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Seismological aspects of the Varzeghan twin Earthquakes on 11 August 2012 (Mw 6.3 and Mw 6.1), in East Azerbaijan province, NW Iran

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Two earthquakes occurred in the east Azerbaijan province of NW Iran with Mw 6.3 at 12:23:15.9 and Mw 6.1; 11 minutes after the first shock at 12:34:34.8 GMT time on 11 August 2012. The epicenters of the earthquakes were determined using seismograms recorded by the International Institute of Earthquake Engineering and Seismology (IIEES) broadband stations. We obtained their focal mechanisms and also calculated their seismic moments and moment magnitudes based on the source spectrum of these recordings. Other source parameters such as, stress drops, corner frequencies and $Kappa_{(ave)}$ were determined for earthquakes by the S-wave spectra using a model-fitting approach from the near stations. The maximum intensity of the earthquakes was determined as VIII+ on the EMS98 scale in Varzeghan and affected villages.

Introduction

The Tabriz region is located in the Araxes structural block of northwestern Iran, southwest of the continuation of the western Alborz Mountains toward the Caucasus. The epicenters of the twin earthquakes of 12 August 2012 are located in a region in west of Ahar, at a distance of 60 km NE Tabriz. Historical studies in Tabriz and the surrounding area show that Tabriz city has a history of destructive earthquakes. It has been devastated several times in the past. Two earthquakes occurred in 11 August 2012 NW Iran, in the Ahar region. The earthquakes approximately killed 306, injured 3037 and left 30000 people homeless, based on the Iranian health minister's statement of 13 August 2012. We located the epicenters of the earthquakes using seismograms recorded by Broadband Iranian Network (BIN). The first event occurred at 12:23:15.9 GMT time and the second at 12:34:34.8. Table 1a shows the estimates of the hypocentral location of the two events by the Iranian Seismological Center (IRSC) and the present study.

The Iranian Seismological Center (IRSC) at the Institute of Geophysics of the University of Tehran reports earthquake magnitudes using the corrected Nuttli (1973) magnitude scale (Rezapour, 2005):

$$M_n = \log \left(\frac{v}{4\pi} \right) + 1.66 \log(d) - 0.1 \quad d \leq 106 \text{ km}$$

$$M_n = \log \left(\frac{v}{4\pi} \right) + 2.50 \log(d) - 1.8 \quad 106 > d \leq 600$$

where v is the maximum amplitude in nm s^{-1} , and d is the epicentral distance in km. There were 494 aftershocks in the zone with $M \geq 2.5$ recorded by Broadband Iranian Network (BIN). In the present study, we analyze the 11 August 2012 earthquakes and review the seismicity in the last century within the limits of 36.5° and 39.5° N latitude; and 45.0° and 48.5° E longitude. The earthquakes' source parameters are obtained from spectral studies.

Seismotectonic Setting

The Varzeghan twin earthquakes occurred in the East Azerbaijan range of northeast Iran. This region is located within the seismotectonic area of Alborz – Azerbaijan, located west of the Caspian Sea, south of Caucasus thrust belt, east of Anatolia and north of Zagros mountain range. The earth's crust in northwest of Iran is deformed within a tectonic intersection zone, which is very seismically active. The geodetic and ancient seismology data, as well as scattering patterns of active deformation events, are evidence of high seismicity potential in the East Azerbaijan ranges (Geology Survey of Iran, 2012). Active tectonic movements in this range, as in other parts of Iran, result from the convergence of Arabia and Eurasia plates.

The major faults in the area surrounding the epicenter of the Varzeghan twin earthquakes include the North Tabriz fault, Ahar fault and Bozghoush fault. The North Tabriz fault is a complex structure with NW-SE trend, having a right lateral strike-slip mechanism (Berberian and Yeats, 1999). This basement fault is active and has an apparent outcrop on the surface. While seismically inactive for about two centuries, the North Tabriz fault earlier caused devastating seismic events including the 1641 Tabriz-Dehkhargan earthquake ($M_s=6.8$), 1721 South-East Tabriz earthquake ($M_s=7.3$) and 1780 Tabriz earthquake ($M_s=7.4$) (Berberian and Yeats, 1999).

With an approximate east-west direction and a length of about 60 Km, the Ahar fault is located to the north of Sabalan Volcano. The fault can be categorized geometrically in 3 parts: north-west, central and southeast. The fault zone of north and south of Bozghoush is the eastern termination of the North Tabriz fault and consists of the North Bozghoush and South Bozghoush faults with an approximate east-west trend on the north and south sides of Bozghoush heights (Geology Survey of Iran, 2012).

Instruments and data

Data for the twin earthquakes of NW Iran on 11 August 2012 (M_w 6.3 and M_w 6.1) were recorded by IIEES using Guralp CMG-3TD instruments. 16 stations of the BIN (Broadband Iranian Network) were useful, and had suitable signal to noise ratios. Coordinates of the stations used for determining the location and focal mechanism of the earthquakes are listed in Table 1b. The earthquakes were located using SEISAN software (Havskov and Ottemoller, 2005).

Causative fault

The Varzeghan earthquakes caused ground surface rupture. The causative fault is assessed to be the South Ahar fault, having an east-west trend and a length of about 60 km. The surface rupture of the Varzeghan fault was surveyed along about 4 km of ground surface by the investigating team and is located 13 km south of Varzeghan. Its Azimuth is N 245-260 degrees, as shown on Figure 1. Figures 2a, b also show the surface rupture near the Tabriz-Varzeghan road.

Focal depth

The focal depth of the earthquakes were reported to be 10 and 11 km respectively by the USGS (2012; <http://www.usgs.gov>) and 12.6 and 18 km by Harvard University (Harvard, 2012; <http://www.globalcmt.org/CMTsearch.html>). The field observations and analysis of macroseismic data indicate a shallow depth for the both the earthquakes. A preliminary analysis of the location of the recorded strong ground-motion data in the present study also suggests a focal

Table 1. a. Hypocentral location, b. Station Coordinates

(a) Hypocentral location				
Latitude N (degrees)	Longitude E (degrees)	Magnitude	Depth (km)	Reference
38.5	46.91	6.2 (M_n)	10	IRSC
38.4	46.8	6.0 (M_n)	4	IRSC
38.529	46.841	6.3 (M_w)	16	Present study
38.525	46.787	6.1 (M_w)	14.1	Present study

(b) Station Coordinates				
Station	Latitude	Longitude	Altitude (m)	Name
ASAO	3432.88N	5001.52E	2217	Ashtian
BJRD	3741.98N	5724.49E	1337	Bojnoord
CHTH	3554.48N	5107.56E	2250	Charan
GHVR	3428.80N	5114.72E	0927	Qom
GRMI	3848.59N	4753.63E	1300	Germi
KHMZ	3344.38N	4957.85E	1985	Khomein
MAKU	3921.29N	4441.00E	1730	Maku
MRVT	3739.56N	5605.36E	0870	Maraveh tapeh
NASN	3247.95N	5248.50E	2800	Naein
SHGR	3206.50N	4848.08E	0150	Shushar
SHRT	3338.77N	6017.46E	0837	Shah-rakht
SNGE	3505.55N	4720.82E	1940	Sanandaj
TABS	3338.94N	5707.14E	0000	Tabas
THKV	3554.94N	5052.73E	1795	Kavosh
ZNJK	3640.25N	4841.11E	2200	Zanjan

depth of 16 and 14 km. Also, field observations from the region by Zaré (2012) in the first week after the twin main shocks supported the view that they were shallow earthquakes.

Figure 1. Surface faulting trend of the Varzeghan fault along the outcrop of South Ahar fault.

Figure 2. Surface rupture on the Varzeghan twin earthquakes fault (Zaré, 2012).

Seismic catalogue and local Mechanism

Instrumental seismicity of the region recorded in Broadband Iranian Network (BIN) shows that until 30 March 2013 more than 810 seismic events of $M \geq 2.5$ have occurred in the region. Figure 3 shows seismicity of Eastern Azerbaijan from 2012/08/11 to 2013/03/30 from these aftershocks.

The focal mechanism of the two events on 11 August 2012 in the Ahar region were obtained using recorded P-wave first motions from the IIEES seismograms and FOCMEC software (Havskov and Ottomoller, 2005). The focal mechanisms of both events show

right-lateral strike-slip faulting on E-W trending fault, parallel to the aftershocks and the trend of the South Ahar fault (Figure 3). Besides, in this study, we identified a considerable reverse component for the second main shock, $M_w = 6.1$, which is consistent with a CMT solution and work at Harvard University (<http://www.globalcmt.org/CMTsearch.html>) and the USGS (<http://www.usgs.gov>). The field observations also revealed the existence of an E-W trending right-lateral strike-slip surface rupture (Figure 4). Study of records of seismicity (Table 2) shows that the historical earthquakes of this area are part of the historical earthquakes of Tabriz region, the most important of which was that of 1780 in Tabriz. In the epicentral zone of the Varzeghan twin earthquakes, no severe earthquake was reported during approximately the past 1300 years for which documentary records exist (Ambraseys and Melville, 1982).

The instrumental seismicity of the region shows that nearly 810 seismic events have been recorded during the past century. The seismicity of the region is presented in Figure 5. In addition, we present an Ahar map in Figure 6. This shows the E-W trending South Ahar fault, which seems to be the causative fault responsible for the Varzeghan earthquakes. The inferred fault zone is marked by dashed lines on a part of Ahar geological map (1:250000).

Figure 3. Main shock epicenter estimates, reported by different agencies and this study (with IIEES Data), their focal mechanisms and distribution of aftershocks of the 2012 Varzeghan twin earthquakes.

Major earthquakes in the region before 1900

The seismic history of Tabriz shows that region has experienced active seismicity since 634 A.D., but there is no macroseismic information. The earthquakes were strong enough to destroy Tabriz several times (Berberian and Arshadi, 1977). Several major destructive earthquakes have occurred in Tabriz, the most important of which occurred in 634, 1441, 1522 and 1780 (Eprikian, 1903). The Tabriz earthquake in 634 was reported by Adjemian (1937), Moazami-Goudarzi (1972) and Moazami-Goudarzi et al. (1972) [Berberian and Arshadi, 1976].

The North Tabriz Fault (NTF) is one of the active faults of NW Iran. Among the many historical earthquakes that occurred in the

Figure 4. The appearance of the surface ruptures indicating right-lateral strike-slip faulting (Zaré, 2012).

Tabriz region (e.g., the 858, 1042, 1273, 1304, 1550, 1641, 1717, 1721, 1780 and 1786 earthquakes), the destructive earthquakes of 1042/11/04, 1721/04/26 and 1780/01/08 with Magnitudes of +7 were accompanied by coseismic surface faulting (Ambraseys and Melville, 1982; Berberian and Yeats, 1999). The 1780 earthquake ruptured in the northwest part of the NTF, whereas the 1721 event ruptured in the southeast part of the fault (Hessami et al, 2003).

We present the epicenters for some of the most important historical earthquakes in Figure 5. Based on the plotted seismicity for the 20th century (Figure.5), a probable seismic gap can be identified in the central part of the North Tabriz Fault (NTF) based on comparisons of events reported during historic times (pre-1900) from this part of NTF.

Intensity distribution

The two relatively large shallow earthquakes that struck NW Iran, about 60 and 50 km northwest of Tabriz city, on 11 August 2012, caused about 306 deaths, 3037 injuries and 30000 homeless people (reported by the health minister of Iran).

These events caused panic in the cities of the epicentral region (especially in the cities of Ahar, Varzeghan, Kalibar, Heris, and in Tabriz which is the largest city in NW Iran). Panic among people caused them to settle outdoors in Tabriz and the other cities mentioned. The highest number of deaths reported were in Varzeghan city and “Baj e Baj”, Gourdeh and Dino villages. The most severe damage was reported from the villages of Gourdeh, and Dino. The earthquake was also felt in other cities including Tabriz, Marand, Bostanabad, Soumahe Sara, Ardabil, Bukan, Astara, Khoy, Salmas, Parsabad Moghan, Shabestar, Meshkin Shahr, Rasht, Mahabad, Bonab, Urmia, Mamaghan, Hadishahr, Maraagheh, Meyaneh, Miandoab. Following the Varzeghan earthquakes, reconnaissance coverage of the area was made by a team from IIEES (Zaré et al, 2012). An effort was made to visit the entire region affected by the earthquake. According to results of these investigations, the maximum intensity was estimated to be VIII+ on the EMS98 scale in Varzeghan and affected villages, VII+ in Ahar city and VI+ in Heris city. The intensity of the earthquake in

Tabriz was V (Figure 7). From the view point of surface geology conditions, we studied the surface ruptures and ground fissures (based on the INQUA intensity scale, Michetti et al., 2003) and observed that the iso-intensity map concords with the geological evidence as well.

We here illustrate some examples of earthquake damage to buildings in the region of Azerbaijan. We used the European macroseismic scale 1998 to classify the types of structures. Based on EMS-98, classifications of damage were applied to masonry and reinforced concrete buildings (Grunthal, 1998) in order to determine the intensity level. In this study, for the shaken area, there were several types of houses and buildings. These include very weak building structures, with inferior building materials, that are dangerous to human occupants. These buildings are poorly designed and building material is very weak, so they have little resistance to a variety of

Figure 5. Seismicity of Eastern Azerbaijan in 1900–2013 (red circles) and historical seismicity of eastern Azerbaijan (brown hexagons).

Figure 7. Isoseismal map of the Varzeghan earthquake (11 August 2012) from observations of IIEES reconnaissance team (Zaré, 2012).

vibrations. Based on observations in the region, numbers of very weak buildings existed in the macroseismic zone and, in villages, almost all buildings of this type totally collapsed (Figure 8a-8b). In these villages, most of the people were killed and others injured. Most of the buildings and houses were built of clay brick or masonry without reference to any technical standards. In these regions, the greatest damage was inflicted on traditional constructions. The main failure mode was the collapse of heavy roofs. Masonry buildings, for example in Figure 8a-8b (very weak mortar), suffered very heavy structural damage with a damage grade (based on Grunthal, 1998) of five (destruction), total or near total collapse.

In Baj e Baj (a village with 40 victims and the most demolition in the epicentral region), most of the buildings were made of bricks and arched wood beam roofs, adobe and low-quality masonry materials. Most of the weak buildings suffered total damage and, as seen in Figure 8c-8d, some of them collapsed. Some of this type of building contained heavy materials and also, their problem were poor structural connections. In types of structure with simple stone masonry such as in Figure 8c-8d, some parts of the bearing walls failed and there was

collapse of the roof and floor slabs. This kind of heavy structural damage is of damage grade is 4.

Some facilities such as hospitals, universities, gas stations, roads and bridges were damaged in the earthquake-stricken area. We believe that sometimes, in such buildings, despite the advanced design of the structures, the construction and performance is usually poor.

In Heris city, a hospital was built on a hill slope one year before the 11 August 2012 earthquakes. Although, the city was located about 20 km away from the earthquake epicenter, the hospital was rendered out of service. This hospital (the main health center near the epicentral zone) was located 73 kilometers east of Tabriz, the capital city of the east Azerbaijan province (Figure 9a-9b). As a result, people in need of treatment were referred to a mobile hospital erected by the Ministry of Health or to hospitals in Tabriz. Figure 9 shows an example of damage to Heris hospital.

Moreover, there were some structures with large diagonal cracks in the walls or some cracks in the exterior wall in the twin Varzeghan earthquakes region. Figure 9c shows an example of these buildings that exhibited moderate structure damage of grade is 3. In type of structure with many vertical cracks, such as

Figure 9d, slight structural damage resulted and the damage was of grade two.

Distribution of Earthquakes

We mapped seismicity in the region with 810 earthquakes of $M \geq 2.5$ and 494 aftershocks detected by the BIN network between 11 August 2012 to 30 March 2013. The aftershocks and seismicity for 1900 to 2013 in the region are shown respectively in Figures 3 and 5. The locations of the aftershocks were recorded by permanent stations of the BIN network. The figures show that the seismicity trace has a trend of nearly east-west in this area.

Figures 10a and 10b show histograms of the magnitudes of earthquakes and aftershocks in the region. The distribution of earthquakes in Figure 10 shows non-cumulative frequency of magnitudes for 110 years (Figure 10a) and for the aftershocks during 7 months (Figure 10b). This figure shows that the distribution of frequency of aftershocks is representative of a maximum magnitude of $M=6$ in the region. Before 1994 (when the regional seismograph

Table 2. Magnitude 5 and greater earthquakes within a 100 km radius of Varzeghan earthquake epicenter

Time hh:mm:ss	Date M-Y-d	Latitude N (degrees)	Longitude E (degrees)	FD (km)	Magnitude mb Ms Mw ML	Reference	Region
	858	38.100	46.300		6.0	Amb	Tabriz
18	11-1042-04	38.100	46.300		7.6	Amb	Tabriz
	1598	37.800	47.500		6.1	Amb	Sarab
18	02-1641-05	37.900	46.100		6.8	Amb	Dehkharghan
06	03-1717-12	38.100	46.300		5.9	Amb	Tabriz
07	04-1721-26	37.900	46.700		7.7	Amb	Tabriz
24	01-1780-08	38.200	46.000		7.7	Amb	Tabriz
16	05-1861-24	39.400	47.900		6.0	Amb	Tabriz
17	05-1883-03	37.900	47.200		6.2	Amb	
06 17	01-1905-09	38.000	46.000		6.2	Amb	
11 24 42	12-1960-25	39.500	47.500	33	5.0	BAN	
16 09 53	02-1965-10	37.660	47.090	45	5.0	ISC	Alikhalaj

AMB: Ambraseys and Melville (1982), ISC: International Seismological Center, UK, BAN= BANISADR, FD = Focal Depth

Figure 8. (a and b) Examples of total collapse in very weak buildings, (c and d). Examples of demolished buildings in Varzeghan (left-c) and Baj e Baj (right-d) (Zaré, 2012).

Figure 9. (a and b). Examples of Heris Hospital, (c and d). Example of diagonal cracks in walls, and of slight structural damage in the region, respectively (Zaré, 2012).

Figure 10. a and b. The frequency distribution of earthquake for 1900-2012 in Azerbaijan area (a), and The frequency distribution of earthquake magnitudes from 11 August 2012 to 30 March 2013 in Azerbaijan area (b).

network of Azerbaijan was established and came into service), fewer events were recorded in the region. This might be partially related to the lack of enough seismographic stations throughout the region, or a partial seismic quiescence in the region. Thus, a reliable earthquake database exists only for the last couple of decades.

Data and analysis of regional recordings

We have attempted to use a spectrum fitting method (Shi et al., 1996, 1998) for determination of Varzeghan earthquakes source parameters. First, for minimizing the influence of noise, for the 22 stations of the BIN (Broadband Iranian Network) we obtained their signal to noise ratio for the whole of the signals. We selected 16 stations for examination of the first mainshock because they had good

signal-to-noise ratios whereas the rest did not (their signal to-noise ratio was less than 2). We also corrected instrument response. The seismic moment was calculated from the low frequency spectral level Ω_0 of the displacement for the regional analysis. We assumed the model of Brune (1970) in our analysis and estimated the source radius $r_0 = 2.34 v / (2\pi f_c)$ from the corner frequency (f_c) from the S-wave. The static stress drop $\Delta\sigma$ was then estimated from the standard circular static crack solution (Eshelby, 1957; Brune, 1970), $\Delta\sigma = (7/16)(M_0/r^3)$. In our spectral analysis, we assumed $Q(f) = 140f^{0.90}$, also $\Delta\sigma$ determined 46-51 bars, $K_{ave} = 0.035$ for twin earthquakes from the near stations (GRMI and MAKU) located in the epicentral distance of ≤ 200 km) using trial and error. An example of this analysis is shown in Figure 11. The original velocity recordings come from station GRMI located 96.8 km away from the event. The left-hand figures in

Figure 11 Typical example from a three component seismogram at station GRMI with $M_w=6.3$ and displacement spectra with the best fit ω -square source at a distance of 96.8 km.

Figure 11 show the three-component ground motion recordings at this station, and the right-hand figures show displacement spectra with the best fit ω -square source. The results related to the source parameters and radiated seismic energy is listed in Table 3a.

Table 3

(a) Source parameters for 11 August 2012 earthquakes										
Latitude N (degrees)	Longitude E (degrees)	Magnitude (M_w)	Depth (km)	M_0 (N-m)	ΔE_s (erg)	F_c (Hz)	$\Delta\sigma$ (bar)			
38.529	46.841	6.3	16	3.56E+18	1.78E+21	0.20	46			
38.525	46.787	6.1	14.1	1.82E+18	8.91E+20	0.26	51			
(b) Focal mechanism information of the Varzeghan earthquakes										
M_w	Strike	Dip	Rake	Strike	Dip	Rake	P – axis		T – axis	
							Plunge	Azimuth	Plunge	Azimuth
6.3	201	60	28	96	66	147	3	149	40	56
6.1	19	64	56	256	41	139	13	133	57	243

Conclusion

A preliminary analysis of instrumental data recorded by IIEES and field observations indicate the following results for the Varzeghan 2012 twin earthquakes.

The focal mechanism of the twin earthquakes at Varzegahn on 11 August 2012 was determined using seismograms recorded by the Broadband Iranian Network (BIN) of IIEES. We also calculated the seismic moment and moment magnitude based on the source spectrum of the records. The estimated moment magnitude for these earthquakes are M_w 6.3 and M_w 6.1; the maximum intensity was estimated to be VIII+ on the EMS98 scale in Varzeghan and affected nearby villages.

Based on our analysis of the location of earthquakes, the focal depths of the first and second shocks were determined 16 and 14 km, respectively, indicating shallow earthquakes.

The South Ahar fault (Figure 6) had an E-W trend and a 60 km length. It is consistent with the focal mechanism obtained from the fault plane solutions of the causative fault of the earthquakes determined in this study and also by the USGS (www.usgs.gov) and Harvard University (www.globalcmt.org/CMTsearch.html) as shown in Figure 3. Therefore the causative fault was the South Ahar fault.

A review of the recorded seismicity for the 20th century revealed a probable seismic gap in the central part of the North Tabriz Fault (NTF) in comparison with events reported during historic time (pre-1900) from this part of NTF.

The results related to the focal mechanism and source parameters of the Varzeghan earthquakes are listed in Table 3b and Table 3a.

Data and Resources

The waveform data and catalog for earthquakes from the Broadband Iranian Network (BIN) of the International Institute of Earthquake Engineering and Seismology (IIEES) were searched using <http://www.iiees.ac.ir/>, (last accessed March 2013).

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