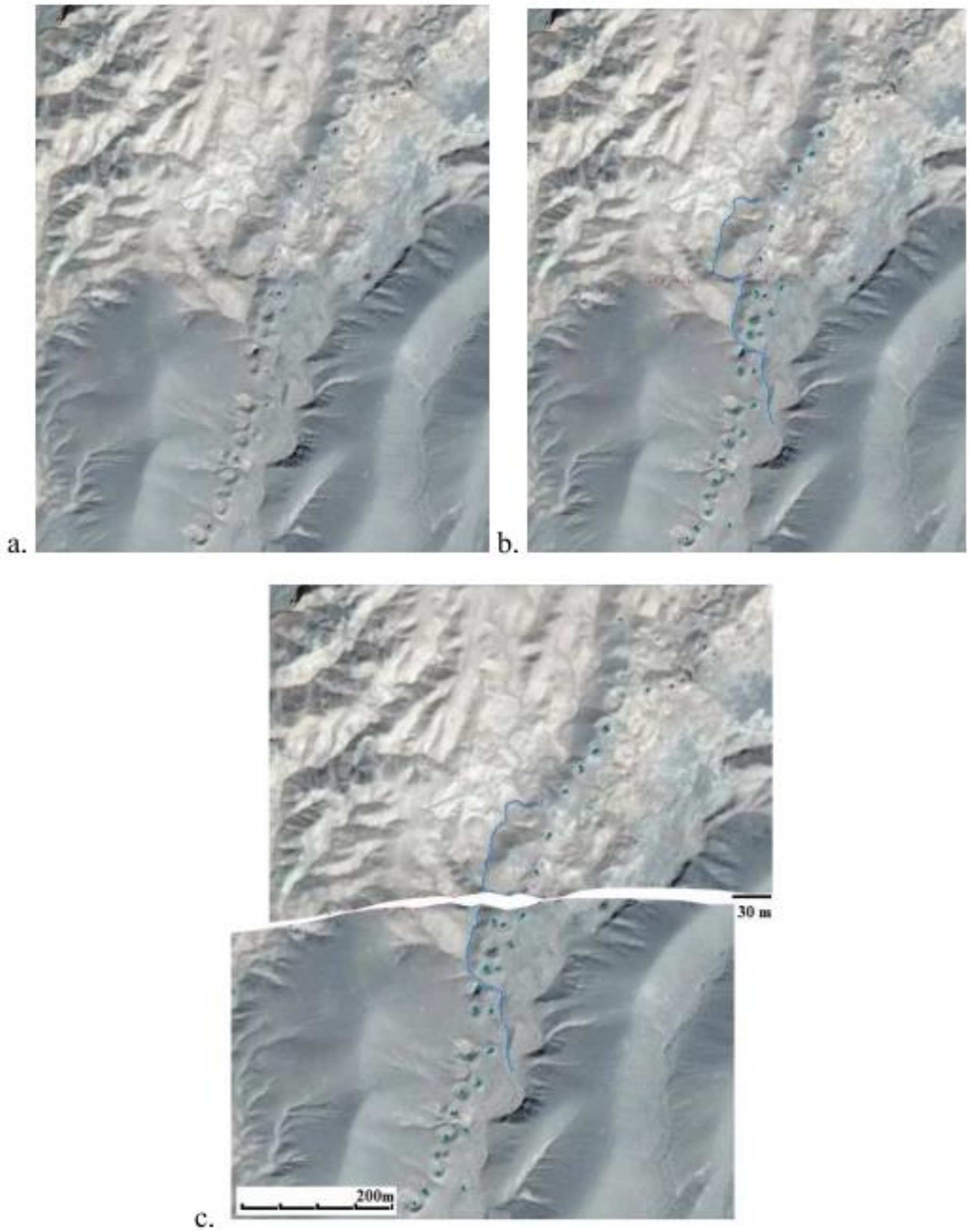

Figure 10a) Quickberd satellite image of location on 35.28N, 57.93E between Bardaskan and Ebrahimabad, b) The trace of river and Qanat are shown, c) Restoration of 30m displacement accommodated to both the river and Qanats (the solid line, small, and large dots show the river, fault strike, and Qanats, respectively).

3- Dataset and Methodology

The geological map with the scales of 1:100,000 and 1:250,000 around the Doruneh fault (e.g. geology map Ferdows, Gonabad, Kashmar, Khartouran, Torbat-e-Heydariyeh, Torbat-e-Jam, and Taybad).Aerial photos in 1:50,000 scale, Landsat 7 with 15m resolution, Quickberd image with 60 cm resolution and topographic maps are considered for remote sensing investigation on the Doruneh fault region.

After conforming different images and maps, the trace of different parts of the fault are drown on the map. Then, with considering fault trace, the displacement of the rivers flowed on alluvial fans and geological layers are measured. From various locations, some of them are proposed to field study, sampling and estimating their slip rate.

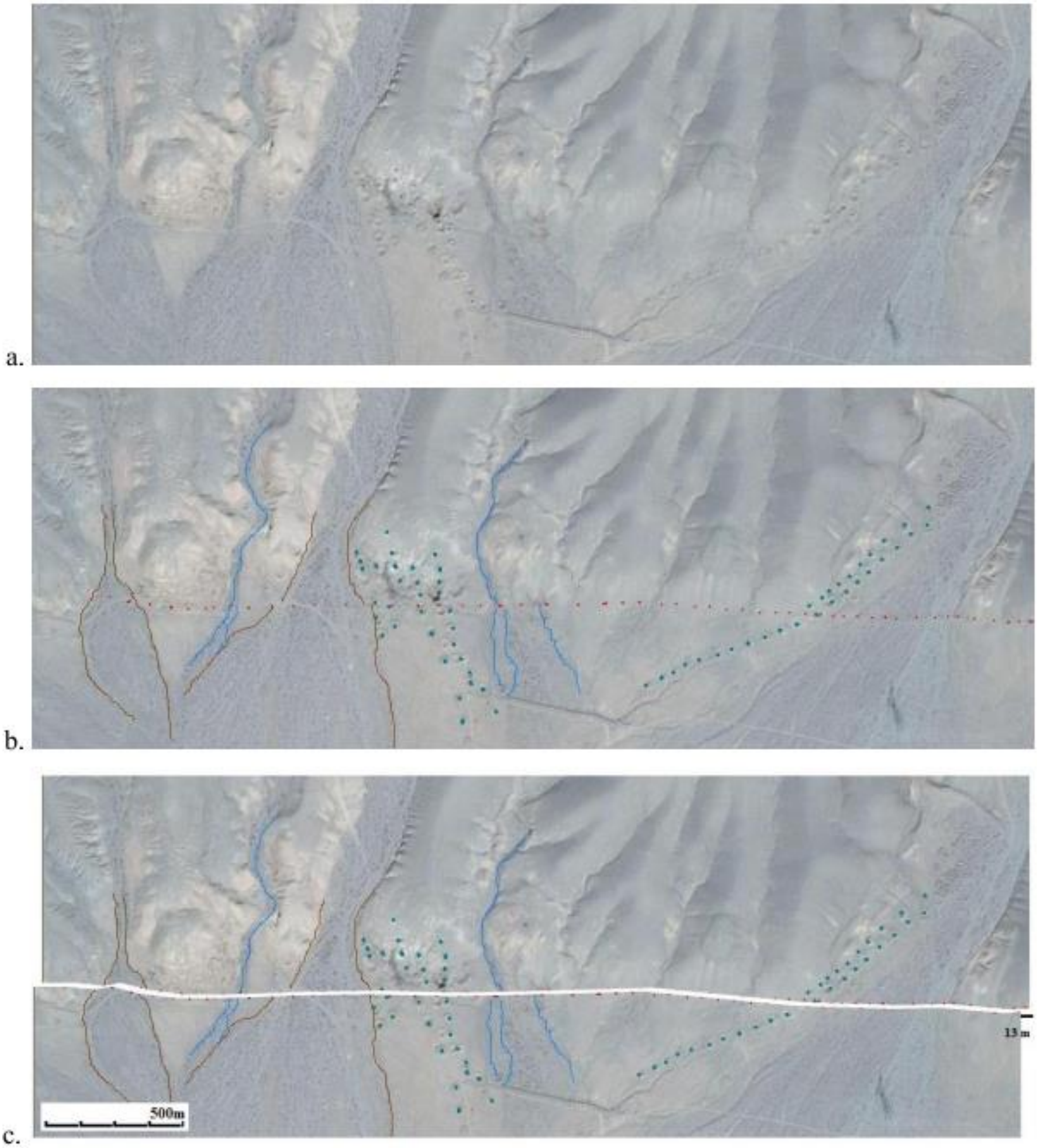

Figure 11a) Quickberd satellite image of location on 35.29N, 58.29- 58.31E near Khalil Abad b) River, Qanats and limitation of two alluvial fans which could be good situations for sampling, c) Restoration of 13m displacement accommodated to all river, Qanats and fans.

a.

b.

Figure 12a) Quickberd satellite image of location on 35.29N, 58.31E near Khalil Abad b) Rivers on the alluvial fan with their fault trace c) Restoration of 100m displacement of the rivers.

Figure 12c) Restoration of 100m displacement of the rivers.

4- Displacements on Doruneh Fault

According to the geometric arrangement and trend of this fault, it is possible to consider three parts:western, central and eastern in NE-SW, E-W, and NW-SE orientations respectively. In each part, there are several fault branches which could be related to this fault. By matching all maps in Global mapper and ArcGIS software the trace of fault and its branches, called the fault system, are determined and plotted (Figure 1). It is possible to distinguish three main traces (in North, in South, and in the middle of them) on this fault (e.g. Figure 3).

The displacements on the rivers and the geological layers of these traces (branches) are measured. According to Amini *et al*. (2014) who presented the displacements in each of branches and each degree of longitude of this fault, both the minimum and the maximum displacements are located between 57˚00´ and 58˚50´E of the southern branch. This included the youngest and the oldest activity of the fault.

4.1- Displacements on Geology layers

The most important displacements on the geological layers of this fault are laid on the alluvial fans of Quaternary and then sediments of the Neogene and Paleogene sediments (Figure 4). These displacements could be considered in two types, the displacements on theirgeological layer and rivers (e.g. Amini *et al*., 2009; Amini, 2009). According to the fact that the geological layers are created before the rivers, the values of measured displacements on the geological layers are more than rivers; for example the displacement information on Anabad (in the North and West part) and Khalil

Abad (in the North and East part) (Amini *et al.*, 2009).

a.

b.

Figure 13a) Quickberd satellite image of location on 35.27N, 58.60E near Rezqabad and Farg, b) Plot the river and Qanats with solid line and points, c) Restoration of 25m displacement accommodated to the river and Qanats.

Figure 13c) Restoration of 25m displacement accommodated to the river and Qanats.

4.2- Displacements on rivers

It is possible to find various river displacements on the Doruneh fault. There are different opinions to explain some river displacements; for instance, in longitudes between 57˚02´ and 57˚10´ or between 57˚59´ and 58˚04´E. Richard Walker, in personal communication in 2008, suggested that these displacements might have been related to the normal faulting before the strike-slip faulting. However, Mohammad Reza Ghassemi believes that this location could be created in folded Paleogene sediments. Location of these parts of the fault without and with considering movement of the fault is shown in Figure (5) and Figure (6).

In some cases, such as longitudes 57˚24´ and 57˚27´Etotal displacement of each branch are in different strikes as there are clear movements of left-lateral strike-slip in two branches and right-lateral movement in the other one (Figure 7).

Moreover, when the rivers are small and flow very fast this may create several line systems of rivers. They may be considered as traces of faults, folds or boundaries of geological layers (Ray, 1967). To distinguish the fault systems from these rivers more investigation of fault activity in that area is required. For example, in location between 58˚23´ and 58˚27´E, a regular system of displacement on the rivers and geological layer could be considered as displacement of faulting (Figure 8).

5- Results

According to the displacement measurements the southern branch of the Doruneh Fault, especially between 57˚00´ and 58˚50´E, could be one of the most active parts of it. From different displacements, five preferable locations are proposed for OSL dating sampling (Figure 9-14). From them, Figures 10 and 12 present the displacements on the rivers. Figures 11 and 13 show the displacements on both rivers and geology layers and the displacements in Figures 13 and 14 located on Qanats.

Figure 14. a and b) Quickberd satellite image of location on 35.26N, 58.85E near Rezqabad and Farg; in this location the displacement of Qanats may be caused by fault movement.

6- Conclusion

Doruneh fault is one of the major active structures in Iran. The plots of different maps and images were applied to investigate the displacements of the geological layers and rivers on three main branches (in North, Middle, and South) of this fault.

The results of different displacement measurements showed that the southern branch, especially between 57˚00´ and 58˚50´, has provided maximum displacements and therefore is one of the most active parts of this fault. The best suggested locations for field study and sampling are near Bardaskan around 35.28˚N, 57.93˚E; in Khalil-Abad around 35.29˚N, 58.29-58.31˚E;in the North of Rezg-Abad and Forg around 35.27˚N, 58.60˚E and North of Forgaround 35.26˚N, 58.85E.

Maximum displacement is ~480m and belonged to the rivers on the northern branch of the fault between 57° 02´ and 57° 10´E (Figure 5). Minimum value of displacement is measured on the rivers near Khalil Abad with about 13m (Figure 11). The same measurements on both rivers and Qanats with 25m occurred on 35.27°N, 58.60°E near Rezqabad and Forg (Figure 13).

OSL on Quartz has proved to be a suitable method for dating the displaced sediments on the Doruneh Fault (Fattahi *et al*., 2006). The measured displacements and the date of each part could be applied to estimate the slip-rate of that part of the fault. These results are useful for analyzing more accurate estimation on the seismic hazard of region.

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Appendix:

List of earthquake with magnitude more than 5, in Doruneh region between 33-36°N, 53-62°E;

Lon	Lat	Year	Month	Day	May	Depth	Hour	Min
60.40	35.20	765	1	1	7.5	0	0	0
60.40	35.20	840	7	1	6.5	0	0	0
59.70	34.70	1336	10	21	7.6	0	6	0
58.90	35.10	1619	5	1	6.5	0	12	0
58.23	35.18	1903	9	25	5.9	0	1	20
60.20	34.70	1907	3	29	6.1	33	20	57
60.70	35.00	1918	3	24	6.0	0	23	15
59.11	35.19	1923	5	25	5.9	0	22	21
60.05	35.21	1925	5	2	5.2	33	2	57
58.10	34.60	1925	12	14	5.7	0	0	0
54.00	34.00	1927	7	22	6.3	0	3	55
54.00	34.70	1927	7	23	5.8	0	20	17
55.00	33.50	1927	7	29	5.2	0	11	33
57.63	35.56	1931	8	8	5.7	35	8	54
57.07	34.52	1933	10	5	6.1	0	13	29
59.35	34.92	1938	7	19	5.2	33	19	45
56.47	34.61	1939	6	3	5.5	33	10	49
56.60	34.20	1939	6	30	5.2	0	0	1
58.50	35.75	1940	5	4	6.4	0	21	1
57.50	34.70	1940	5	5	5.2	0	6	1
59.00	35.50	1947	6	30	5.0	0	3	36
58.75	35.22	1949	12	14	5.2	33	3	43
60.70	34.50	1950	9	24	5.9	0	22	56
56.80	35.60	1951	6	17	5.2	0	18	46
58.60	35.30	1953	6	6	5.1	13	20	24
57.10	35.45	1956	6	30	5.2	16	11	37
58.70	35.60	1958	1	22	5.0	12	0	0
58.38	35.64	1958	1	28	5.2	0	17	14
58.10	35.80	1958	1	28	5.2	13	17	14
58.90	35.30	1958	2	27	5.2	13	3	55
59.52	34.37	1958	9	16	5.4	0	14	22
55.39	34.41	1960	3	7	5.5	15	0	51
58.93	35.44	1961	1	1	5.1	0	19	27
59.00	35.00	1961	5	1	5.0	33	1	37
58.72	35.21	1962	10	5	5.8	15	20	2
58.40	35.20	1962	10	16	5.1	12	7	24
58.06	34.51	1964	2	21	5.1	20	1	3
58.60	35.90	1964	6	5	5.1	0	22	31
57.52	35.29	1965	2	26	5.3	15	1	37
54.96	33.39	1969	11	11	5.2	25	0	30
58.14	35.53	1971	5	26	5.6	15	2	41

Appendix (continued):

Lon	*Lat*	*Year*	*Month*	*Day*	*May*	*Depth*	*Hour*	*Min*
58.35	35.95	1971	9	16	5.0	33	14	20
57.92	35.43	1972	12	1	5.4	9	11	39
57.73	35.48	1973	5	17	5.2	16	16	11
57.13	34.60	1976	3	31	5.2	18	23	38
56.83	35.11	1979	12	9	5.6	8	9	12
55.95	35.30	1988	5	8	5.1	22	6	50
57.55	34.62	1989	12	16	5.1	15	20	55
54.33	33.45	1990	3	21	5.2	15	22	42
57.50	34.70	1991	12	14	5.1	33	5	53
59.16	35.21	1993	5	9	5.0	15	17	42
58.60	35.09	1994	12	14	5.2	15	20	43
59.89	35.69	1995	11	9	5.0	15	5	10
58.38	35.61	1996	2	5	5.0	20	8	28
56.99	35.64	1996	2	25	5.7	25	17	42
58.21	35.23	2000	2	2	5.3	21	22	58
58.22	35.28	2000	3	28	5.3	22	17	55
60.80	35.49	2003	7	3	5.1	15	14	59
56.69	35.39	2005	2	10	5.1	15	3	7
56.85	35.05	2006	1	14	5.1	18	23	23
58.60	35.50	2008	7	3	5.2	4	23	10
58.74	35.55	2008	7	3	5.1	17	23	10
58.54	35.06	2010	4	12	5.0	5	11	56
59.31	35.22	2010	5	12	5.4	24	17	29
59.25	35.22	2010	7	30	5.5	7	13	50
58.77	35.65	2011	5	24	5.2	13	20	30
58.04	35.23	2011	9	5	5.0	5	0	52
59.93	34.48	2012	7	1	5.2	28	22	1