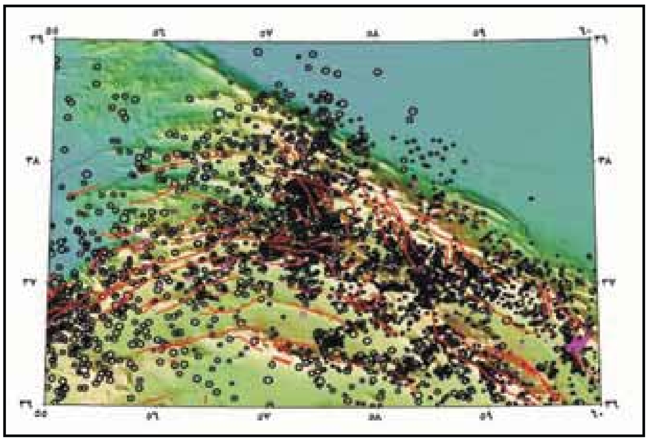

figure5- The epicentral distribution of the locally located earthquakes that were located by the Quchan local seismic network, is shown on the fault map. The information of faults was provided from Geological Survey of Iran.

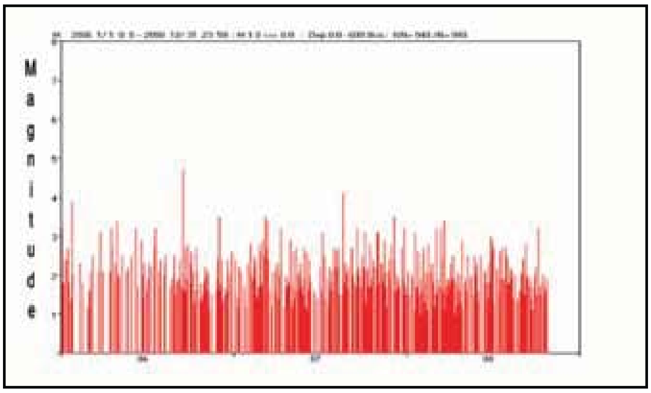

figure 6- Time-Frequency diagram of the recorded earthquakes, by the Quchan local seismic network.

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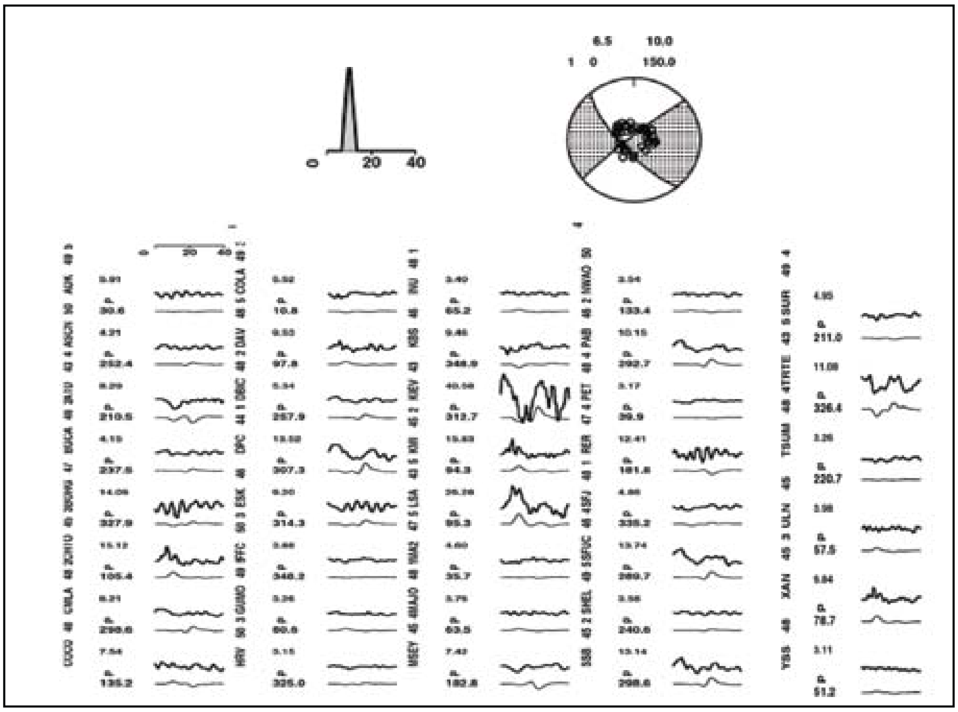

figure 3-The source time function, the focal mechanism, and the ray directions of the stations used in this analysis as well as the comparison of the observed (top) and synthetic (bottom) waveforms after the first iteration for the 1997 Boujnurd earthquake. The correlation coefficient, the name, component and azimuth of station are given on the left side of each waveform.

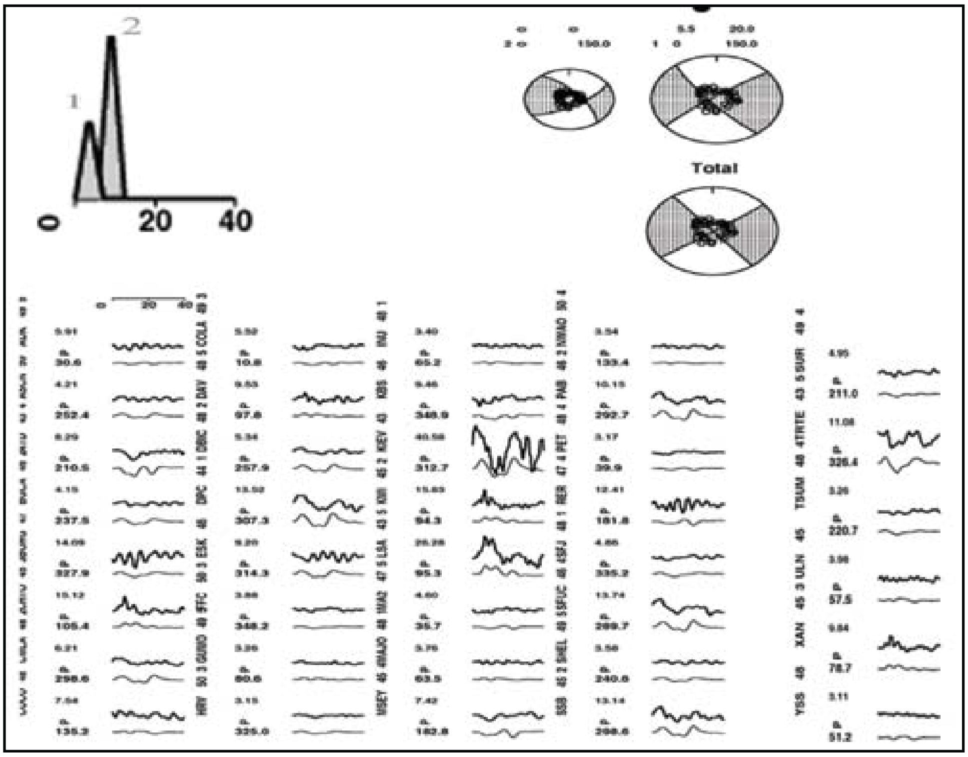

figure 4-The comparison of the observed (top) and synthetic (bottom) waveforms for the final solutions of the 1997 Bojnurd earthquake. The correlation coefficient, the name, component and azimuth of station are given on the left side of each waveform.

Table 1- The seismic station code, azimuth, backazimuth, and epicentral distance of stations used in this study.

Stn	Az	B.Az	Delta
ADK	30.6	-40.9	79.4
ASCN	-107.6	49.9	80.5
ATD	-149.5	24.3	28.9
BGCA	-122.5	42.3	47.8
BORG	-32.1	81.4	52.2
CHTO	105.4	-54	40.7
CMLA	-61.4	62	63.5
COCO	135.2	-34.9	61.7
COLA	10.8	-20.4	76.2
DAV	97.8	-52.5	68.4
DBIC	-102.1	51.5	64
DPC	-52.7	98.1	31.9
ESK	-45.7	87.2	44.5
FFC	-11.8	16.3	86.6
GUMO	80.6	-53.7	79.9
HRV	-35	38.2	87.9
INU	65.2	-62.2	62.3
KBS	-11.1	127.3	45.5
KIEV	-47.3	112.8	24
KMI	94.3	-61	40.3
LSA	95.3	-65.6	29.1
MA2	35.7	-66.3	60.2
MAJO	63.5	-62.2	62.6
MSEY	-177.2	2.2	41.8
NWAO	133.4	-43.4	89.5
PAB	-67.3	71.9	47.5
PET	39.9	-57.8	67.2
PER	-178.2	1.5	58.2
SFJ	-24.8	58.8	62.7
SFUC	-70.3	68.8	49.8
SHEL	-119.4	46	79.5
SSB	-61.3	82.3	39.8
SUR	-149	29	77.3
TRTE	-33.6	123.1	29
TSUM	-139.3	33.3	67.6
ULN	57.5	-87.6	37.4
XAN	78.7	-70.1	41.3
YSS	51.2	-65.1	61

Table 2-The source parameters of the subevents for the final solution of the Bojnurd earthquake obtained by waveform inversion

Subevents	Strike Dip Rake (degree)			Strike Dip Rake (degree)			M.(Dyne cm)	M_w
1st	141	81	74	22	18	150	$4.8*10^{25}$	6.3
2st	321	69	159	52	88	21	$2.2*10^{25}$	6.1
Total	323	89	178	53	88	1	$6.7*10^{25}$	6.5

Table 3-The source parameters obtained by USGS, the University of Harvard and Hollingsworth et al (2006) as well as the result of this study.

Name	Strike Dip Rake (degree)			Strike Dip Rake (degree)			M.(Dyne- cm)	Mw
USGS	143	86	-178	233	88	-4	$6.2*10^{25}$	6.5
HRVD	328	81	-171.0	326	81	-9	$7*10^{25}$	6.8
Hollingsworth	326	75	173	58	83	15	$5.7*10^{25}$	6.4
This study	323	89	178	53	88	1	$6.7*10^{25}$	6.5

are very small, this fact in consistant with the radiation pattern of P waves for strike-slip mechanism. The pattern of locally recorded seismic activity indicates that the region has become seismically active, after the occurrence of the mainshock.

Acknowledgements

We acknowledge the Geophysics Institute of Tehran University for providing us data from local seismic network.

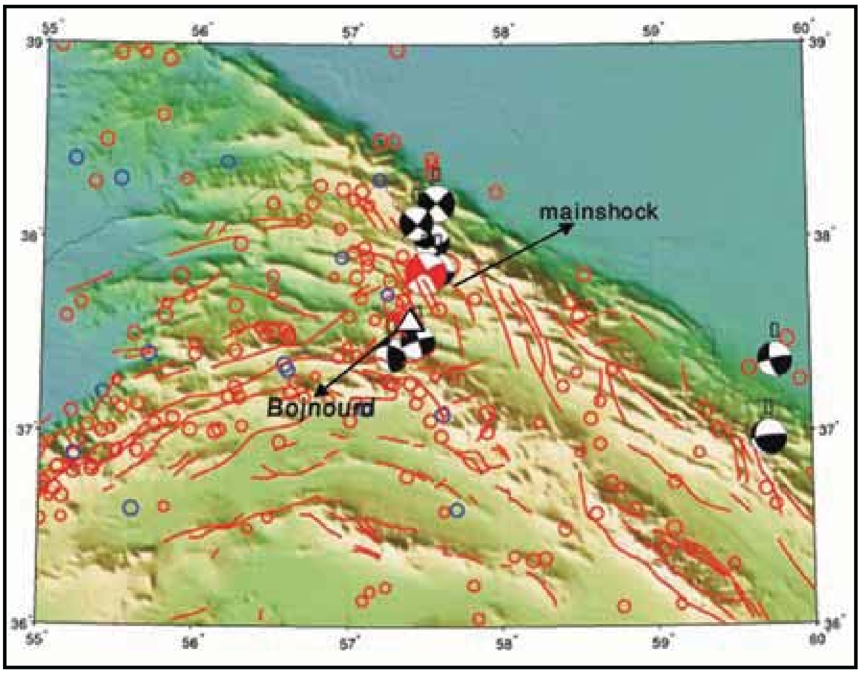

figure 1-The epicenter of foreshock, aftershocks, main shock, the teleseismic aftershocks, and instumentally located earthquakes as well as mechanism of strong earthquakes given by HRV (Red color mechanism belongs to the 1997 Garmkhan mainhock).Red circles have shallow depthes less than 20 kilometers. Blue circles have deeper depthes greater than 20 kilometers.

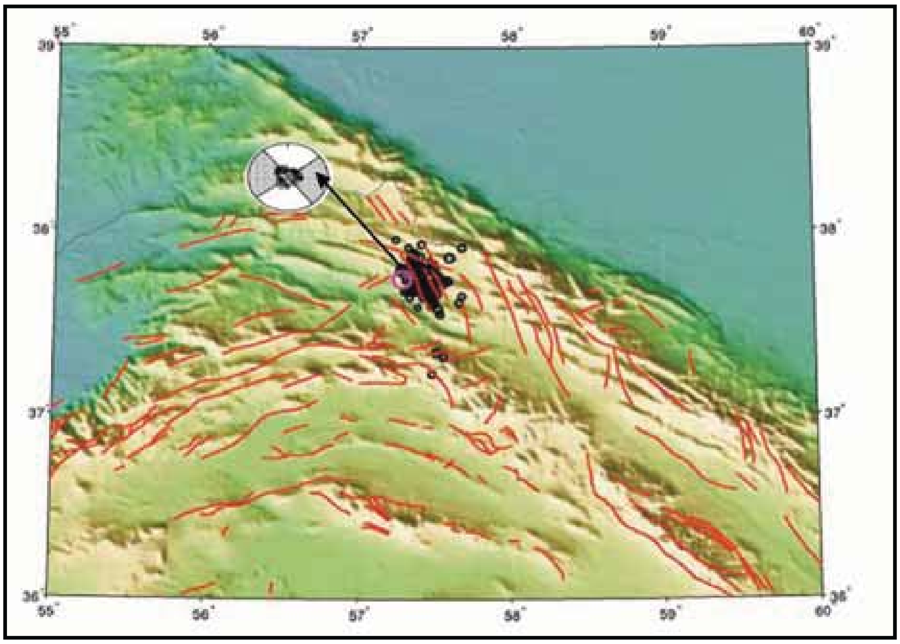

figure 2-The mechanism obtained in this study and the epicentral distribution of locally recorded aftershocks (Gheitanchi et al., 1998) are shown on the fault map. The epicentral distribution roughly suggests NW-SE trend for fault plane.

of significant magnitude has been located in the epicentral area. The Bojnourd earthquake may be considered as an event associated with the northern boundaries of the Alborz, at the junction of this range with the Kopeh Dagh. (Hollingsworth et al., 2006)

3- Source parameters of mainshock

Using the inversion technique developed by Kikuchi and Kanamori (1991), the body waves of Bojnourd earthquake recorded by GDSN stations were inverted to their sources to investigate the source mechanism. The P waveforms of 38 stations with epicentral distances between 30 and 100 degrees were used for this study. The locations of selected seismic stations are given in Table 1. The records with a duration of 40 seconds were inverted with a sampling interval of 1.0 second. Both the observed and synthetic Green's functions for all the stations were equalized to GDSN seismograms with the same gain (Gheitanchi, 2002). In calculating the synthetic wavelet for a point dislocation we used the Jeffreys-Bullen A model (Jeffreys and Bullen, 1958). First, a source time function of trapezoid shape having rise time of 3 seconds and process time of 4 seconds was best fitted. Then, with the fixed source time function, the data was inverted for several source depths. The residual error was minimized for the depth of 5-10 kilometers. This suggested that the centroid depth was not deeper than 10 km. In next stage, by a point source approximation, we obtained the mechanism solution. The source time function, focal mechanism, and the comparision of the observed and synthetic seismograms after the first iteration is given in figure 3. This figure indicates that the fit of observed and synthetic waveforms is acceptable around the 20 seconds. The iteration was repeated two times; no significant decrease in the residual error was found after two iterations. This suggested that there were two main fault slip during the source process of the mainshock.The final result of inversion is summarized in Table 2. Examples of the observed and synthetic waveforms,the source time function, the focal mechanism and the ray directions of the stations used in this analysis are given in figure 4.

The largest slip took place during the first 10 seconds while the next slip initiated within 5 seconds. Out of two possible fault planes, the one striking NW-SE gave a much better variance reduction and was in agreement with the strike of geological faults in the region. The mechanism solution for the total source was obtained as striking N323W, dipping 89, and having rake angle 178. The fault slip was consistent with the geological evidences such as folding and strike-slip faulting in the region. The total seismic moment was calculated to be M0= 6.7×10^{25} dyne cm. The calculated maximum dislocation was about 50 cm and the obtained moment magnitude in this analysis was Mw = 6.5 while the estimated rupture velocity was 3.0 km/s. Using the relation $\Delta\sigma = 2.5M_0/(S)^{3/2}$ and approximating the rupture area, S, by L×(L/2), where L=40 km was the fault length which was estimated by the extension of aftershock activity, thus the average stress drop, Δσ, could be estimated (Gheitanchi et al., 1993). In this study, following the same relation, the average stress drop, Δσ, was estimated to be about 25 bar. Using the relation M0 = μDS, where $\mu = 3\times10^{11}$ dyne cm^{-2} was the rigidity and S the fault area, the average dislocation, D, was calculated to be 25 cm.

4- Review of Seismic Activity In The Region During 2006-2008

Recently, as a part of the national seismic network, the Institute of Geophysics of Tehran University deployed a telemetric seismic network in Quchan to monitor the seismic activity. During 2006-2008, many earthquakes were recorded by the Quchan local seismic network. The epicentral distribution of the locally located earthquakes that were located by the Quchan local seismic network is indicated on the fault map in figure 5. The information of faults was provided from Geological Survey of Iran. As it is shown in this figure, the major seismically active areas in the region, are located in the vicinity of the epicenter of the 1997 Bojnourd earthquake, in Quchan located in the eastern part, as well as in the west around Gorgan. The epicenters of local earthquakes are roughly distributed around the trends of major faults. In the figure 5 indicates that a significant activity in the region with high concentration around the epicentral region of the mainshock. The Time-Frequency diagram of the local earthquakes is given in figure 6. About 948 earthquakes were detected by the Quchan seismic network during 2006-2008. The majority of earthquakes have magnitutes less than 2.

5- Discussion and conclusion

The mainshock have a right-lateral strike slip mechanism. Regarding the faults movements in the region, the strike slip mechanism consistent with the geological and seismological obrevations (Hollingsworth et al., 2006). A Moment Tensor analysis was reported by USGS for the mainshock and the strong foreshock and a similar solution was given by Harvard University as well as Hollingworths et al. (Table 3). Assuming a NW-SE direction for the fault strike, as revealed from the aftershock activity, the mainshock has a right-lateral strike-slip mechanism which is predominant in this region. The extent of aftershock activity indicates an average source dimension of about 40-50 km (as suggested by Fatehi, 1997) . The waveform modeling of the first 40 seconds of teleseismic data indicates two subevents. The first subevent is smaller than the second one. Both subevents have strike-slip mechanisms. From the source time function a duration about 15 second could be estimated. If we assume the rupture velocity to be 3 km/s then the rupture length would be 45 km and is in good agreement with the result of aftershocks activity. As indicated in figure 4 and table 2, the first subevent has a small reverse component and is in agreement with geological evidence. Regarding the positions of stations in the focal mechanism given in figures 3 and 4, several seismic stations are located along the strike of the activated fault system. Thus the amplitudes of P waves recorded by these stations

Source Parameters of the February 1997 Garmkhan Earthquake (North-East Bojnourd), Northeast Iran

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Abstract

The Bojnourd earthquake occurred in a mountainous area in North Khorasan provinc. The mainshock produced extensive destruction. Field investigation and aftershocks distribution suggest a NW-SE trend faulting. The distribution of locally recorded aftershocks was extended to a length of about 40-50 km and a depth of about 30 km. Aftershock activity was scattered indicating a complex mode of faulting. The result of waveform inversion indicated that the mainshock followed mainly strike-slip mechanism and the source process included at least two main fault slip. The source time functions indicates that the major amount of seismic energy was released within the first 10 seconds. Considering the field observation, the distribution of aftershocks and the source mechanism, an average source dimension of about 45 km, a NW-SE strike and a SW dipping fault plane could be estimated. The mechanism for the total source is obtained as (strike, dip, rake) = (323, 89, 178). The total seismic moment was calculated to be M0= 6.7×10^{25} dyne cm. The calculated maximum dislocation was about 50 cm and the obtained moment magnitude was Mw = 6.5. The average stress drop was estimated to be 25 bar and the average dislocation was 25 cm.

Keywords: Bojnourd Earthquake, Source Time Function, Source Mechanism, Source Parameters, Seismicity and Seismotectonics of North-East Iran.

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1- Introduction

On 4 February 1997 at 10h 37m 51.2 GMT, 14h 7m 51.2 in the afternoon local time, a moderate but considerable destructive earthquake occurred in Bojnourd, a mountainous area in North-East Iran, in North Khorasan Province. Using the onset times of 599 stations, the epicenter of mainshock was computed as 37.74N-57.29E by ISC. The magnitude of the mainshock, given by ISC, was mb=5.8, Ms=6.6 and focal depth determination indicated a focal depth of 35.7 kilometers. The shock was felt in many parts of northeastern Iran, including Esfarayen, Mashhad, Neyshabur, Quchan and Sabzevar. The mainshock was followed by many aftershocks. The Bojnourd earthquake is the largest instrumentally recorded shock in the vicinity of Bojnourd and one of the rare earthquakes with magnitude greater than 6 in northeast Khorasan. The quake killed about 100 people, injured nearly 2000 and about 5,500 houses destroyed and 11,000 houses damaged in the Bojnourd-Shirvan area (Fatehi, 1997). The mainshock was preceded by a strong foreshock that occurred about 44 minutes before the mainshock at 09:53:56.2 GMT and its epicenter was computed as 37.65N-57.32E by ISC, using the onset times of 444 stations. The magnitude of foreshock, given by ISC, was mb=5.2, Ms=5.4 and its focal depth estimated10 kilometers. The epicenter of mainshock and large aftershocks as well as the strong foreshock are overlapped in the fault map and are given in figure 1. The instumentally located earthquakes and the mechanism of strong earthquakes are also given in figure 1. This paper uses the result of field reports and aftershock activity and analyze the source complexity of mainshock by the inversion of far-field data collected by the data management center of the incorporated research institutions for seismology. The main goal of this study is to obtain source dynamics of mainshock and how far the rupture was propagated during the source process.

2- Background Seismicity and Activating Fault System

Historical seismicity of Iran has been studied by Ambraseys and Melville (1982) . This study suggests that the region has experienced many destructive earthquakes in historical time. Most of the destructive earthquakes have occurred either in the Alborz ranges or at the junction between the Alborz ranges and the Kopeh Dagh (Gheitanchi et al., 1998) . Compared with the historical background the seismicity of the region, in the the 20th and 21th century, is better known both from the macroseismic and instrumental point of view. The instrumentally located earthquakes suggest that seismic activity since 1900 has been remarkably increased. All epicentres fall within the limits of the principal ranges such as in the Alborz, Kopeh Dagh (Aminipanah., 2008). Most seismically active areas are those connected with the Alborz range, particularly at the junction between the Alborz and Kopeh Dagh. The seismicity map of North-East Iran is shown in figure 2.

Background seismicity of the region indicates that the Bojnourd earthquake of 1997 occurred in a relatively quiet region, at least from the microseismic point of view. During the 20th and 21th century, no earthquake

پارامترهای چشمه زمین‌لرزه ۱۹۹۷ گرمخان (شمال خاوری بجنورد)، شمال خاوری ایران

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چکیده
زمین‌لرزه بجنورد در منطقه کوهستانی در استان خراسان شمالی به وقوع پیوست. زمین‌لرزه اصلی تخریب گسترده‌ای را ایجاد نمود. بررسی‌های صحرایی و توزیع پس‌لرزه‌ها، گسلشی با راستای شمال باختری – جنوب خاوری را برآورد می‌کند. توزیع پس‌لرزه‌های ثبت شده در محل، طولی حدود ۵۰-۴۰ کیلومتر و ژرفای ۳۰ کیلومتر را نشان می‌دهد. فعالیت پس‌لرزه‌ها پراکنده بوده و گسلش پیچیده‌ای را نشان می‌دهد. نتیجه برگردان شکل موج نشان می‌دهد که زمین‌لرزه اصلی سازوکاری به طور عمده امتدادلغز و فرایندی شامل دست کم دو گسلش دارد. تابع زمانی چشمه نشان می‌دهد که عمده انرژی آزاد شده در ده ثانیه اول بوده است. با توجه به مشاهدات صحرایی، توزیع پس‌لرزه‌ها و سازوکار زمین‌لرزه، طول گسلش حدود ۴۵ کیلومتر و امتداد شمال باختری – جنوب خاوری و شیب جنوب خاوری برای گسل مسبب برآورد می‌شود. سازوکار چشمه (۱۷۸، ۸۹ ،۳۲۳)(زاویه، امتداد، شیب) به این ترتیب است. ممان لرزه‌ای کل $M_0 = ۶/۷\times۱۰^{۲۵}$ دین- سانتی‌متر برآورد می‌شود. بیشترین جابه‌جایی حدود ۵۰ سانتی‌متر محاسبه شده است و بزرگی گشتاوری Mw = ۶/۵ است. افت تنش متوسط حدود ۲۵ بار و جابه‌جایی متوسط ۲۵ سانتی‌متر برآورد می‌شود.

کلیدواژه‌ها: زمین‌لرزه بجنورد، تابع زمانی چشمه، سازوکار چشمه، متغیرهای چشمه، لرزه‌خیزی و لرزه‌زمین‌ساخت شمال خاوری ایران

برای مشاهده مقاله انگلیسی به صفحات ۱۸۱ تا ۱۸۶ مراجعه فرمایید.

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